“Ecological Understanding through Transdisciplinary Art and Participatory Biology”

By Brandon Ballengée

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AUTHOR'S DECLARATION

At no time during the registration for the degree of Doctor of Philosophy has the author been registered for any other University award without prior agreement of the Graduate Committee. Work submitted for this research degree at the Plymouth University has not formed part of any other degree either at Plymouth University or at another establishment.

These studies were financed with the aid of research commissions by Arts Catalyst (London, England), Yorkshire Sculpture Park (Wakefield, England), Hartwick College (Oneonta, USA), McGill University (Montréal, Canada), Society for Art and Technology (Montréal, Canada), Environment Canada (Montréal, Canada) and the Sunriver Nature Center (Sunriver, USA).

Relevant cultural and scientific conferences were attended at which I presented my research; several keynote talks were given where I presented my work; several group and solo exhibitions were generated; external institutions were visited for consultation purposes, and several papers were prepared for publication.

The author’s curriculum vitae is located at the end of the thesis, following the list of appendix materials.
Abstract

In this study evidence is presented that suggests transdisciplinary art practices and participatory biology programs may successfully increase public understanding of ecological phenomenon. As today’s environmental issues are often complex and large-scale, finding effective strategies that encourage public awareness and stewardship are paramount for long-term conservation of species and ecosystems. Although artists and biologists tend to stay confined to their professional boundaries, and their discourses largely remain inaccessible to larger audiences, arguments here are presented for a combined approach, which may disseminate knowledge about ecology to non-specialists through novel art-science participatory research and exhibitions. Moreover, historically several scientists utilized varied creative art forms to disseminate scientific insights to a larger populace of non-specialists, such strategies as engaging writings and visually provocative artworks may still be effective to captivate contemporary audiences. In addition such historic hybrid science-art practitioners may have laid a conceptual terrain for some of today’s transdisciplinary art and citizen science practices. Furthermore, seminal ecological artworks from the 20th Century by Joseph Beuys, Patricia Johanson and Hans Haacke utilized novel strategies to reach audiences with a message of wetland conservation, blurring boundaries between art, ecology and activism. More recently artists like Cornelia Hesse-Honegger, Helen and Newton Harrison and others have integrated biological research into their art practices, which resulted in new scientific discoveries. Through my own transdisciplinary artwork about frogs, data suggests that the visual strategies I employ were effective to increase non-specialist understanding of the ecological phenomenon of amphibian declines and deformations. In addition through my participatory biology programs, Public Bio-Art Laboratories and Eco-Actions, evidence suggests that non-specialists achieved an increased awareness of the challenges amphibians and ecosystems currently face. Likewise, that through such participatory citizen science research new scientific insights about the proximate causes for deformities in anuran amphibians at select localities in middle England and Quebec were achieved. Here laboratory and field evidence, generated with the aid of public volunteers, found that non-lethal predatory injury to tadpoles from odonate nymphs and some fishes resulted in permanent limb deformities in post-metamorphic anurans. From an environmental-education and larger conservation standpoint, these findings are very relevant as they offer novel strategies for experientially engaging non-specialist audiences while generating important insights into biological communities and wetland ecosystems.
Executive Summary

Throughout this research I sought to examine how transdisciplinary art and participatory biology practices could increase public understanding of ecological phenomenon. This is an important question as today’s environmental issues are global in scale and daunting challenges which neither the fields of science nor art can remedy alone. Worldwide declines of biodiversity, coupled with the continued loss of terrestrial and other ecosystems along with changes to the earth climate threaten the survival of many species and perhaps the long-term subsistence of our own. Ironically, many people remain unaware that we are in the middle of a mass extinction event. How may artists and biologists concerned about the environment reach individuals and larger audiences?

Perhaps the weaving together or even moving beyond the isolated disciplines of art and science may be required to move our species towards environmentally sustainable behaviours. Theorists such as Jean Piaget, Erich Jantsch, Basarab Nicolescu, Jürgen Mittelstraß, Edward O. Wilson and others have called for a transdisciplinary approach to unify knowledge and solve problems that are beyond the scope of single disciplines. However the role that art may have in contributing to such efforts is not larger addressed in these philosophies. This is why I found it necessary to formulate characteristics of what I refer to as my Transdisciplinary Art with Ecology. Here transdisciplinary art practice is an active form of inquiry into ecological phenomenon utilizing the research methods of science, conscious of a specific space in terms of biological communities and geography and seeks solutions to real world environmental issues with the aid of local participants.

Over recent decades, many efforts within the field of biology have been made to integrate non-specialists into the research process. Such “citizen” science programs have been described by scientists David Pilz, Eric Hand, Rick Bonney, Alan Irwin and others as intentionally involving the public into primary research for the purpose of generating larger scale studies as well as increasing participant understanding of varied ecological phenomenon. Although questions on the validity of data in such citizen inclusive research have been raised. Likewise participatory programs rarely or if ever encourage volunteers to reflect through art or other creative means after research involvement. I found that by requesting participants to create art about their experiences in our participatory amphibian studies, it offered a way for them to express their views and even expand a message of conservation to larger audiences.

Although these combined art-sci practices are novel to contemporary citizen science programs and much of the larger arts community, the underlying philosophy of connecting the public to nature through art dates back several centuries. As historically, several scientists such as Alexander Von Humboldt, John James Audubon, Aldo Leopold and others utilized the creative tools of visual art and/or engaged descriptive writing to transfer their knowledge of natural history to a larger lay audience. Representational strategies employed in these historic works will be examined as such approaches may still be an effective means to reach today’s populace with an environmental message. Likewise, these early practitioners may have laid the conceptual terrain for today’s ecological and biological art practices, a research trajectory that has not been well explored in art history.
Within the context of Ecological Art, there are seminal examples of works by Hans Haacke, Patricia Johanson and Joseph Beuys that utilized art as a catalyst to inform diverse audiences about wetland conservation. These were conducted through various sculptural and performative actions. Such seminal strategies will be referenced as pertinent examples of ways contemporary artists may activate ecological awareness and offer pragmatic solutions through transdisciplinary means.

Furthermore, methods of scientific research were utilized within the artistic practices of Helen and Newton Harrison, Mel Chin, Tissue Culture and Art Project, and Cornelia Hesse-Honegger. I will explain how several new scientific understandings were achieved through these hybrid practices as a result. Although seemingly divergent, I will show how these artists all worked as primary researchers, and in an entirely new context about their work in relation to both art and science history. Likewise, I will show how each one of them facilitated larger environmental discourses, an aspect that has not been addressed in prior critical analysis of their works.

Engaging non-specialist audiences and disseminating to them knowledge about ecological phenomena may be paramount for long-term conservation efforts. My transdisciplinary artwork and participatory biology programs have concentrated on increasing public understanding of ecological issue for amphibian declines and deformities through a combination of primary scientific research performed with the aid of volunteers and the creation of my own art inspired from this process. My research suggests that the combination of communication through transdisciplinary art and experiences in nature through participatory biology practices can increase audience consciousness of ecosystems, the plight of non-human organisms and potentially inspire environmental stewardship at an individual level. Evidence presented as a case study from my own transdisciplinary art project, Malamp will demonstrate that arts professionals achieved an increased understanding of the challenges amphibian currently face through the exhibition of these works.

In a second case study I found that individuals involved in my participatory biology programs, Eco-Actions and Public Bio-Art Laboratories, gained a better comprehension of the ecological phenomenon of amphibian declines and deformations. Likewise, these participants helped generate scientific data on ratios of amphibian deformities and identified potential etiologies at select localities in two continents. The underlying aims of this citizen inclusive method was to explore the affectivity of such programs towards raising participant understanding of issues amphibians currently face, assess if such efforts could generate viable data on anurans and how this information could be disseminated to the larger amphibian research community. The benefits and challenges addressed in these kinds of participatory amphibian research programs from my own experiences will be discussed in this thesis.

The ecological phenomenon of amphibian deformities is analysed extensively in the later chapters of this dissertation. To begin I present an extensive literature review to introduce readers to discourses about deformed amphibians and attempt to shed light onto current hypotheses about the underlying causes for such malformations. Such literature reviews are an essential component to scientific research and this aided immensely in the problem identification utilized during my participatory field and lab programs. Likewise, I could not have disseminated relevant information about the plight of amphibians to the public
without firstly performing such an analysis.

This will be followed by two case studies of research into the occurrence, ratios and potential causes for deformities found in natural populations of anurans at select localities in middle-England and southern Quebec. By comparing these seemingly divergent (evolutionarily and regionally) groups of amphibian I attempt to posit previously not understood ecological insights: firstly, that predator attacks by dragonfly nymphs and some fishes may injure tadpoles inducing permanent limb (and other) deformities in post-metamorphic anurans; secondly, that such predatory induced frog and toad deformities may be increased as ecological quality of wetlands declines. Neither observation has been well studied in prior research within the genre of amphibian deformity science.

In the last chapter of this thesis, I will discuss ideas on the intersection and potential merging between art and science as posited by C.P. Snow, Stephen Wilson, Jonah Lehrer and others. Such attempts at merging such distinct disciplines may offer novel strategies for solving 'post-normal' problems, however may not be without limitations. Through such blurring of boundaries science may loose it rigorous method of analysis, an important means to identify individual elements within complex systems in the first place. Likewise, through such a synthesis of art-science, art may become less open-ended by becoming a mono-interpretive tool for communicating science. However I argue for a more transdisciplinary and participatory approach that utilizes the methods of both art and science, and involves community participation may be the most effective strategy for facing complex ecological challenges.

In conclusion, I will explain why transdisciplinary art and participatory science can become a catalyst for increased popular ecological understanding. I will demonstrate that such practices, in our current time of biodiversity crisis, may offer important ways to facilitate public ecological understanding and conservation involvement while simultaneously generating seminal observations on biological communities and wetland ecosystems.
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“How can transdisciplinary art and participatory biology increase popular understanding of ecological phenomena?”
“How can such practices contribute new knowledge to the field of primary research biology, and how can the results be disseminated?”

I.2. Premise

Transdisciplinary art and participatory biology practices may increase popular understanding of ecological phenomena. Likewise, such projects may offer an important point of access for the public to become directly involved within the insular fields of contemporary art and research science. Participants within an arena of democratized field and laboratory studies may express their findings artistically as well as disseminate discovered knowledge to the larger scientific community. This model of all-inclusive inquiry may be an important strategy for increasing environmental awareness and imparting ecological stewardship within a local and sometimes larger public arena. Moreover, such participatory research may generate new scientific insights, helping to solve questions about ecosystems and organisms.

I.3. Contextual Analysis of the Primary Questions

Originally this thesis was divided into two parts to reflect my practice and approach as both an artist and biologist towards this overall Ph.D. research. I conducted investigations within two intertwined areas of study: firstly, research into transdisciplinary art practices, and secondly, primary biological investigations performed through participatory research programs that involved the public.

In the revisions just completed, I have attempted to further integrate these two practices; however certain chapters remained tied to one question rather than both. For example, chapters 2, 3, 4, and 5 analyze artistic strategies utilized to increase popular understanding of ecological phenomena. Hereby ‘popular’ is meant to indicate local and in some cases the larger general populace (e.g. participants, audiences, viewers, readers) who are not specialists in either art or biology. Furthermore ‘increased understanding of ecological phenomena’ refers to an enhanced comprehension within such non-specialist individuals of facts relating to the relationship of organisms to one another and to their biotic and abiotic environment.

Chapters 6, 8, and 9 address my second primary question, which explores the creation and dissemination of new scientific knowledge through participatory biology programs. In these chapters, presented as case studies, it was necessary to use the reductionist methods of primary research biology (albeit employed through participation of non-specialist volunteers) to see if new insights into the proximate causes of limb deformities in amphibians could be found. Additionally, I attempted to learn whether this work could shed light on a potentially larger environmental phenomenon: ratios of such predation-induced amphibian limb deformities appear to correlate with habitat quality of wetlands; specifically, malformations
increase as ecosystem quality declines.

In a further attempt to integrate and clarify the art and science threads of my research I found it necessary in chapter 1 to analyse various definitions of transdisciplinarity and participatory science. Through this analysis, areas of conceptual overlap and partial integration between art and biology were found. However, I found little to no evidence that a true synthesis between these disciplines has yet largely emerged (discussed in more detail in chapter 10). With my own work, discussed in chapters 5, 6, 8, and 9, I embrace this duality of approaches between art and biology, as I find it fundamentally important that the rigorous methods of scientific research practiced in ecological studies remain empirical. Moreover, with my artworks it is vitally important that they remain conjectural and open to interpretation, lest they become mere objects of science communication. This retention of core disciplinary methods with a combination of methodologies through several disciplines to solve complex, real-world problems is attuned with some definitions of transdisciplinarity by Jürgen Mittelstraß and others, as discussed in detail in chapter 1.
1.4. List of Primary Aims of this Research

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<th>Aims</th>
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<tr>
<td>1. To explore the potential pragmatic interlacing between art and science through transdisciplinary art and participatory scientific practices focused on ecological studies</td>
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<td>2. To provide evidence that historic hybrid art and science practices may have built a conceptual foundation for some of today’s transdisciplinary art and participatory scientific practices, as well as demonstrating how these historic works offered new philosophical approaches that challenged popular perceptions and approaches towards nature in their day and which still underlies much thinking in the environmental movement.</td>
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<tr>
<td>3. To provide evidence that by employing transdisciplinary methods, ecological artworks and actions increased audience understanding of the threats to wetlands.</td>
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<tr>
<td>4. To explore several creative transdisciplinary art processes employed in biological art practices that contributed new scientific knowledge.</td>
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<td>5. To explore the effectiveness of increasing popular understanding of ecological phenomena through my own transdisciplinary art practices involving deformed amphibians.</td>
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<tr>
<td>6. To investigate the effectiveness of my participatory biology programs for increasing participant understandings of amphibians, local ecosystems, and larger environmental phenomena.</td>
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<td>7. To provide evidence that primary research conducted with the assistance of trained citizens could achieve new ecological insights into the temporal, spatial, and occurrence ratios of injuries and developmental deформities among wild populations of anuran amphibians.</td>
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<tr>
<td>8. To provide evidence that primary research conducted with the assistance of trained citizens could generate new scientific insights into the causes (e.g. chemical pollutants, parasitic infection, predatory injury, others) for amphibian deformations.</td>
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<tr>
<td>9. To provide evidence that primary research conducted with the assistance of trained citizens could generate new scientific insights into the interrelationships between anuran larvae prey, their predators, and parasites within complex natural wetland ecosystems.</td>
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<tr>
<td>10. To provide evidence that such transdisciplinary art and participatory scientific practices focused on ecology may be an important strategy for increasing localized public understanding of environmental issues while generating new scientific insights.</td>
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Table 1. List of primary aims explored during this research

1.5. Methods, Methodologies, and Approaches

As my primary research questions require responses from both natural and social science perspectives, a mixed-methods strategy was utilized for gathering data: a method approved in my 2009 Transfer Paper. This involved collecting both numeric information (quantitative) from laboratory and field studies as well as surveys from audiences. Also, qualitative methods (e.g., interviews) were performed to look for trends in responses from interviewed program participants, artists, and scientists. According to John W. Creswell, professor of educational psychology at the University of Nebraska-Lincoln, such a mixed-method approach ‘bases the inquiry on the assumption that collecting diverse types of data best provides an understanding of a research problem’ (2003: 21). Moreover, as my first primary research question attempted to gauge the effect of both transdisciplinary art practices and participatory science programs towards increasing ecological knowledge, methods for
acquiring data were varied and included reviews of relevant literature, interviews, surveys, and questionnaires (table 2). On the other hand, my second primary research question attempted to measure the viability of field and laboratory data generated during participatory biology research. To do this, firstly a quantitative analysis needed to be performed (e.g. what experiments were performed? What were these findings?; table 2), followed by post-reflective analysis (Were such findings able to provide insight into the larger deformed amphibian phenomenon?).

Although a singular thematic analysis addressed both primary questions, the approaches to different types of data were varied, a strategy aligned with the ideas of research theorists Victoria Clark and Virginia Braun (2006, 2012). Braun and Clarke have advocated a form of thematic analysis that is reflexive, interpretive, and adaptive in approach towards varied forms of data in an attempt to identify for a larger pattern (Braun and Clarke 2006, 2012). Furthermore, Braun and Clarke (2012) identify varied approaches to data analysis, which I found relevant to further clarify the mixed-methods strategy I employed during my Ph.D. research. As I am working with participatory biology, I have decided to take the approach of a real or essentialist way with the hope of reporting on assumed realities from gathered evidence and data. However, in the arts, a semantic approach is important to consider, and the impact of the image relies on explicit content to be exposed and poetically experienced as well as post-reflected. In relation to the historical contexts for my dissertation, I have taken a more constructivist approach, one that focuses on how a certain reality is created through a body of evidence found in pre-existing literature. To address my first primary question these three approaches are necessary to help locate a potentially larger pattern: that transdisciplinary art and participatory science may be able to increase non-specialist public understanding of ecological phenomena. The use of multiple approaches is also required to address the second primary question, which sought to understand if data during such participatory biology programs were viable and if so, how they may provide new insights into ecological phenomena (table 1).
<table>
<thead>
<tr>
<th>Methods</th>
<th>Methodologies</th>
<th>Approach</th>
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| Questionnaires to short-term volunteers/ visitors in participatory biology programs | 1. Answers from short-term volunteers/ visitors from my amphibian surveys and labs in England (Chapter 6)  
2. Answers from short-term volunteers/ visitors from my amphibian surveys and labs in Quebec. (Chapter 6) | Realist or essentialist way: focused on reporting an assumed reality evident in the data |
| Interviews with long-term participants in participatory biology programs | Answers from long-term volunteers from my amphibian surveys and labs in Quebec (Chapter 6) |  |
| Primary research field and laboratory studies | 1. Results of field and laboratory studies in England (Chapter 8)  
2. Results of field and laboratory studies in Quebec (Chapter 9) |  |
| Surveys to biologists | Answers from biologists on their citizen science programs (Chapter 6) |  |
| Artist interviews | Reflections by artists working along transdisciplinary lines within the fields of Ecological Art (Chapter 3) and Biological Art (Chapter 4) | Semantic way: theme development to reflect the explicit content of the data |
| Surveys to exhibition organizer | The post-reflective effect of my exhibitions on the people who saw them (Chapter 5) |  |
| Literature Reviews | Collection and comparison of historic and recent evidence based on my findings in the following fields:  
1. Transdisciplinarity (Chapter 1)  
2. Participatory Science (Chapter 1)  
3. Science to art practices (Chapter 10)  
4. Amphibian deformities (Chapter 7) | Constructionist way: focused on looking at how a certain reality is created by the data |

Table 2. Methods, Methodologies and Approaches utilized in Research, modified from Transfer Paper, Ballengée (2009)
I.6. Role in the Collaborative Elements of This Research

Throughout this research numerous forms of collaboration occurred among myself, other biologists, my advisors, and participating members of the public. My primary advisors, Dr. Jillian Scott and Dr. Angelika Hilbeck, offered overall support for structuring methods, methodologies, and approaches towards research. In addition, Dr. Jillian Scott and Dr. Angelika Hilbeck offered immense help in the design of participant questionnaires and the format of video interviews. My external advisor, Dr. Stanley K. Sessions, provided important feedback on my primary research designs for field and laboratory studies in England and later Quebec. While in England, naturalist Richard Sunter aided in numerous field studies, helping to collect and record data on British anurans over three summers. My employer, Dr. David M. Green, provided important feedback on my primary research designs for field and laboratory studies in Quebec and later analysis of field data, which I presented in 2010 at the Joint Meeting of the American Society for Ichthyologists and Herpetologists. Numerous participating members of the public aided in the collection of anurans and their predators at field sites in England and Quebec as well as helping to monitor and maintain animals in laboratory experiments. In addition they provided non-specialist viewpoints, and these important and unique observations stimulated the evolution of the entire research process.

I.7. Context for This Research

Today’s environmental issues are extensive, complex, and often daunting, leaving much of the populace to become apathetic and with the sense there is little they can do to contribute to change. However, there are many examples of historic art and science creative endeavours that have changed the way the populace viewed the natural world, often challenging the dominant cultural perception of nature in their day. Such strategies as visually engaging art and captivating writings may still be effective means to disseminate knowledge of ecosystems and organisms to a larger non-specialist public, perhaps even inspiring stewardship.

More recent ecological artworks have contributed increased public understanding of wetlands, even in some cases offering pragmatic solutions to real-world ecological challenges. This suggests that transdisciplinary methods may be useful for larger conservation efforts. Likewise in the emerging field of biological arts, several practitioners have made new scientific discoveries. Such practices stand in direct opposition to the often widely assumed belief that art has no substantial function at a social or tangible level.

As an artist who creates work inspired by the scientific study of animals and ecosystems, I strongly believe that art can influence the way people view nature and understand their environments. In this dissertation, art projects that transgress disciplines are explored. They may have the potential to increase popular ecological understanding as well as in some cases generate new knowledge for the scientific community, thus verging on transdisciplinarity.

Over recent decades, evidence has emerged that suggests biology itself may be opening to larger society. Traditionally, primary biological research has been conducted within the isolated discipline of science by a minority of specialists. However the growing
field of citizen and participatory science has shown that members of the public are able to generate large quantities of environmental and other forms of observational data. Likewise non-specialist volunteers in such programs may gain a better understanding varied scientific phenomena.

I believe that such inclusive biological monitoring programs are paramount at this point in history, when losses to biodiversity are so acute, yet allocation of resources (both human and economic) for such investigations has increasingly become limited. As amphibians are in the middle of a population crisis and the problem of deformed frogs has persisted for almost two decades, help from the public is desperately needed. Significantly, within the amphibian research community, the majority of published deformed frog studies were not able to establish proximate cause(s) for the abnormal animals that they reported. Several prior studies have implicated teratological chemicals as the most likely candidate for such malformations but were unable able to demonstrate this experimentally under laboratory conditions. In my own participatory biology research, however, I sought to better understand potential etiologies for such anuran deformations with the aid of non-specialist volunteers. Through field and laboratory studies we examined the inter-relationship of tadpoles to other organisms within complex wetland ecosystems. Further, the studies conducted surfaced reliable data that may suggest causative factors for amphibian deformations, in certain circumstances.

Within such transdisciplinary art and participatory science practices, overlapping between disciplines may occur. It is even possible that the ember for a larger movement beyond disciplines has ignited. Surely we will need diverse forms of creativity and knowledge to solve the complex, real-world environmental problems we currently face. I will explore the potential fusion of art-science in relation to ecological studies throughout this paper.

1.8. Overview of the Chapters

Chapter 1. Creative Entanglement: An Introduction to Transdisciplinary Art and Participatory Science Programs for Ecosystem Studies. Over recent decades, transdisciplinarity has been a widely utilized term to describe practices that transcend traditional boundaries between disciplines. However definitions of transdisciplinarity are often in conflict and range from a complete paradigm shift, as suggested by Basarab Nicolescu, to more pragmatic approaches towards unifying knowledge to solve complex, real-world problems, as suggested by Jürgen Mittelstraß, Edward O. Wilson, Gibbons et al. (1994) and others. What role may art play in such transdisciplinary arenas? Perhaps a new definition of transdisciplinary art with ecology is required. Also in recent times, many efforts in biology have been made to integrate non-scientists into the primary research process. Such citizen science programs, according to scientists Rick Bonney, Alan Irwin, and others, intentionally involve the public to implement larger-scale studies. What do participants gain from such experiences? Is the data that non-scientists generate viable for a large research community? Perhaps isolated disciplines such as art and science may find fruitful overlaps within transdisciplinary thinking and participatory research.
Chapter 2. Raising Public Ecological Awareness through Historic Art and Science Practices. Several historic hybrid scientist-artists utilized creative writing and visual art to effectively raise public understanding of natural history. Erasmus Darwin and Ernst Haeckel utilized representational strategies to engage audiences, while Alexander von Humboldt, John James Audubon, and Charles Darwin challenged anthropocentric belief systems through their creative outputs. These ideas were furthered through early forms of ecocentric ethics through the works of Henry David Thoreau and Aldo Leopold. How did these practitioners employ various art forms to disseminate knowledge of natural history to a larger, non-science audience? Would such strategies be effective today? How did these works challenge dominant popular perceptions of the natural world during their day? Did these practices build a conceptual foundation for some of today’s transdisciplinary practices in art or participatory science?

Chapter 3. Wetland Conservation and Art: Activating the Community. Seminal ecological artworks by Hans Haacke, Patricia Johanson, and Joseph Beuys increased public understanding of wetland ecosystems. Haacke created a filtration sculpture to comment on the environmental degradation of the Rhine River, while Patricia Johanson actually implemented wetland remediation as an art practice. Joseph Beuys performed with a bog to draw attention to such declining wetlands. What strategies did each of these artists employ to draw public attention to wetlands? How did these artists actively increase environmental awareness for audiences? What are the complex bio-ethical implications of artworks that utilize animals and actual ecosystems as artistic material?

Chapter 4. Biological Research as Art Practice. Several artists have utilized biological research in their artistic practice and made scientific discoveries. Helen and Newton Harrison, Mel Chin, Tissue Culture and Art (TC&A), and Cornelia Hesse-Honegger, each in a unique way, contributed new understandings to the field of science but also increased popular awareness of larger environmental issues through their art. However it is important to ask how such artists went about this transdisciplinary art practice. How did a literary scholar and a figurative sculptor (the Harrisons) develop a scientific method for breeding rare crabs? How did the artist Mel Chin’s collaboration with scientist Rufus Chaney challenge ideas of public art and work to establish the field of phytoremediation? As creative protagonists, how did TC&A create a new tissue engineering technique while questioning the biomedical industry? How did Cornelia Hesse-Honegger’s paintings compel scientists to further investigate radioactive, contaminated wildlife?

Chapter 5. Case Study I, Malamp: The Occurrence of Deformities in Amphibians—Transdisciplinary Artworks. As a case study I will examine my own long-running transdisciplinary art practice that explores the recent global demise of amphibians, Malamp. This on-going body of work consists primary in three forms: Styx, a sculptural series; Malamp Reliquaries, a photographic series; and Un Requiem pour Flocons de Neige Blessés, an ephemeral film. How and why have these works been created? Could the exhibition of such artworks effectively inform audiences about the worldwide plight of amphibians and larger ecological phenomena? How can such works of visual art relay a message to audiences about the severe ecological stresses we face today?

Chapter 6. Case Study II: Participatory Biology to Study Deformities in
**Amphibians.** As a case study I will examine my participatory biology projects, *Eco-Actions* and *Public Bio-Art Laboratories*. Such projects have investigated the health of amphibian populations while involving the public through participatory biology programs consisting of field and laboratory work open to and in the public realm. Why involve the public in the study of amphibians? Are such participatory programs effective for informing audiences about the problems amphibians currently face? Can real scientific studies be conducted in such situations? Is the data that has been generated in such citizen science programs viable at a peer reviewed, scientific level? Could and should these strategies be utilized at a larger scale?

**Chapter 7. Unravelling the Ecological Mystery of Misshapen Amphibians: An Analysis of Prior Research in the Field.** Before disseminating information on the plight of amphibian deformities to the public, it was first necessary to perform an extensive review of relevant literature. Hereby I hoped to shed light on historic and recent discourses to identify potential causes for such malformations. A number of important questions will be addressed in this chapter, such as: Do amphibians make good bio-indicators? Are anuran deformities natural, and at what point do frequencies become high enough that we should be concerned? Based on available evidence, what suspected causes for deformed anurans seem the most likely to be occurring in nature? How do these suspected etiologies correspond with what was found during my participatory amphibian studies?

**Chapter 8. Case Study III: The Occurrence and Causes of Amphibian Deformities at Selected Localities in Yorkshire England.** This chapter deals with my second primary question, which ponders whether such participatory programs may contribute new knowledge to the field of primary research biology. Presented as a case study, this chapter explains the rigorous scientific methods that were utilized in my *Eco-Actions* and *Public Bio-Art Laboratories* in middle England. Here, through participatory programs we sought to study the occurrence, ratios, and potential causes for deformities found in natural populations of anurans at select localities. There are many questions that arose from this research, including: Do developmental deformities occur in wild populations of anurans in middle England? Are recent deformities occurring at beyond-natural levels? What potential role may predators have in inducing non-lethal injuries to tadpoles, which result in permanent limb (and other) deformities in post-metamorphic anurans? Were the insights from this participatory research valuable to the larger amphibian research community?

**Chapter 9. Case Study IV: The Occurrence and Causes of Amphibian Deformities at Selected Localities in Southern Quebec.** This chapter presents as a case study the scientific research that took place in Canada. In these participatory programs, fewer public participants were involved, but they contributed over longer periods of time. Because of this, a more in-depth analysis of the occurrence, ratios, and potential causes for deformities among natural populations of anurans at select localities in southern Quebec was performed. Many questions arose along the way, such as: Are these recent deformities occurring at beyond-natural levels? What potential role could predatory dragonfly nymphs and some fishes have in inducing limb (and other) deformities in post-metamorphic anurans? Are such intra-specific tadpole predation pressures increased as ecological quality of wetlands declines? Do these findings offer an underlying explanation for deformities not explored in prior research in the region? Were the insights from this participatory research program
valuable to the larger amphibian research community?

**Chapter 10. Interweaving of Art and Science in a Time of Ecological Crisis.**

Several important ideas about the division and potential threading of art and science, as put forward by C. P. Snow, Stephen Wilson, and others will be discussed in this chapter. However, authors such as James Elkins have argued against a synthesis between science and art, and other scholars have condemned environmental efforts as overtly reactionary and lacking scientific rigor. However, I will argue here that combined art and science efforts may be an important and effective tool for addressing the complex ‘post-normal’ ecological challenges we currently face. However, through the blurring of boundaries with art, will science lose it rigorous methods for analysis? Will art become merely a device for communicating science? For ecological studies, how could art work in harmony with science to help our species behave more sustainably? Is such a fusion of disciplines even possible at this moment in history?

**Conclusion and Suggestions for Further Research.** The conclusion to this dissertation offers further expanded analysis of both the qualitative and quantitative data generated in these studies. Further, such data is used to argue that, for the complex, real-world environmental challenges we currently face, a mixed approach of transdisciplinary art and participatory biology may aid in finding solutions. I also argue that the results of scientific studies conducted with participatory programs are relevant, provided rigorous methods are utilized throughout the research process. Could such combined art-science efforts be a catalyst for increased popular ecological understanding? Here I will attempt to demonstrate that such practices, in our current time of biodiversity crisis, may offer important ways to facilitate public ecological understanding and involvement in conservation efforts while simultaneously generating seminal observations on biological communities and wetland ecosystems.

However, in my experience, transdisciplinary art and participatory science programs are not without limitations and challenges. Are transdisciplinary artworks still art as defined by the mainstream arts community? By delivering a message about ecology, do such transdisciplinary artworks become overly didactic? Do citizen science programs risk becoming too large for professionals to effectively manage datasets? Is the amount of time required to properly train participants worth the effort? Does participation in such programs really change behaviour in ways that lead to stewardship? For work that can aid the long-term survival of numerous species—even our own—are disciplinary boundaries standing in the way?
Chapter 1. Creative Entanglement: An Introduction to Transdisciplinary Art and Participatory Science Programs for Ecosystem Studies

1.1. Introduction

Transdisciplinary art and participatory science practices may be important strategies for increasing non-specialist understanding of other organisms, ecosystems, and ecological phenomena. Additionally such practices may offer an important point of access for the public to become directly involved within the insular fields of contemporary art and research science, allowing for the production and transfer of knowledge to larger non-science/art specialist audiences. To understand how this dissemination of information is achieved, it is important to first shed light on larger approaches in transdisciplinarity as well as participatory science. This will help to contextualize my definitions of ‘transdisciplinary art’ and ‘participatory biology’ as utilized throughout this dissertation. To do this I will begin with a critical analysis of the major schools of thought on transdisciplinarity, which will lead to my consideration of the novel characteristics of ‘transdisciplinary art with ecology’. These ideas will be followed by an investigation into the origins and varied approaches of the growing citizen science movement as well as my own ‘participatory biology’ methodologies.

1.2: Defining Transdisciplinarity

The terms ‘transdisciplinarity’ and ‘transdisciplinary’ have increasingly been used over recent decades in the fields of science, health care, education, management, economics, and others, but rarely in art (except for digital and, more recently, post-studio practices). Although there is no singular definition for the term ‘transdisciplinarity’, it generally is used to define novel strategies and theoretical models for practices that move ‘beyond’ or ‘across’ disciplinary (specialist) boundaries. It most often is described as involving disciplinary integration, cooperation, and communication, or breaking free of organizational hierarchies. Often such efforts are undertaken to address complex institutional, social, or ecological problems (Klein 1990, 2003; Gibbons et al. 1994; Jahn 2008; Pohl et al. 2008). Several key theoreticians have attempted to describe characteristics of transdisciplinarity in the fields of knowledge production in science and society at large. Among them are Basarab Nicolescu, Jürgen Mittelstraß, Edward O. Wilson, and Michael Gibbons et al. (1994).

The term ‘transdisciplinarity’ was applied to science in 1970 by Swiss developmental psychologist and philosopher Jean Piaget and further defined by Austrian astrophysicist and philosopher Erich Jantsch (Klein 1999, 2003; Nicolescu 2002, 2005; Jahn 2008). Piaget’s grand ideas included the fundamental shift in academia to a new ‘total system without any boundaries between disciplines’ (1972: 138). Jantsch focused more on pragmatic restructuring of academia into an ‘education/innovation system’ motivated towards problem solving (1972:

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1 There are a number of other important ideas underlying current understandings of the term transdisciplinarity’ that are not critically analysed here but that informed to some degree my attempts towards a describing transdisciplinary art with ecology. Among those are: plural-disciplinary integration of knowledge in/beyond science, and integration across research activities and across disciplinarily structures as suggested by Pohl et al. (2006a, b); issues with abstract concepts and misuse of the term ‘transdisciplinarity’ and the coining of the new term ‘supradisciplinary’ by Kötter and Balsiger (1999); various ideas on the approach and methods of ‘transdisciplinary research’ (Hadorn et al. 2008; Gleiniger et al. 2010).
In broad terms both Jantsch and Piaget suggested the necessity of a future transdisciplinary academic paradigm founded on heterogeneous scholarship, whereby knowledge across disciplines is shared to create a more holistic form of learning and pluralistic approaches to problem solving that are reflective of the complexity of the real world (see Apostel et al. 1972; Klein 2003). As Julie Thompson Klein has stated, the underlying ideology of transdisciplinarity ‘signifies the interconnectedness of all aspects of reality, transcending the dynamics of a dialectical synthesis to grasp the total dynamics of reality as a whole’ (1990: 60). Such a model, which attempts to embrace complexity, may be an important tool for ecological studies as well as knowledge transfer about such phenomena to a larger public.

Building upon Piaget’s ideas of dissolved boundaries between disciplines, Romanian theoretical physicist Basarab Nicolescu has outlined his own theoretical (and almost theological) model of transdisciplinarity. Nicolescu has stated that ‘[as] the prefix ‘trans’ indicates, transdisciplinarity concerns that which is at once between the disciplines, across the different disciplines, and beyond all disciplines’ (2005: 7). Inspired by his own work in quantum physics, Nicolescu has suggested we must not just rethink science and academia, but also the nature of reality itself. In his Manifesto of Transdisciplinarity (1985; tr. 2002), Nicolescu challenged fundamental aspects of science and society at large, which included: the perception of a singular reality; duality in scientific inquiry between object and subject; and the loss of the sacred and universal meaning due to reductionist rationalism. According to Nicolescu, society has adopted science as universal truth, and science itself is an insular discipline that has ‘reached its own limitations’ and is in need of fundamental philosophical restructuring for the long-term survival of the human species (1985, 1998, 2005: 104).

According to Nicolescu, in order to begin such a paradigm shift, Newtonian views of a singular material reality ought be challenged. Instead Nicolescu proposes plural or several realities existing simultaneously (attuned to thoughts in quantum mechanics). This new viewpoint allows us to consider a multidimensional Reality, structured by multiple levels replacing the single-level, one-dimensional reality of classical thought’ (2002: 49). Hereby, reality exists at many levels simultaneously, and through a transdisciplinary framework we may start to perceive such complexity. Three distinct classifiers of meaning arise within such a paradigm: the horizontal ‘interconnections at a single level of Reality … what most academic disciplines do’; the vertical ‘interconnections involving several levels of Reality … what poetry, art, and quantum physics do; and the meaning of meaning, or ‘interconnections involving all of Reality’ — the interconnected area between the Subject and the Object that Nicolescu refers to as the ‘Hidden Third’ (2005: 157). By accounting for such complexity, we may begin to restructure not only academia but the way our very species and societies at large operate.

From a semantic standpoint, Nicolescu’s ideas give impetus for the necessity of multiple interpretations of reality. However by taking the idea of multiple viewpoints to the wording level of plural realities, Nicolescu’s ideas become very abstract and limited to the realm of specialists (e.g. quantum physicists), a limitation that he has argued against in the first place. This may also be problematic in terms of ecological studies, whereby material science has proven to be useful to conservation and remediation; just as gravity still is the best
explanation to account for a falling apple, biochemical reactions explain toxic death in organisms exposed to teratological pollutants (Wieger 1988; Wilson 1998).

That is not to say that such a ‘single lens’ approach in primary research should not be questioned; in the science of ecology itself a debate between holistic views versus more reductionist approaches has been waged during recent decades (Hutchinson 1978; Wieger 1988; Looijen 2000). Additionally, numerous researchers have called into question the reliability of traditional Newtonian approaches to comprehend the complexity of ecosystems and even organisms themselves (Van Regenmortel 2004; Singer 2007; Morin 2007; others). Such a fundamental transition in the life sciences to embrace a more complex understanding of both the material and theoretical universe may have begun but at this point is still more hypothetical than pragmatically applied, at least in biology (Mazzocchi 2008). To be fair however, Nicolescu has stated that his work in this area is ‘theoretical’ (2005: 145), or not applied. Yet one has to wonder if such specialized ideas (derived from theoretical physics, according to Nicolescu 2010) may at some point be fully combined with future material approaches in biology to help combat the ‘self-destruction of the human species’ (2005: 142) and aid in our comprehension of the complexity of ecosystems as well as ourselves as complex organisms.

Nicolescu also challenged the fundamental duality between subject of study and observer still present in much of material science practice (2005, 2010). As Nicolescu has boldly stated, ‘The death of the Subject is the price we pay for objective knowledge’ (2010: 21). This dualistic view has for centuries promoted a linear, ‘logical’ form of analysis based on objective observation of a subject to form a singular view of reality, or ‘truth’ (2010: 21). Meanwhile, other forms of inquiry have been ‘cast into the inferno of subjectivity, tolerated at most as a meaningless embellishment, or rejected with contempt as a fantasy, an illusion, a regression, or a product of the imagination’ (2005: 142). One only need to reflect upon evolutionary biologist Richard Dawkins’s public attacks on systems of belief outside science to see confirmation of Nicolescu’s point.

Nicolescu has suggested that this objective duality has spread beyond science to society as a whole, leading our species to approach ‘self-destruction on a global scale’ (2005: 143) and must be ‘transgressed by the open unity that encompasses both the universe and the human being’ (2002: 56). In Nicolescu’s vision of transdisciplinarity, we must overcome rigid distinctions between objectified subject, researcher, and a larger universal community as well as realizing that there are many interpretations of what could be considered truth (2002, 2005, 2008). Already though, since the 1960s through ‘post-positivist’ approaches in science, this

2 Nicolescu has called into question the dualist approach (e.g. the dichotomy between ‘object’ and ‘subject’, sometimes referred to as the Cartesian divide) still heavily applied in material science, which may have permeated the larger Western society. I agree that duality at a social level must be challenged for the greater welfare of all people. However in material science, particularly in biology and ecology, a dualistic research method is still a fundamental and widely practiced means for the analysis of physical evidence in an attempt to better comprehend phenomena under the laws of Newtonian physics (Odum and Barret 2004). Utilizing objective observation to understand non-human animals within the context of ecosystems and complex ecosystems themselves is still the very basis of science-informed conservation and environmental policies (Wilson 1998). If such observations are not made in the first place nor recorded or objectively analyzed, how will we begin to understand how to successfully protect species and ecosystems or to remediate habitats already compromised?

3 Often referred to as the Cartesian divide, this will be discussed in more detail in later chapters.

4 Post-positivism in science attempted to amend attitudes of empiricism or absolute objectivity within post-enlightenment, ‘positivist’ approaches to research. Mostly attributed to science philosopher Karl Popper, post-positivism position still strives towards objective analysis but is conscious that the researcher himself influences to some degree the research, and as such, no study can be completely objective (see Popper 1963).
mode of thinking has already increased in at least some of the research: psychology, neuro-biology, human medicine, and even more recently in an amphibian study which utilized an epidemiological approach developed for humans to surmise health of wetlands (Cherryholmes 1992; Eliot et al. 1999; Phillips and Burbules 2000; Tayler 2005; Singer 2007; Braun and Clarke 2006).

Another major aim of Nicolescu’s definition of transdisciplinarity is to combat contemporary societies’ loss of the sacred and of universal meaning. As Nicolescu has suggested, under the singular scientific paradigm of reality there is no space for a concept of the sacred or anything else that cannot be accounted for in the material perception of reality (1999, 2002, 2005). Because of this devaluing of the spiritual along with singular ways of thinking in academic programs, Nicolescu suggests society has as developed a ‘universal hunger for meaning’ (1999: 5). As a remedy, ‘transdisciplinary education can open the way towards the integral education of the human being’, leading to a more holistic view of reality (1999: 5). Such academic programs would fundamentally have no boundaries between disciplines and potentially could revalue the arts, philosophy, spirituality, and other areas of study currently overshadowed by science (and more likely technology and economics, in my opinion). I strongly agree with the opinion of Nicolescu here, as equality for the varied fields in inquiry within educational institutions could be an important strategy for aiding society to become less ecologically and intra-socially destructive.

From my perspective as an amphibian biologist, several potential issues arise from Nicolescu’s ideas. Firstly, as a practitioner in material science, I study ecological phenomena at biotic and abiotic levels that can measured, recorded, and analysed for larger patterns through a reductionist process. This method has been shown over time to be an effective strategy of analysis in biology and the foundation for much of today’s conservation efforts (Wiegert 1988; Trout 1991; Wilson 2002). Through a singular objective lens questions are posed of material phenomena, inquiries are tested through repeatable experimentation, and results are shared with peers. This method is repeatable, and if other researchers find similar results, it may suggest a larger trend in natural systems. On the other hand, other researchers may derive different findings to rebut earlier observations. This process is of fundamental importance, as biology at its core is a collective process undergoing continuous revision in order to understand the material world (which is also undergoing constant changes) through data collection at particular moments in history (Wilson 1998).

This method of inquiry in biology, of course, has limitations and is only one means of attempting to understand and collectively agree upon a single reality based upon material evidence under the laws of traditional physics. As such, this materialist approach may seem at odds or completely incompatible with Nicolescu’s theoretical ideas. However, the necessity of multiple viewpoints has been suggested, as ‘transdisciplinarity is both unified (in the sense of unification of different transdisciplinary approaches) and diverse: unity in diversity and diversity through unity is inherent to transdisciplinarity’. Thus, perhaps there will be room for traditional biologists within this new paradigm (2010: 23). Already in the science of ecology, both materialist (traditional) methods and novel theoretical means (such as computational modelling) have increasingly been applied for better understanding of complex ecological systems (Odum and Barret 2004).
Additionally, Nicolescu has heavily promoted the idea of ‘joint problem solving’ more attuned with ideas of Jantsch than Piaget (2005: 144) and also my own working philosophy. Nicolescu has warned that specialization has led to isolation and lack of communicating knowledge across disciplines (referred to as ‘Babelization’; 2003: 109). Collaboration, cooperation, and moving beyond disciplines should be an effort we collectively strive towards. I am in agreement with this sentiment; in my own experiences of working among the artistic, scientific, and educational communities, there is a tremendous amount of lack of understanding between these groups. As today’s environmental issues are incredibly complex, this creative entangling of knowledge in Nicolescu’s vision of transdisciplinarity may be an important strategy for the survival of numerous species, including our own.

The German science philosopher Jürgen Mittelstraß first introduced his concept of ‘Transdisziplinarität’, or transdisciplinarity, in 1986 (Mittelstraß 2002, 2011). Fundamentally diverging from Nicolescu, Mittelstraß views transdisciplinarity as a pragmatic principle of research that leads and directs, instead of theoretical or philosophical paradigms. For Mittelstraß, transdisciplinarity is grounded in pre-existing scientific methodologies and the understanding of a single material reality through an objective scientific lens: ‘not merely a philosophical fantasy’ but coming to fruition through the cooperative efforts of researchers (from different backgrounds of specialization) to understand a complex whole (2002: 46).

Also differing from Nicolescu’s view of creating a ‘new’ universal transdisciplinary approach, Mittelstraß posited that transdisciplinarity has already increasingly emerged within science over recent decades, in response to complex problems, an approach ‘which is most effective where a merely disciplinary, or field-specific definition of problematic situations and solutions is impossible’ (2002: 44). According to Mittelstraß, scientific research over time has already moved towards some degree of transdisciplinarity, and it should be the goal of individual researchers to strive towards greater cooperation and the role of academia to facilitate this necessary development.

In his approach Mittelstraß does not call for a paradigm-shifting relationship to or within science or reality as called for by Nicolescu. Instead Mittelstraß appeals for a transdisciplinary model that is ‘first of all an integrating, although not a holistic concept. It resolves isolation on a higher methodological plane, but it does not attempt to construct a “unified” interpretative or explanatory matrix’ (2002: 45). At odds with Nicolescu’s view of how science has led to a single, dogmatic definition of ‘truth’, Mittelstraß instead has suggested scientific approaches as means to identify phenomena based on evidence that is transmutable over time as further research is conducted and new results are found. This reaffirms the fundamental role of scientific research.

Also in opposition to Nicolescu, Mittelstraß did not suggest we dismantle the fundamental framework for existing science nor scientific objectivity: ‘it is not the standards of rationality, nor with them the methods and forms of theoretical construction which are changing, but the organizational forms of science and scientific research’ (2002: 47). Hereby Mittelstraß does not fault the underlying philosophy of inquiry in science but instead the way in which, over the course of history, scientific efforts have grown within institutions to be ‘increasing particularization of disciplines and fields’ that have led to the inability of
researchers to see larger trends across disciplines or to solve complex problems that are beyond the means of single, disciplinary approaches (Mittelstraß 2002: 43).

To do this, Mittelstraß suggested that academia must move beyond restrictive, historic disciplines, which over time have begun to lose their ‘problem-solving capacities due to an excessive specialization’ in favour of more cooperative and cross-communicative strategies for issue resolution (2011: 332). As such, transdisciplinarity does not strive to become a new discipline nor replace areas of specialization but instead should attempt to combine the strengths of such disciplines towards increased comprehension (Mittelstraß 2002, 2011). Hereby we must retain the organization of science to understand the complexities of problems in post-technological societies. Likewise Mittelstraß suggested that nature itself does not distinguish between disciplines; why should we do so in our attempts to understand natural phenomena? (2002, 2011).

Thus Mittelstraß does not aim to solve underlying, grandiose social problems (such as the ‘human condition’ or others that Nicolescu’s approach might address) but instead to find solutions to scalable, real-world issues, particularly in the fields of ‘the environment, energy, or health’ and within the field of science and academia itself (Mittelstraß 2002: 44). To do this, he suggests that we need ‘lasting and systematic’ planning and that we should move beyond traditional ‘structures and strategies in research extending beyond fields and disciplines (and thus indirectly in teaching as well’; (2002: 44). Mittelstraß cites several laboratories around the world that have already moved in this transdisciplinary direction, such as the Center for Nano-Science (CeNS) at the University of Munich, the Bio-X Center at Stanford University, and the Center for Genomics and Proteomics at Harvard University. Researchers from varied scientific backgrounds have worked in cooperation across disciplines and achieved significant findings (Mittelstraß 2002, 2011).

Individuals participating in such transdisciplinarity environments retain their expertise in order to ‘contribute what they know’ but cooperate with others in the process of problem-solving; ‘they do not change themselves in their forms of knowledge or methodology’ (Mittelstraß 2011: 336). Thus research retains a high level of quality without being generalized down to the non-expert level. Pragmatically Mittelstraß (2011) offers a framework for cooperation for individuals in such settings:

1. being open to accepting other points of view outside one’s own area of specialization (‘the unconditional will to learn and the readiness to do without one's own disciplinary ideas’ — 2011: 337);
2. learning others’ areas of specialization (‘the development of interdisciplinary competence, consisting of a productive immersion into the approaches of other disciplines’ — 2011: 337);
3. questioning oneself (‘the capacity to reformulate one's own approaches in light of the interdisciplinary competence thus gained’ — 2011: 337);
4. results presented across disciplines (‘the production of a common text, in which the unity of the argumentation (‘transdisciplinary unity’) takes the place of an amalgamation of disciplinary components starting with drafts squarely falling into one discipline, going through repeated revisions from different disciplinary perspectives, finally leading to a common text’ —2011: 337).
This underlying, pragmatic approach of Mittelstraß is much more attuned to the Z_Node Ph.D. research group that I am a part of than the highly theoretical ideas of Nicolescu (for review, see Gleiniger et al. 2011). Also in my own practice, which has involved partnerships with other art and science specialists, I find the ideas of Mittelstraß to be much more conducive to meaningful collaboration and real-world problem solving (discussed in later chapters of this dissertation).

Another approach that I found important to examine came from American biologist Edward O. Wilson, who called for a cooperative and further integrated approach between disciplines towards complex problem solving and the betterment of all humankind (1998). Though not utilizing the term ‘transdisciplinarity’, Wilson instead called this model ‘consilience’, in which specialized sectors of knowledge production should work unanimously to better ascertain the complexity inherent in the universe, ecosystems, organisms, and even our own species. Wilson, inspired by the scholars of the Enlightenment\(^5\) (those not yet aligned to a singular disciplinary lens of analysis) and borrowing the term ‘consilience’ from nineteenth-century scientist and philosopher William Whewell, insisted that such a new enterprise must involve the coherence of ‘knowledge by the linking of facts and fact-based theory across disciplines to create a common groundwork of explanation’ (Wilson 1998: 8).

In alignment with views by Nicolescu and Mittelstraß, Wilson believed that to achieve this increased complex understanding of nature, academia itself needed to be restructured and varied isolated sectors of knowledge needed to be reconciled.\(^6\) As he stated, ‘A balanced perspective cannot be acquired by studying disciplines in pieces but through pursuit of consilience among them’ (Wilson 1998: 13). Such a transition in learning will involve the revaluing and restructuring of the humanities with science, as under Wilson’s paradigm, ‘true reform will aim at the consilience of science with the social sciences and humanities in scholarship and teaching’ (1998: 13). Such a multifaceted platform of knowledge acquisition and sharing would, on one hand, involve cooperation between areas of specialization, but also, importantly, would value equally those areas of specialized research.

According to Wilson, science over time has already moved towards consilience,\(^7\) whereas the social sciences and humanities (even the arts) have become increasingly stratified within their own discipline-referential circles of knowledge. As he posited, in the recent focus of natural sciences, researchers have ‘begun to shift away from the search for new fundamental laws and toward new kinds of synthesis—‘holism’ … in order to understand complex systems’ (Wilson 1998: 267), an insight not dissimilar to views on post-war science as discussed above by Mittelstraß.

To join this consilience movement, the humanities, arts, and social sciences must

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\(^5\) As Wilson stated, ‘The great branches of learning emerged in their present form—natural sciences, social sciences, and the humanities—out of the unified Enlightenment vision generated during the seventeenth and eighteenth centuries’ (1998: 40).

\(^6\) The problem here is not specialized scholarship but the lack of cooperation and even awareness of disciplines from one to the other, which has resulted in ‘the ongoing fragmentation of knowledge and resulting chaos in philosophy [,which are not reflections of the real world but artifacts of scholarship’ (Wilson 1998: 8).

\(^7\) Wilson suggested, ‘Disciplinary boundaries within the natural sciences are disappearing, to be replaced by shifting hybrid domains in which consilience is implicit’ (1998: 10). He further stated, ‘The central idea of the consilience world view is that all tangible phenomena, from the birth of stars to the workings of social institutions, are based on material processes that are ultimately reducible, however long and tortuous the sequences, to the laws of physics' (1998: 266).
break free from their disciplinary isolation and embrace fundamental outlooks of material science, which views life as having evolved according to laws of evolution within a material world organized by the laws of physics (Wilson 1998). Further, to understand the origins of such divergent disciplines, a reductionist approach (like that utilized in biology) is required. In fact, according to Wilson, all human intellectual endeavours, including the arts, humanities, and even religion, can be reduced down to natural *homo sapiens* evolution, which responded to environmental (ecological and societal) stimuli over the course of history. Hereby a belief in God, the creative impulse to paint, and a poem all find their origin in neurological processes programmed over eons within our collective human genome.

This embrace of reductionism (though in opposition to views of Nicolescu as well as decades’ worth of works in the humanities and arts), argued Wilson, is required for consilience, as only through this empirical lens of science may we further comprehend complex systems, like environments, and even human behaviours and our very nature. As Wilson has suggested, ‘Science advances by reducing phenomena to their working elements … it does not aim to diminish the integrity of the whole. On the contrary, synthesis of the elements to recreate their original assembly is the other half of scientific procedure. In fact, it is the ultimate goal of science’ (1998: 211). In other words, if we are to understand reality and ourselves, we must comprehend them firstly by their smallest parts, leading to an understanding of the sum as these parts are pieced together to make a whole: a position to which to some degree I find relevant and which is reflected in my own practice as an artist and biologist (discussed in later chapters).

However, several problems arise in Wilson’s ideology of consilience. Firstly, Wilson himself is a trained entomologist and, although an avid reader (as well as supporter of the arts), is not a specialist in the social sciences or the humanities. As such, his analysis may over-simplify the breadth and merits of each of these disciplines. Also, by suggesting that science has succeeded where other disciplines have failed to comprehend the human condition in relation to the environment, Wilson leaves little room for a critique of science itself nor the origin of how rationalism (developed during the Enlightenment), coupled with technological advancement, paved the way for the industrial revolution and modern agriculture, among the most profound environmental calamities in the history of planet earth. Likewise such outlooks are still echoed in many of today’s unsustainable practices (as discussed by Jim Mason; see chapter 2).

Wilson did attempt to valorise the visual arts more so than did Mittelstraße: ‘The defining quality of the arts is the expression of the human condition by mood and feeling, calling into play all the senses, evoking both the both order and disorder’. This suggests that such works of art have the profound ability to ‘communicate feeling directly from mind to mind’ (Wilson 1998: 213, 218). Art thus has the means to translate, describe, and disseminate information about the artist’s experiences to others in intimate ways (a position very congruent with my own artistic practice, as discussed in chapter 5).

Wilson further suggested that at this point in history, neither science nor art can be

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8 E.g. that all human behaviours stem from genetic (or epigenetic) origins within the context of evolution. As he stated, ‘Science, however is not marginal … it is a universal possession of humanity, and scientific knowledge has become a vital part of our species’ repertory’ (Wilson 1998: 268).
complete without consilience. At a larger level, such a merger of art with science may provide greater understandings. As Wilson stated, what is needed is a ‘fluency across the boundaries [that] will provide a clear view of the world as it really is’ (Wilson 1998: 13). Wilson warned that such consilience between art and science should not become a hybrid, but instead that the two disciplines should meet within the field of interpretation. However, in critique of Wilson, one of the fundamental characteristics of contemporary fine art is that it needs to be open to interpretation, lest it become a mono-interpretive form of illustration (please see Ballengée 2009, in appendix).

More Wilson’s ideas, which have discussed the intersection between art and science, will be examined throughout this dissertation. Regardless of issues that arose in Wilson’s writings, his suggestion of consilience did offer a potential means to address the complex global environmental problems we and other species currently face, subjects that crucially need be addressed. As Wilson surmised, ‘To the extent that we banish the rest of life, we will impoverish our own species’ (1998: 298).

Another set of ideas I found very helpful in my research in ‘Transdisciplinary art with ecology’ was Gibbons et al. (1994). More akin to the pragmatic ideas of Jantsch and Mittelstraß, Gibbons et al. (1994) defined a new model of transdisciplinarity they referred to as ‘Mode 2’ that gave impetus to team problem solving and was a reaction to the failure of previous interdisciplinary efforts. Gibbons et al. stated, ‘We see the emergence of a new mode of knowledge production as resulting from wider societal and cognitive pressures. It arises out of the existing dysfunctionalities and breakdowns of disciplinary modes of problem solving’ (1994: 29). Under the framework of Mode 2 transdisciplinarity, temporal partnerships are formed with participants from diverse backgrounds working in cooperation and ‘focused primarily on the problem area’, with ‘preference given to the collaborative rather than the individual performance’ (Gibbons et al. 1994: 30). Additionally projects are mutable and transient to ‘reflect the transdisciplinary nature of the problems being addressed’ (1994: 33). Knowledge gained from cooperative projects is shared equally by all participants across ‘less and less relevant’ disciplinary boundaries (Gibbons et al. 1994: 29).

According to Gibbons et al. there are three primary distinctions between the proposed Mode 2 transdisciplinarity and the traditional academic approaches referred to as ‘Mode 1’ (1994: 3). Firstly, traditional academic pursuits are discipline-focused, whereas Mode 2 uses the resources of partners with diverse backgrounds. Secondly, at a fundamental level Mode 1 is homogeneous, while Mode 2 is heterogeneous. Lastly, at a structural and temporal level, Mode 1 is a based on organizational hierarchies and tries to ‘preserve its form’, whereas Mode 2 is ‘more heterarchical and transient’ (Gibbons et al. 1994: 3). Fundamentally these ideas are similar to those discussed already by Nicolescu and Mittelstraß, although because they are less theoretical and of a more modest scale they may be more readily useable to potential practitioners, making them more effective for actual real-world, localized problem

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9 As he stated, ‘Neither science nor the arts can be complete without the combining their separate strengths. Science needs the intuition and metaphorical power of the arts, and the arts need the fresh blood of science’ (Wilson 1998: 211).

10 In his defence, to clarify what Wilson stated was, ‘Science is free and the arts are free … the two domains, despite the similarities in their creative spirit, have radically different goals and methods. The key to the exchange between them is not hybridization, not some unpleasantly self-conscious form of scientific art or artistic science, but reinvigoration of interpretation with the knowledge of science and its proprietary sense of the future’ (1998: 211).
Additionally because the partnerships exist for short periods of time (differing from Nicolescu, Mittelstraß, and Wilson) this allows for considerable flexibility in issue resolution, as problems themselves may change during the course of the project. As Gibbons et al. stated of their Mode 2 model, it ‘consists in a continuous linking and relinking, in specific clusterings and configurations of knowledge which is brought together on a temporary basis in specific contexts of application … any such core is highly sensitive to further mutations depending on the context of application’ (1994: 29). This approach allows methods to adapt to fluctuations in participants as well as issues that may shift in the course of the overall program.

Another attractive feature of the model presented by Gibbons et al. (1994) is the focus on localized and scalable problem solving by local participants (stakeholders). Here smaller groups with diverse backgrounds work cooperatively to find solutions to proximate issues, as opposed to a large populace collectively responding to larger issues, as suggested by Nicolescu, or full institutional shifts, as recommended by Mittelstraß. Gibbons et al. (1994) stated that such methods need be ‘… driven and locally constituted … in response to problem formulations that occur in highly specific and local contexts’ (1994:30). On a theoretical level Gibbons et al. (1994) is about democratizing research (an important aspect of participatory science, as discussed below), and as such suggests a move from centralized power of larger organizations to empowerment of individual, local citizens. As Gibbons et al. stated, such projects involved a ‘shift from control located within disciplines to more diffuse kinds of control’, and as such, they ‘reflect the transdisciplinary nature of the problems being addressed’ (1994: 33).

At a practical level, the Mode 2 transdisciplinarity of Gibbons et al. (1994) is designed to be accessible to large audiences and focused on addressing real-world problems, with three fundamental characteristics:

1. Develop a structural but ‘evolving framework to guide problem solving efforts’ (1994: 5).

2. Create a model to understand and evaluate results/solutions. As findings ‘emerged from a particular context of application’, they may be both ‘empirical and theoretical … though they may not be located on the prevailing disciplinary map’. Thus, teams may need to build their own ‘theoretical structures’ for analysis of affectivity and usefulness (1994: 5). Such novel models for evaluation and critique (compared with traditional peer review) would evaluate ‘efficiency or usefulness, defined in terms of the contribution the work has made to the overall solution of transdisciplinary problems’ (1994: 33), which may help to develop and inform future transdisciplinary ‘research methods and modes of practice’ (1994: 5).

3. Share results with a larger community. Unlike traditional ‘Mode 1’ models where results are shared with insular disciplinary communities such as ‘institutional channels … professional journals, or at conferences’, Mode 2 should share findings with all diverse members of a project who participated (1994: 5). This diffusion of findings, along with continued communication of participants, will enable new knowledge to be utilized on future problem-solving projects. A particular prior finding may be used again and again for another problem, free of disciplinary constraints and validation. Whereas in traditional disciplinary
‘Mode 1’ means of operation, findings may be built upon, Gibbons et al.’s transdisciplinary model allows for post-disciplinary communication and growth based on multidimensional findings.

Gibbons et al.’s vision of Mode 2 transdisciplinarity also involved revaluing the humanities (even the visual arts), whereby participants with diverse backgrounds may help to look at and address a problem from a different starting point and offer insights from their own ‘disciplinary epistemologies’ or fields of expertise, leading to ‘clustering of disciplinary rooted problem-solving’ (1994: 29). However this attempt to value the arts fell short, as their evidence of growth in this sector of knowledge production is largely based on monetary increases, not the generation of new ideas; Gibbons et al. cited the rise in the number of commercial art galleries in New York as proof that the humanities have evolved simultaneously with science over the centuries (1994: 94).

However, in defence of the overall ideas presented as Mode 2 transdisciplinarity, I find the flexibility of temporary, multidisciplinary partnerships much more applicable to address localized problems and to foster novel diffusion of gained knowledge to larger audiences, compared with either of the grandiose suggestions offered by Nicolescu and Mittelstraß. The democratic idea of partners with diverse backgrounds (including the arts) being equally valorised in a research effort is very new and may be an important way to get the public interested and engaged in the process of solving complex ecological problems. As a practicing artist and biologist who has for nearly two decades worked with individuals of diverse backgrounds during participatory science and transdisciplinary art programs, Gibbons et al.’s idea of restructuring studies to include local persons to address local issues has been an important influence on my practice (as discussed in chapters 5 and 6).

These ideas by Wilson, Nicolescu, Mittelstraß, and Gibbons et al. (1994) informed my thinking about transdisciplinarity and to some degree touched upon my creative practices. However, all of these discourses came from scientists. Though they addressed other disciplines and the potential of moving beyond disciplinary boundaries, I found it important to further analyse thoughts and definitions of transdisciplinarity coming from the arts, and especially those practices contextualized by ecology, as discussed below.

1.3: Defining Transdisciplinary Art

Over the past two decades, the term ‘transdisciplinarity’ has been increasingly utilized to describe some forms of art that fundamentally go beyond a single, traditional disciplinary boundary. Examples of such works include: research-based artistic inquiry as an art form (Bijvoet 1997; Johnston 2002; Sullivan 2010); plural disciplinary and collaborative art-science projects (Obrist and Akiko 2002; Wilson 2003, 2010); interactive, ephemeral public art festivals involving collaborations with scientists and artists (Obrist and Vanderlinden 2001; see also Transmediale Festival 1997–2013); artists working in professional science research laboratories (Scott 2006, 2010); multi-discipline, integrative post-studio art practices (Coles 2012); ‘trans’ media technological and digital art works (Broeckmann and Jaschko 2001; Paul 2003; Blais and Ippolito 2006; Gibson et al. 2008); techno-performances and computational paintings (McKenzie 2002; Adams et al. 2008;
Petersen 2010); transgenic and other manipulation of living material art (Grande 2005; Vita-More 2007; Franklin 2012); and works in, about, and even remediating ecological systems (Spaid 2002; DiSalvo et al. 2009; Tayler and Gilbert 2009; Kagan 2011; Kastler 2012; and others). In spite of this remarkable amount of usage, the term ‘transdisciplinary’ in art it has remained somewhat elusive, and very few structured definitions are yet available.

In addition, although various conferences/symposium/colloquia/festivals/biennales have recently addressed the potential transdisciplinary intersections between art, technology, and science, they have not clearly defined what ‘transdisciplinary art’ is. Some of these events have included: ISEA (International); BEAP (Australia); Transdisciplinary Imaging Conference at the intersections of art, science, and culture (Australia); Prix Ares Electronica (Austria); Cleckenflap (Hong Kong); Elektra (Canada); Artfutura (Spain); NODE (Germany); Oddstream (Netherlands); Amber (Turkey); and many others. Even though the term ‘transdisciplinarity’ has been widely discussed in these events a unifying definition for transdisciplinary art has, to the best of my knowledge, remained elusive.

Some of the confusion over a definition of transdisciplinary art may lie in the fact that providers of cultural discourse themselves may see art as a fundamental field made up of many mediums and crossing several disciplines. As arts and education scholar Rosemary Ross Johnston has stated, ‘Arts not only provide an exemplar of what transdisciplinarity actually is, but demonstrate the scope and potential of how transdisciplinary thinking contributes to both knowledge production and current intellectual debates’ (2008: 223). On a pragmatic level however, how does this help us to frame the idea of transdisciplinary art or to understand how artists utilize transdisciplinarity as means to perform real-world problem solving?

Johnston addressed this question by making ‘art’ synonymous with and even beyond ‘transdisciplinarity’; she suggested that the arts are ‘a plurality of transdisciplinary, core-disciplinary, artistic practices, processes, and paradigms that spill over, usually at the deepest point, into all disciplines’ (2008: 231). As such, art/transdisciplinarity under Johnston’s construct ‘is a dynamic that encourages movement between, across, and beyond structures. If we imagine the disciplines as branches of a tree (of knowledge, say), then transdisciplinary thinking is the trunk (or even, perhaps, the sap); the roots are the epistemologies connecting the tree to universe. At a profound level, transdisciplinarity is connection and connectedness’ (2008: 225). Although this is a wonderful way to perceive art as a holistic foundation for our species’ attempts to understand the universe, where does it leave artists? Do we as artists have the responsibility of proving meaning for or providing intersection with the rest of intellectual creation? Are projects from artists who do not want to be connected to other disciplines any less valuable?

Under Johnston’s definition of transdisciplinarity in art or art as transdisciplinarity, art has the capacity to be a strong unifier and producer of knowledge, as it may ‘offer powerful, transformational experiential ways of learning’ (2008: 231), an opinion which I share to a degree. My concern with this sentiment, though, is that art is reduced to a model for education and as such overtly didactic. Thus art would fall into pure communication or a kind of mono-interpretative illustration. Though art can teach and deliver messages, being open to interpretation is fundamental. In my own work there is a form of didacticism (intended to
increase public understanding of the global amphibian crisis) but the messages are often pluralistic and open to individual interpretation. My installations and photographs are experienced—so the readings are open-ended. Even in the field and lab studies, ideas from the participating public are explored, and we experience the process of inquiry as a group. This is the praxis of my method, which diverges from standard pedagogical practices (discussed in detail in later chapters). So, though under Johnston’s ideas, transdisciplinary art may be characterized by its ability to unify knowledge and educate, a singular definition is not posited.

Uniting knowledge and the limitations of transdisciplinary art/science projects were discussed by Tröndle et al. (2011) in the context of their long-term eMotion project. Here artist/scientist teams 'entangled' to create novel interactive devices to experimentally examine the experience of museum visitors. The overall goal of eMotion was data collection through transdisciplinary research, not the creation of art objects or standard science processes. However, in their study, they identified interesting hurdles for transdisciplinary collaboration that included the following factors. First, scientists generally have a poor understanding of art and as such, generally believed that working with artists would mean merely making their diagrams ‘prettier’ (Tröndle et al. 2011: 6). Also, such collaborations are more time-consuming than normal, discipline-insular projects. Additionally, the findings of such collaborations may not be accepted at a peer-review level. Scientists may be concerned for their reputations, as working on transdisciplinary projects may seem frivolous to their peers. Likewise, artists were concerned with losing their status as individual creators, which could be harmful in the commercial art market.

Although many problems arose within eMotion collaborations, one very important finding emerged, which was that the perceived difference between natural sciences and the humanities appeared to be institutionally constructed instead of existing at a fundamental level of inquiry. As Tröndle et al. noted, such differences were also ‘culturally conditional … it appears to be a question of the university-disciplinary socialisation’ (2011: 6). This is particularly important, as it suggests the way people perceive the division of disciplines comes from academic training. Thus, changes towards a more transdisciplinary model could facilitate a more open viewpoint between art and science.

Transdisciplinary art has already moved towards the transvergence between disciplinary boundaries, according to Ami Davis of the ADRE Laboratory for New Media at San Jose State University. Hereby, in such transdisciplinary projects, the constructed duality between art and science is exposed and transcended, an underlying function of such projects. As Davis has stated, ‘The objective of transvergence is to transcend choice, to consider impossibilities, and to critically examine artificially constructed disciplinary divisions’ (2005: 2). However, such projects are not easily defined, because they do not easily fit into a readily available academic canon or into ‘Western society's comfortable and complacent definitions of art’ (Davis 2005: 1). For Davis, this breaking away from traditional means of classification is fundamentally important for transdisciplinary art, as it highlights and challenges divisions between disciplines while forcing new models to interpret new forms of art, an opinion
furthered by some working within the realm of the digital.\textsuperscript{11}

Expanding upon the definition provided by Davis, Massachusetts Institute of Technology graduate student Jason Rockwood attempted a more descriptive (and among the most complete to date) explanation for transdisciplinary art in his unfinished thesis. Rockwood simply defined transdisciplinary art\textsuperscript{12} as ‘art which uses transdisciplinary research and methods to explore a problem of humanitarian concern’ and ‘draws upon any and all disciplines needed to research and create … No method or discipline is off-limits’. Such art responds to a real-world problem that is beyond the capacity of a single discipline to solve (Rockwood 2008: 1). This focus on complex strategies (beyond single disciplinary limits) to solve real-world issues echoes early ideas of transdisciplinarity originated by Jantsch and expanded by Mittelstraß and Gibbons et al. (1994). An important distinction with Rockwood’s research is that it is being used to describe an art project, not an initiative within the sciences.

Rockwood also affirmed the underlying holistic approach suggested by Nicolescu of transdisciplinarity, as it is ‘between the disciplines, across the different disciplines, and beyond all discipline. Its goal is the understanding of the present world … the unity of knowledge’ (Nicolescu 1998:1). Or, as Rockwood noted, this new form of art responds in necessity to ‘the existence of people, events, society, and institutions … in short, reality’. Transdisciplinary art is inclusive, democratic, and heterarchical; ‘It doesn’t operate in a bubble of disciplinarity or ivory tower exclusiveness … it is engaged with the participants and society’ (Rockwood 2008: 3).

This engagement with audiences to the degree that they may actually participate is an important underlying characteristic of transdisciplinary art, according to Rockwood (2008). Artworks of this sort may reflect of a larger movement (especially in technology) towards a ‘participatory culture’, as Rockwood noted, which ‘stands in opposition to consumer culture. The idea is one of a culture in which individuals (members of the general public) do not act solely as consumers but also as contributors or producers’ (2008: 8). Here the audience of such an artwork has the potential to be transformed from the passive state of the spectator to the active role of collaborator or even co-producer, a position similar to volunteers in participatory programs, discussed below.

\textsuperscript{11} Canadian scholar and interactive media artist Steve Gibson offered his definition of transdisciplinary (digital) art. Differing from prior collaborative forms of interdisciplinary art, Gibson’s idea of transdisciplinarity is manifested as a cooperative project, produced by participants with varied backgrounds of expertise. Under such a working process, ‘a level of direct connection and cross-over between mediums’ occurs (Gibson 2008: 1). Additionally the knowledge base of participants is increased through this cooperative venture, leading to a melding of disciplines. ‘The artist also becomes the engineer, the engineer becomes the artist, and when they collaborate they actually have enough expertise in the other’s field to be able to address concerns across the mediums and even across disciplines’. Under this process, traditional systems, which value some disciplines over others, are diminished; ‘science is no less important than art, art no less than science … elitism of the isolated discipline is broken down’ (Gibson 2008: 1). So hereby Gibson’s definition of transdisciplinary digital art is a project where boundaries between art, science, and technology are broken down and each discipline is revalued at an equal level.

\textsuperscript{12} Rockwood cited the work \textit{FEMA Trailer Project} by artist Jae Rhim Lee as an example of transdisciplinary art. Lee’s public art project included bringing a FEMA (US Federal Emergency Management Agency) trailer used to house Gulf Coast residents displaced by Hurricane Katrina, to the MIT campus. At MIT, students, ‘artists, designers, humanists, engineers, and practitioners from many other disciplines’ worked to outline problems with the design and construction of the trailer, ranging from ‘social inequities, flawed governmental systems, institutionalized injustice, and environmental issues, among others’ that created an ‘an opportunity to rethink and re-engineer not only disaster shelter but also housing and design’ (Rockwood 2008: 3). Participants then worked cooperatively to transform the housing unit to be more socially (for the inhabitants) and environmentally sustainable. This worked at a project level but also went beyond, spreading a larger message about the social and ecological consequences to ‘understanding the Katrina tragedy, alerting the broader MIT community to the ongoing problems’ (Rockwood 2008: 4).
However, this model for activating the audience is not unique to new, transdisciplinary art. As art historian Clare Bishop has stated, ‘There is now a long tradition of viewer participation and activated spectatorship in works of art across many media’ (2004: 78), and ‘considering the work of art as a potential trigger for participation is hardly new—think of Happenings, Fluxus instructions, 1970s performance art, and Joseph Beuys’s declaration that ‘everyone is an artist’’ (2004: 61). Although not addressed in Rockwood (2004), what makes recent transdisciplinary art participation different is the underlying goal of identifying and solving real-world problems that single disciplines and individuals could not do without cooperation. Of course Beuys’s actions, various political, performative happenings, and Fluxus events sought a level of social problem solving; however today’s transdisciplinary art does so with a higher degree of understanding and even expertise in the sciences. Any pragmatic, effective solution to real-world problems must be grounded in the scientific understanding of our collective reality. This, among others, is an important distinction for my definition of transdisciplinary art.

Within the context of transdisciplinary art and ecology, several scholars have discussed the overlapping and potential merging of art with other disciplines (most often science) to address complex environmental issues, often referred to as Eco-Art or Ecological Art (discussed in more detail later in this dissertation). To date the most thorough analysis of transdisciplinary art in relation to ecology has been performed by art sociologist Sacha Kagan in his book Art and Sustainability: Connecting Patterns for a Culture of Complexity (2011). Kagan’s intention is not to merely define transdisciplinary art but instead to demonstrate that transdisciplinarity (under Nicolescu’s characterization, discussed above, as well as the writings of French sociologist Edgar Morin) in the attitudes and approaches of artists in the context of ecology and larger social practices maybe an important tool of transformation for moving towards a ‘second Enlightenment’ and a sustainable society.  

To begin this movement, we must acknowledge the limitations and failures of modernism, which viewed individuals, objects, and the earth as separated from one another (with linear thinking and attitudes driven by Cartesian philosophy and ‘dominator’ approaches in patriarchy, discussed in more detail in chapter 2). This separation from ‘others’ joined with a linear explanation of reality based on evidence of material phenomena (e.g. empiricism, as discussed above), which has lead to ‘disjunctive thinking and knowing’ (Kagan 2011: 57). This, coupled with rapid technological advancement driven by capitalist tendencies towards short-term gain versus long-term, maintainable development, has manifested itself in numerous unsustainable contemporary attitudes and behaviours such as over-consumption, estrangement from nature, continued violent conflicts, xenophobia, and numerous others. In agreement with Hungarian science philosopher Ervin László, Kagan

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13 Here I refer to eco-art as works of art (physical and conceptual), artistic interventions, or performative actions that directly involve actual ecosystems and species, and/or focus audience attention towards ecosystems and species while positing an environmental message: a position informed by the writings of Lucy Lippard, Barbara Matilsky, Linda Weintraub, Timothy Collins, and others, discussed in more detail later in this dissertation. Art historian Sue Spaid (2002) coined the term ‘EcoVention’ to describe artistic ecological inventions that on one hand are science experiments conducted under the auspices of art and directly attempt to solve environmental problems (such as remediating contaminated ecosystems, repopulating declining species, or restoring and creating new habitats); all approaches that to some degree correlate to the varied definitions of transdisciplinarity discussed above.

14 Of his definition of sustainability, Kagan stated, ‘Use of the term “sustainability” suggests a different priority in framing the future of humanity in terms of its balanced evolution, linking social and ecological issues, rather than framing it in terms of a linear development course with the economy as its main focus’ (2011: 10).
suggested that what is required is to shift away from these ‘separatist’ outlooks and destructive impulses towards more systems-oriented and reflective approaches that would emphasize connections between individuals, greater communities of life, and even the earth itself. Such an approach (as with some of the ideas of transdisciplinarity discussed above) would inherently shift focus away from that of reduced individuals to that of whole complex systems, which in turn would help ‘heal the fragmentation of reality’ (Kagan 2011: 57).

To comprehend systems, society must replace linear modes of thinking (limited by the single lens of causality or cause and effect) with multiple interpretive models for understanding the countless layers of interconnected phenomena found in the milieu of the real world. This ‘paradigmatic shift in world views’ (Kagan 2011: 93) will require a systemic approach towards thinking to which Kagan referenced the ideas of English cyberneticist and social scientist Gregory Bateson. Hereby Kagan suggested that a ‘system thinker’ needs to ‘look for the big picture’ to realize that ‘the issue that is observed is always part of a larger system’ but also to ‘balance the short with the long term’ so as to avoid short-term fixes that through constant feed-back loops may have enduring consequences (2011: 99). As such, the system thinker is conscious of being part of a larger system and that actions have consequences. In an attempt to comprehend such a system (which is under constant change), the system thinker needs to value ‘varied sources and forms of knowledge’: those that are quantifiable and qualifiable as well as that which cannot be measured with known techniques (Kagan 2011: 99). Kagan has also suggested that the system thinker must stay curious and be open to explore new tools and languages as they emerge, as well as to not be ‘afraid of paradoxes’ as the ‘complex reality of systems is not as nicely logical as linear theories or models’ (Kagan 2011: 99).

According to Kagan, once one strives towards system thinking, accepting complexity follows. Citing the work of Austrian physicist Fritjof Capra, Kagan argues that we must emphasize the connections between organisms and not hold onto dated views of separation, which do not reflect biological reality (an opinion shared by many of the artists discussed later in this dissertation). With this we may be able to begin see a larger patterns making up a much bigger picture, ‘focusing on the relationships rather than on the details’ (Kagan 2011: 98). Hereby, under the systematic view of life, everything is complexly intertwined between form, matter, and process, which are all undergoing constant reshaping within a larger feedback loop (Kagan 2011). By examining these connections and processes (with the awareness that they are temporal and undergoing constant change) with inherent degree of the concept of a feedback loop, we can more closely begin to understand ecosystems, larger biomes, and our own species in relation to them. If we are aware that our society is part of such a larger connected community of life, long-term decisions on the part

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15 As Kagan described it, ‘Feedback loops can be of two basic sorts: either they are self-reinforcing or they are balancing. Reinforcing loops are engines of growth or collapse. They indeed reinforce change in one direction, accelerate movement in the same direction (i.e. in one direction or the opposite direction) … Balancing loops basically work like thermostats: they keep their elements in a certain balanced relationship to each other. They resist change in one direction by producing change in the other direction’ (2011: 98).

16 As Kagan stated, ‘Complexity disarms the explanations based on single empirical bases, single and linear logics: complexity requires multiple logics that are neither separated from each other into neat boxes, nor integrating neatly with each other, but enter into ambivalent relations and tensions’ (2011: 21).
of society can begin to be made based on actions towards sustainability. Kagan believes that the arts may play a fundamental role in the dissemination of these ideas and the overall restructuring of society towards awareness of complexity and systemic approaches. This may be no easy task as under modernity ‘high’ art has worked to reinforce, not challenge, structures of modernism, even forming its own elitist sector (e.g. the institutionalized art world). The art world became autonomous, ‘put on a pedestal … apart from other social groups’, and has remained largely self-referential instead of acting as a force towards social or environmental change (Kagan 2011: 67). In the modernist art world, ‘(1) artists are specially gifted people who (2) create works of exceptional beauty and depth which (3) express profound human emotions and cultural values’, a position that both frees them from larger society (as well as social and environmental concerns) yet marginalizes them into a minority of the creative, solitary geniuses whose product has ‘sublime purposelessness’ (Kagan 2011: 68, 69). Attempts by artists to re-join larger society, work collaboratively, and attempt to address real-world issues have been ‘often looked down upon’ or completely ignored by the modernist arts community (Kagan 2011: 67).

Regardless, numerous artists over recent decades have transgressed modernist tendencies to produce socially and environmentally engaged practices verging on varied degrees of transdisciplinarity. In his analysis Kagan refers to the specific practices of artists Helen and Newton Harrison, Hans Haacke, Joseph Beuys, Patricia Johanson, (each discussed in detail in chapters 3 and 4 of this dissertation), and others who have, through their focus on ecosystems and non-human organisms, ‘de-centered’ mankind to reposition our species back among a larger context of life within a complex nature. At odds with modernist views of aesthetics, Kagan suggests such works strive towards an ‘aesthetics of sustainability’ (which complemented and synthesized earlier ideas by John Dewey of the ‘aesthetic experience’, Gregory Bateson’s system aesthetic, and Edgar Morin’s ‘art principle’ among others). Such practices involve ‘system thinking’ and attempt to embrace complexity (both natural and social, as the latter evolved from the former) yet are sensitive to specific patterns arising in such complex systems that remind us of our connection to all of life.

For artists to begin this journey towards creating sustainable art, they must move towards a transdisciplinary approach (from the perspective of Nicolescu), which involves

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17 To which, Kagan added, ‘But fundamental uncertainty cannot be overcome, i.e. any long-term decision is to be considered as always a ‘bet’… As the Harrisons say, only improvisation remains constant…’ personal communication (2014)
18 Kagan clarified, ‘Understanding of complexity means that everything shall be ecologized and that everything shall be seen in meta-perspective and with loops. It further means that the Western logical tradition of the disjunctive, i.e. the excluded third, shall be modified in order to also consider the included third and the existence of several levels of reality (and more generally of emergency)’ (2011: 21).
19 Kagan stated, “This institutionalization process established [across the late nineteenth and twentieth centuries] the field of art as an apart social world with separate laws, insider’s values, and discourses” (2011: 67).
20 As Kagan described it, ‘The institutionalized autonomy of the high arts increasingly turned into a concern for “art for art’s sake” or more generally for self-referentiality, i.e. the art world became much more interested in [its] own internal history, discourses, and overall languages, than in [its] relationships with the environment’ (2011: 67).
21 Kagan posited, ‘The seemingly liberating autonomy of the art world offers merely an escapist strategy as long as one contributes to the inwards-looking activities of a social world largely disregarding its environment’ (2011: 68).
22 As Kagan further stated, ‘In order to foster cultures of sustainability, the aesthetic experience should foster a sensibility that would acknowledge the shared process of creativity between natural phenomena and the artist, highlight the interpenetration of nature and culture, and more generally function as a “sensibility to the patterns that connect”. However, such a sensibility should neither turn into a holistically simplified perception, nor into a merely individualized and localized perception, nor into a merely individualized and localized perception, but strive to become a sensibility to complexity’ (2011: 267).
exploring and becoming increasingly sensitive to multiple perceptions of reality\textsuperscript{23} or, even further, to question the basis of a singular reality derived from the traditional linear form of logic. One must be effective (in pragmatic terms) and affective (in the context of emotions) in action and act ethically towards others (humans, other animals, the earth itself), while avoiding polarized views\textsuperscript{24} of ‘for’ or ‘against’ along with absolutes in the context of reductionist reasoning (Kagan 2011: 242). Under the framework outlined by Kagan, art may help guide others towards conscious and conscientious behaviours, reminding us that through remembering we are all part of a larger complicated whole. This, in turn, may lead us all towards sustainability.

Although Kagan, Rockwood, and others have characterized and offered some explanations for transdisciplinary approaches in art, I found it necessary to present my thoughts on this genre of new work specific to the context of ecology. Please note that these thoughts are by no means intended as fixed definition. Rather, they are presented as an open set of generalized characteristics, as transdisciplinary art with ecology remains an emerging field, and establishing such a classification at this point would be premature, perhaps even counter to the very aim of transdisciplinarity itself. My intention is instead to discuss the characteristics shown below, which may provide further clarity for the practices discussed in this dissertation and for my own work in the fields of art and science.

1. 4: Some Notes on the Characteristics of Transdisciplinary Art with Ecology

Transdisciplinary art with ecology (TAE, figure 1), although sometimes more theoretical than applied,\textsuperscript{25} has pragmatic intentions\textsuperscript{26} and is aimed at addressing real-world issues that our species, other species, or ecosystems currently face. To borrow from Mittelstraß and Gibbons et al. (1994), such problems are complex and beyond the capacity of single disciplines. Thus, a transdisciplinary approach is required, which involves individuals with specialized areas of knowledge (or those individuals with backgrounds beyond single disciplines) working in cooperation towards a common goal. Necessary to this scenario is inclusion of the arts on equal grounds to all other participating disciplines, a position attuned with the ideas discussed above by Gibbons et al., (1994) and a cornerstone to this entire study

\textsuperscript{23} Nicolescu stated, ‘Reality, whereas on the individual level, it is that of the flow of consciousness crossing the different levels of perception’ (2002: 83, quoted in Kagan, 2011: 240). To which Kagan clarified ‘It is not that there is not one reality; it is that reality cannot be accessed all at one level, because it is discontinuous, it has a complex unity, it exists across an open multiplicity of levels (2 famous ones, discussed at length by Nicolescu as quantum physicist, being the macro-physical level vs. the quantum physical level; but definitely I think that life is another level, and the emergence of culture, somewhere among animal species, is another level again, etc. Nicolescu also considers certain levels of reality accessed by religions, but I refrained from that myself…). In short: I am not saying there is not one reality, but I am saying there is not a single level of reality’ personal communication (2014)

\textsuperscript{24} Kagan further clarified ‘avoiding essentialized “for” or “against”… but NOT avoiding strategic/tactical uses of “for/against” conceptions. I mean: I am not a proponent of consensus politics. I rather combine Morin’s tetralogical loop of complexity with an attention to not losing the qualities of Chantal Mouffe’s agonistic politics’ personal communication (2014)

\textsuperscript{25} As discussed in chapters 3 and 4 in the works of Patricia Johanson and Helen and Newton Harrisons, many of their works of grander scale have yet to be achieved and remain as hypothetical concepts.

\textsuperscript{26} TAE may have large philosophical repercussions, however it needs to be focused on actions with pragmatic approaches to deal with challenges we currently face for the survival of our species and as such is a form of moral action towards the long-term conservation of other species and ecosystems at a localized and larger global level. Such forms of inquiry need to be grounded in current scientific knowledge, either through cooperation with participating scientists or a high degree of understanding of the sciences among participants. Not understanding the science behind phenomena may lead to disastrous results, creating new problems instead of the remediation of the initial issue. For a specific example, please see Ten Turtles set Free (1970) by Hans Haacke, discussed in chapter 3.
(discussed in more detail in chapters 2 and 3 in connection with the works of Patricia Johanson, Hans Haacke, Mel Chin, Helen and Newton Harrison, and chapter 4 in connection with my own artistic practice).

In alignment with Gibbons et al. (1994), problem identification and framing of such questions should involve locals in cooperation with specialists to insure that divergent viewpoints are addressed from the beginning. As such, TAE is inclusive, not exclusive, of communities in opposition to modernist tendencies in art, as discussed by Kagan (2011). TAE strives for diversity of outlooks leading to problem identification, research design, and experimentation, along with interpretation of results in the context of addressing complex problems. As participants are on equal grounds from the outset, TAE moves towards heterogeneous, not hierarchal, structuring. This is reflected in varied degrees of student and public inclusion in the practices of Patricia Johanson and Mel Chin (chapters 3 and 4, respectively) and in more detail with my own work in the arts and participatory biology (chapters 5 and 6).

Through the utilization of methods from multiple areas of disciplinary specialization (often intertwining at least two or more), TAE challenges traditional boundaries between disciplines and organizational structures that maintain such academic boundaries in the first
place (Davis 2005; Rockwood 2008). TAE inquiries are not easily defined nor do they neatly fit within traditional canons of art history. TAE may even begin to move beyond disciplines, a specific attribute of transdisciplinarity as discussed above in the ideas of Johnston (2008) and Nicolescu. Such a transgression of disciplinary boundaries will be discussed in more detail in chapter 4 within the context of works by Tissue Culture and Art Project (TC&A) and Cornelia Hesse-Honegger.

As suggested by Kagan (2011), TAE practitioners to some degree employ system thinking in their approaches. All of the practitioners (discussed in chapters 3, 4, and my own practice in chapter 5) had to begin a process of gaining understanding of the complexity and unstable nature of living organisms (parts) in relation to one another within an ecological system (micro, macro, or both) as part of their project creation. The Harrisons began by learning and reflecting upon the complex ecosystem requirements of an exotic crustacean; Patricia Johanson explored the intricate and multifaceted process involved in remediation of a wetland ecosystem; TC&A gained the biomedical understanding required to propagate and nurture disembodied cells; Cornelia Hesse-Honegger searched for patterns of mutation within insect communities located in complex terrestrial habitats making up larger, polluted environments.

The intention of TAE is not object creation but agency. If static (passive) objects persist (photographs, videos, sculptures, etc.) beyond the active fundamental investigation, these are by-products or artefacts of the transdisciplinary investigation, not the sole artwork itself. In alignment with ideas discussed above by Tröndle et al. (2011), Rockwood (2008), and Kagan (2011), TAE is not art about art—art for art’s sake—not only a form of expressing oneself. Rather, TAE reaches out and engages with larger non-art specialists. Furthermore, it is a creative means to engage such audiences towards involvement in the identification and addressing of complex issues. These ideas will be discussed in more detail in chapter 3 within the context of seminal works/actions by Hans Haacke and Joseph Beuys.

TAE reminds us that we are part of a larger community of living beings. Fundamental to the science of ecology is the awareness that our species is part of a complex web of biological entities responding in context to one-another and abiotic factors in a constantly changing environment (Wilson 1994; Odum and Barret 2004). TAE may be utilized as an effective and affective vehicle to disseminate this knowledge to a larger populace. Such attempts at ‘reconnection’ challenge traditional Western views of human dominance over the earth and confront ideologies of some religions with placement of our species outside of rest of nature. Early attempts by Alexander Von Humboldt, Charles Darwin, and others towards the reuniting of humans beings with the larger community of life will be discussed in chapter 2.

TAE is aware of place, not only from the local perspective but also in the larger sense of locality in biospheric terms. This is implied not only in geographic and environmental contexts but also through understanding the specific communities inhabiting that space (human, non-human animal, microbial, ecological). This is congruent with views discussed

27 Although such artifacts may engage audiences, leading to future actions and participation, they are not the primary focus for creating TAE, discussed through examples of such engaging artifacts in the works of TCandA, Hans Haacke, and my own work as discussed in chapter 5.

above by Gibbons et al. (1994), whereas TAE responds and is to some degree reflective towards this space in the context of that specific community.  

TAE is open to the use (and even the development of) new tools, responding as the project changes but also conscious that not all phenomena can be measured with techniques currently available. As such, it is reminiscent of ideas discussed above Wilson (1994), Mittelstraß, Kagan (2011), and Tröndle et al. (2011). Because of its intention, TAE is not new media art but may encompass the use of mediums that are novel. Likewise TAE is not media-specific but rather media-responsive, to reflect the complexity of issues being addressed.

In closing, the characteristics described above of TAE are not intended to rebut other definitions of transdisciplinary art nor impede further development in this arena. They are simply a modest attempt to identify attributes of practices by artists (discussed in this research) and my own work that through some degree of transdisciplinarity afford increased understanding of ecological phenomena to their audiences. Likewise, not all practitioners discussed in this dissertation ascribe to all of these characteristics, and some, like Helen and Newton Harrison, reject the terminology of transdisciplinarity altogether. The area of transdisciplinary art is still emerging (although arguably, these approaches and attitudes have been around for decades) and will take form (or totally break beyond forms) as more artists and other creative people respond to ecological crisis. Then, perhaps, we may transcend disciplines.

1. 5: Defining Citizen Science and Participatory Science

As with the term ‘transdisciplinarity’, ‘citizen’ and ‘participatory’ science have been widely used over the past two decades. Generally ‘citizen science’ and ‘participatory science’ have been used to describe scientific research that to some degree involves participation of non-scientists. It should be noted that public, amateur, and naturalist participation in research of natural phenomena is not new, dating back centuries; it perhaps is the very the foundation

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29 Informed by Mode 2 models of transdisciplinary approaches discussed above by Gibbons et al. (1994) and thoughts by environmental philosopher Andrew Light (discussed in chapter 2), such projects need to be accessible, and local participants (as shareholders) work towards a positive outcome for that ‘space’. Likewise indigenous knowledge of space (anecdotes from fisherman, farmers, home-cooks, laboratory technicians, naturalists) may offer important insights into such locations (discussed in chapter 8 with my own experiences working with volunteers), and as such, locals may be pivotal to the success of the overall project.

30 New media art (digital, computational, etc.) involving the utilization of new technologies may cross disciplines but would not be transdisciplinary, at least not in the context of TAE. Some forms of interactive new media work designed to gauge (problem identification, experimentation to gather data) and facilitate behavioural changes (solving a problem) in communities come closer to works characterized as TAE (please see Tiffany Holmes, 7,000 Oaks and Counting, 2007).

31 In the emerging fields of bio-art and eco-art, media often include the use of living materials (discussed in more detail in chapters 3, 4, and 5). These have included full living systems at micro (cellular or even genetic level) and macro levels (ecosystems) such as ecosystem remediation, selective breeding, field investigations, tissue culturing, and others. These could be considered forms of TAE so long as they address real-world ecological issues. Secondly, such projects tend not to be artifact-centric (instead involving near-constant changes over time through biological or environmental processes) as they identify real-world problems, develop and implement experiments, and share their results with diverse audiences (not just art viewers; see thoughts by Sue Spaid in chapter 3). Additionally the necessary knowledge of science for artists and cooperation with scientists and research organizations moves beyond disciplinary boundaries. As Also, in some cases projects involve trans-species cooperation (see ideas by Jens Hauser discussed in chapter 4). TAE would not include: genetic or transgenic art in which scientists are commissioned by artists to create genetically modified organisms; manipulation or harm of organisms or living materials or environments for art’s sake (e.g. some forms of land art and Bio-Art); art visualizing scientific phenomena; data visualizations; interactive science education displays for the public; landscaping/park-scaping where aesthetic is the primary goal over ecosystem functioning and conservation efforts; art made from natural materials; art made from the landscape itself for aesthetic or anti-aesthetic reasoning; art critiquing science from a postmodern standpoint.
of modern science (Cohn 2008; Bonney et al. 2009a; Miller-Rushing 2012; Louv 2012). However, what has emerged recently is a renewed interest and acceptance of public participation in the primary scientific research process (Louv 2012). In addition several authors have suggested that such programs may remodel scientific approaches towards research with a focus on problem-solving outside the capabilities of disciplinary science alone and as such are fundamentally transdisciplinary (Brandt et al. 2013; Dedeurwaerdere 2013) and democratic (Brown 1998; Hartley and Robertson 2006). As science journalist Jeffrey Cohn has stated, such ‘collaborations between scientists and volunteers have the potential to broaden the scope of research and enhance the ability to collect scientific data … [the] public may contribute valuable information as they learn about wildlife in their local communities’ (2008: 192). As with some definitions of ‘transdisciplinarity’ discussed earlier, ‘citizen’ and ‘participatory’ science programs are community-inclusive, moving beyond insular disciplinary boundaries and often focused on real-world problem solving.

To date numerous terms have been utilized, sometimes synonymously, to describe such public-to-science/science-to-public input and outreach programs: ‘citizen science’ (Irwin 1995; Boney 1996); ‘civic science’ (Shen 1975; O’Riordan 1998); ‘post-normal science’ (Funtowicz and Ravetz 2003, discussed in more detail in Chapter 10); ‘team science’ (Stokols et al. 2008); ‘street science’ (Corburn 2005); public participation in scientific research/PPSR (Cooper 2012); ‘participatory science’ (Moore 2006; Zoellick et al. 2012); ‘participatory conservation’ (Berger 1993; Khadka and Nepal 2010); ‘democratic science’ (Brown 1998; Hartley and Robertson 2006); ‘transdisciplinary sustainability research’ (Brandt et al. 2013; Dedeurwaerdere 2013), ‘participatory environmental citizenship’ (Ellis and Waterton 2004), and others. The most commonly used of these terms is ‘citizen science’ which, according to a new United Nations-sponsored report, is defined as ‘a series of activities that link the general public with scientific research ... volunteers and non-professionals contribute collectively in a diverse range of scientific projects to answer real-world questions’. However, even here the report concludes that there is no ‘one generally accepted definition of citizen science yet’ (Socientize Project 2013: 21).

The term ‘participatory science’ has been used to describe hands-on activities employed in science education, according to ecologist David Pilz et al. (2005) in relation to public participation in biological and ecosystem monitoring. Here the public aided in the collection of environmental data on—and as such became stakeholders in—the overall research program (Pilz et al. 2005). Often scientists organizing such programs have the intention of helping participants to gain an increased interest and knowledge of the environments/species/phenomena they study (Bonney et al. 2009; Louv 2012).

Citizen scientists may contribute observations, document findings, and other factors, as described by the Open Scientist (2010) as ‘the systematic collection and analysis of data; development of technology; testing of natural phenomena; and the dissemination of these activities by researchers on a primarily avocational basis’. Science journalist Eric Hand (2010) in Nature described citizen science as means to empower the public with scientific knowledge through direct participation in the research process. Over the past two decades citizen science has been an important tool in biological, ecological, and astronomical monitoring, in recent decades precisely because the quantity of observations made by large
numbers of participating members of this public may be far more robust than materials collected by a single researcher or even research team (Hand 2010).

One attempt at defining citizen science by describing what it is not was offered by Miller-Rushing et al. (2012). According the authors, it is not volunteers collecting data primarily for leisure or entertainment purposes but instead is the gathering of information for hypothesis-led, ‘genuine scientific research’ (2012: 285). Secondly, it is not the demonstration of experiments publically or in ‘canned teaching labs’ where the results are already known prior to testing (2012: 285). It is not a hobbyist activity whereby data collected is ‘not analysed or the knowledge generated is not communicated beyond the participants’ (2012: 285). Lastly it is not the mere generation of data for ‘scientific objectives’ but also functions as a ‘means to improve participants’ scientific literacy and understanding of the topics they are studying’ (2012: 289). Thus, citizen science is the active pursuit of knowledge between scientists and non-scientists for scientific purposes and educational enrichment for participants.

The term ‘citizen science’ itself, although often credited to Cornell University ornithologist Rick Bonney (1996), appears to have been coined first by Alan Irwin, at least in book form (Irwin 1995). Irwin here described citizen science as a science ‘which assists the needs and concerns of citizens … and at the same time … implies a form of science developed and enacted by citizens themselves’ (1995: xi). Hereby Irwin suggested that what is needed in light of the complex environmental and social problems we face today is a ‘constructive renegotiation between science and the needs of the citizens’ (1995: 110). As such these problems are not problems within science but instead have ‘their origins in and through consequences— are thoroughly social problems, problems of people’ and will need public participation and understanding to solve them (Irwin 1995: 168). This opinion is very reminiscent of the complex problems discussed above in the context of transdisciplinarity by Mittelstraß and Gibbons et al. (1994).

As a praxis towards his call for ‘citizen science’, Irwin argued that as civilization has become more technologically aware and dependent on technology for day-to-day life (actually, survival), people have become more technologically literate and to some degree understanding of the sciences (1995). However with this techno-dependence, more people have grown skeptical and even mistrusting of science: ‘For most citizens, science has become an obstacle to the expression of concerns’; he also cites ‘the tragedy of technology’ (Irwin 1995: 9, 46). Likewise people globally are much more aware of the increasingly dire state of the environment. Accordingly, Irwin suggested that democratization of scientific research to allow public and student participation would be an aid to regaining the public’s trust in science and likewise changing the aspect of science from that of a ‘monolithic’ discipline towards a more community-oriented framework for understanding problems we all face (1995: xi). Additionally such programs have the ability to work collectively with local communities to solve proximate socio-ecological issues, moving towards more sustainable behaviours. In fact, Irwin suggested, ‘There will be no ‘sustainability’ without a greater potential for citizens to take control of their own lives, health, and environment’ (1995: 7). According to Irwin, citizen science is intrinsically linked to environmental citizenship (a

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position reminiscent of goals for transdisciplinarity as discussed above by Mittelstraß and Gibbons et al. 1994).

Underlying Irwin’s ideas is a plea for the way science itself operates. Funtowicz and Ravetz had previously described the need for ‘post-normal science’ to face increasingly complex real-world ‘post-normal problems’ (2003: 6). The authors suggested that what is required is the refocus of science from routine, ‘normal’ practice to more issue-driven research. This also would involve the inclusion of those most impacted (the public) in the research process and would necessitate decision making intended to deal with these problems long-term. This fundamentally would allow science to become more transparent, democratic, and community-oriented, permitting it to move past its ‘traditional unreflective, dogmatic style’ (Funtowicz and Ravetz 2003: 6). In addition to restructuring, new forms of evaluation would need to be developed, according to the authors. This would move quality assurance from traditional peer or disciplinary review towards more of a community-wide, reflective judgment—further empowering locals as stakeholders. As the authors stated, ‘Maintenance of quality depends on open dialogue between all those affected’ or an ‘extended peer community … consisting not merely of persons with some form or other of institutional accreditation, but rather of all those with a desire to participate in the resolution of the issue’ (2003: 1). Hereby, under Funtowicz and Ravetz’s vision of post-normal science, research planning, implementation, and evaluation would be conducted in communal cooperation. This approach then would lead to a more informed populace who would push for better governmental policies, potentially alleviating future problems.

This role that citizen participation may play in the democratization of science, which Funtowicz and Ravetz compared to various historical suffrage movements, is noted in the opinions of numerous other authors. As environmental studies scholar Ilan Kapoor has stated, the approach of such citizen-inclusive programs ‘is decentralized, community-oriented, and holistic … aimed at making environmental decision making socially inclusive and environmentally sustainable’ (2001: 269). Cornell University ecologist Caren Cooper has suggested that the democratic ideology underlying citizen science dates back to Thomas Jefferson. She says that his vision ‘relied [on] citizens relishing civic duty and claiming their right to be informed and educated in order to self-govern and curb corruption, privilege, and aristocracy’ (2012a: 1). Cooper also has stated that participation in science involves ‘empowering people to contribute to the formation of knowledge and the articulation of values as needed for decision making in policy, management, and environmental issues’ (Cooper 2012b: 3). In this sense, citizen science is a democratic process that embodies Jeffersonian ideas of a science-literate, participatory populace.

The public in such programs is often age-diverse. Moss et al. (2008) and Zoelllick et al. (2012) cited examples of youth participation in such programs, which enhanced their understanding of science and empowered them through active contribution. Such programs also have the potential to involve people from diverse cultural and socio-economic backgrounds (McCaffrey 2005; Cooper 2012; Chandler et al. 2012) as well as involving women more in the scientific research community (Cooper and Smith 2010). In its most idealized form, democratized science creates a citizen community that ‘becomes a microcosm through which scientific events and their effects can be analysed’ (Mueller et al. 2012: 3). It is
hard to argue that any of these ideas or efforts are a problem.

However, as some authors have suggested, it is important to retain a critical view of these new programs; as Mueller et al. (2012) reminded us, they may fall back into old patterns of scientific exclusivism and even exploitation of volunteers. Under these programs it is all too easy to arrive at a situation where ‘participants primarily serve to collect data for scientists rather than to collaborate with scientists, democratize protocol and equipment, assess ideas, and work in relation to others’ (Mueller et al. 2012: 3). Thus, science retains an elitist stance, teaching the populace from a top-down approach and imparting a singular vision of objective ‘truth’ (a danger voiced by Nicolescu in his critique of the empirical world views of science). Additionally race is still a problem in citizen science as, to date, the role of minorities has remained low and ‘may contribute to reduced diversity in the current and future scientific workforce’ (Pandya 2013: 314). However in defence of citizen science, it is a very new field (with old roots) that has yet to fully come to fruition and, like all human endeavours, will undeniably face numerous future hurdles.

One potential way to address such problems is establishing a clear framework for the models for citizen science and what their expected outcomes should be. Bonney et al. (2009) described three primary categories for public participation in scientific research: contributory models, which are ‘designed by scientists and for which members of the public primarily contribute data’; collaborative models, designed by scientists with public contribution of data but in which participants ‘may also help to refine project design, analyse data, or disseminate findings’; and co-created models, which include the contributory and collaborative elements but also in which ‘the public participants are actively involved in most or of all the steps of the scientific process’ (Bonney et al. 2009: 11). Under all models, citizens contribute data towards a primary research investigation and benefit to varied degrees from the experience of being involved in the project. Such benefits include an increased awareness and understanding of the issue studied and the scientific process; increased interest and engagement of subject being studied; development of science-related skills; and potentially long-term changes in attitudes and behaviours (Bonney et al. 2009). According to the authors, depending on the model adapted for a citizen science program, potential participant benefits can be gauged to ensure that the community is satisfied with the outcomes. In the larger context of my research, this is an important consideration, because for participatory biology programs to be effective at disseminating understanding of ecological phenomena, they must firstly engage volunteers who feel good about the overall outcomes (discussed in more detail in chapter 6).

At a pragmatic level, scientists organizing such participatory research programs may choose to do this for a number of reasons. According to Pilz et al. (2006), these may include: pooling intellectual resources between locals and specialists for ‘building cohesion through group learning’; having a larger workforce ‘supporting community development’; spreading funding limitations; community outreach and education for ‘improving community relations’; and working as group to address real-world issues and ‘public concerns’ (Pilz et al. 2006: 1). In my own experiences with amphibian monitoring, time and physical and economic resources were very limited, and I found the collaboration with volunteers crucial towards project completion. Additionally, volunteers benefited from research experiences by learning
more about amphibians and by helping to address a local ecological problem (deformed anurans), discussed in detail in later chapters of this thesis.

Technology has increasing played a role in citizen science and has worked towards reaching large audiences. Various scholars have discussed ‘crowd-sourcing’ to find volunteers; through the Internet, participants may make observations and record them on their own schedules (Silvertown 2009; Sullivan et al. 2010; Wiggins and Crowston 2011; Dickenson et al. 2012; Newman et al. 2012). For example, Sullivan et al. (2010) cited the example of eBird (www.ebird.org, an Internet-based citizen science program) where participants globally can submit local observations of encountered species that are then added to a growing public database. This collected information has been used by researchers, governmental agencies, and others to model population movements. Sullivan et al. (2010) also discussed how this data has been used to highlight potential impacts from climate change and even environmental catastrophes such as the 2010 Deepwater Horizon Oil spill.

Furthering the ideas of the importance of neo-technologies towards democratizing science and conservation, Newman et al. (2012) have even suggested creating interactive online gaming elements to encourage younger audiences to participate in citizen science. As such, these new models for techno-participatory science may be very effective for groups of citizens who desire to contribute to larger conservation efforts but have physical limitations. This might include groups such as children, elderly, and the disabled. Certainly, one must wonder how the virtual differs from the real in the overall experience of volunteers in such techno-citizen science programs, as limited sensory experiences may have less impact than those of embodied practices (discussed further in chapter 6). However, technology was an important tool for crowd-sourcing and outreach in my own participatory amphibian monitoring programs (discussed in later chapters of this thesis). Through an open online call I connected with volunteers in England and Quebec. Additionally, in the Quebec studies (2009–2010) participants created a ‘Malamp QC’ blog33 to share experiences and updates on studies, to find other volunteers, and to generate their own creative content (discussed further in chapter 6).

Another important concern with citizen science is the validity of data collected by the public. Recent reviews have shown that in some instances students misreported information when compared to professionals (Galloway 2006). In other cases citizens have over-reported more rare species while not consistently reporting more common ones (Dickinson et al. 2010). In another case, citizens misidentified species of butterflies, creating an unviable dataset (Fitzpatrick et al. 2009). Acoustic monitoring of amphibian populations by volunteers has created issues, as the public, to varying degrees, misidentified calling frogs and toads, impacting datasets (Weir et al. 2005). In light of these issues, several authors have offered methodological changes to programs such as testing volunteers before primary studies to gauge their abilities, in order to increase viability of publicly generated data (Dickinson et al. 2010; Wiggins et al. 2011). As modern citizen science is still an emerging field such issues may still be resolved through trial and error: ‘Information and knowledge derived from science (with its inherent self-correction processes) should be reliable, repeatable, and indisputable’ (Cooper 2012b: 3).

1.6: Some Notes towards a Definition of Participatory Biology

Within this thesis I found in necessary to coin the term ‘participatory biology’ to further distinguish my approach from other terms (often more generalized and widely used) such as ‘citizen science’ and others discussed above. My term ‘participatory biology’ is defined as ‘primary research biological studies in which students, volunteers, or general members of the public are involved directly in the scientific methods of field and laboratory observations, monitoring of experiments, aid in the establishment of experiments, data collection, or other tasks in field and laboratory settings’, an approach in alignment with ideas discussed above by Irwin (1995), Bonney (1996), Cooper (2012), and others.

This public involvement aids in the research process, firstly by allowing the research process to be developed by a group rather than an individual (Puntowicz and Ravetz 2003, discussed more in Chapter 10; Gibbons et al. 1994). This may also in increase overall research depth through more people making more observations and collecting larger quantities of data (discussed in more detail in chapters 8 and 9). Additionally locals may offer important insights about ecosystems and species they know and suggest different vantage points to identify problems, develop strategies to understand these problems, and aid in designing frameworks for developing and testing hypotheses and making their own novel observations (an approach much more attuned with Gibbons et al. 1994 than most citizen programs, discussed in more detail below).

Diverging from any other example of participatory science I have found, I have asked my volunteers to reflect on these research experiences through creative means, sometimes resulting in visual, written, or auditory artworks that can be shared with a larger audience. This incorporation of art into science, though reminiscent of recent attempts at STEAM educational programs (discussed in more detail in the final chapter) is novel to citizen science. Overall, such research and post-reflective, creative experiences may increase participant understanding of ecological phenomena and scientific methods and enhance appreciation of local species and ecosystems (evidence presented in chapter 6).

Under my definition of ‘participatory biology’, there are five important components in which volunteers may be involved (here contextualized through my own research experiences with volunteers studying anuran deformations, clarified further in chapters 6 through 9):

1. Identification of problem (in my research, the occurrence of limb deformities in natural populations of anuran amphibians)

2. Testing hypotheses through field and laboratory studies:

   Site choice and pilot field studies:
   - Choosing wetlands with viable amphibian populations (with input of locals’ knowledge of good ‘frog’ sites)
   - Categorization along an environmental gradient based on obvious signs of ecological stressors (proximity to agriculture, proximity to residential lawns, streets, parking lots, fountains, and other anthropogenic factors, others

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34 Recent integrative education programming strategies referred to as STEAM (Science, Technology, Engineering, Art and Math) by physicist and professor Roger Malina, and others discussed in Chapter 10.
[please see appendix materials for greater detail])

• Preliminary training to safely capture and handle specimens for observation
• Preliminary training on data collection and documentation

Primary field surveys:
• Observations and data collection of animals surveyed at sites during consecutive visits
• Observations and data collection of field sites during consecutive visits
• Documentation of specimens, field work, and sites during consecutive visits

Primary Laboratory studies:
• Preliminary training on humane handling and experimentation with living amphibians, animal husbandry, observation, data collection, documentation
• Running of pilot and primary experimental sets
• Data collection and documentation
• Post-experimental care of animals

3. Post-research experience reflection through creative means
• Creative writing outputs
• Visual or auditory art outputs
• Others

4. Analysis and understanding of results
• Preliminary interpretation and analysis of field finding and experimental results
• What these results suggest? Do they reflect larger trends?

5. Dissemination of results
• How these results may be disseminated to a larger audience
• Peer dissemination with the scientific community
• Public dissemination through art, online platforms, social media, others

Within this thesis I will present two examples as case studies (chapters 8 and 9) whereby volunteers in my participatory biology research into amphibian deformities were crucial to the overall outcome of the project. Participants aided in all aspects of the research and importantly, gained knowledge of amphibians and local ecosystems (as discussed in chapter 6). Important scientific discoveries were achieved through these participatory programs, also suggesting that such citizen-inclusive programs have the potential to offer new knowledge to science (chapters 8 and 9).

1.7. Conclusion

It is hoped that this chapter will help to contextualize the overall research presented in this dissertation. Both transdisciplinarity and citizen-oriented science may be important means to disseminate knowledge of ecological phenomena to a larger populace of non-specialists. Specifically though, one must ponder through what means such information can be passed on to such audiences and whether this could have potentially larger positive impacts. Are some strategies more effective than others?
Additionally there are several potential overlaps in the views of transdisciplinarity posited by Mittelstraß, Gibbons et al. (1994), Kagan (2011), and others with those of participatory science advocates such as Irwin, Cooper, Bonney et al. (2009). Are such intersections merely correlative, or could they represent larger trends in science and art towards being inclusive of the larger populace? At a larger level, could these overlays be new forms of disciplinary hybrids or reflective of a growing trend beyond traditional disciplinary boundaries? These questions and others will be addressed in the following chapters. However, work in the arena of transdisciplinarity and citizen-oriented science offers a hopeful trend; at this moment in history, we need the creativity found within and beyond disciplines, along with the participation of global citizens, to address the onslaught of ecological issues we and numerous other species currently face.
Chapter 2. Raising Public Ecological Awareness through Historic Art and Science Practices

2.1. Introduction

As this research seeks to shed light on how transdisciplinary art and participatory biology may increase understanding of ecology among non-specialist audiences, it is important first to explore the historical trajectory from which these contemporary practices stemmed. Several hybrid scientist-artists have utilized the creative tools of visual art and/or engaged descriptive writing to transfer their knowledge of natural history to a larger lay audience. These science-to-art devices, along with varying degrees of ethical approaches toward nature, inspired an increase in popular ecological awareness. Similar devices may still be effective means for reaching the public with an environmental message. Likewise, these early practitioners may have laid the conceptual foundation for today’s ecological and biological art practices, a research trajectory that has not been well explored in art history.

2.2. Representational Strategies toward a Popular Understanding of the Natural World

Physician, botanist, and respected poet Erasmus Darwin (1731–1802)\(^{35}\) used seductive metaphors through poetry as a strategy to educate readers about plant ecology. He also transgressed popular Judeo-Christian anthropocentric beliefs in human separation and superiority over other living species. In his popular science book, The Botanic Garden: A Poem in Two Parts (1791), Darwin delivered two profound fundamental ecological concepts in a poetic format accessible to the lay public: first, that species change over time; second, that all living organisms are connected by universal biological material. According to sociologist John Bellamy Foster, Darwin and French scientist Jean Baptiste Lamarck were among the first material biologists since antiquity to speculate on the complex origins of all living entities and their thresholds for change.\(^{36}\) According to Darwin and Lamarck, individual species were not static creations from God but instead changed over time through generations. This concept would inspire countless future evolutionists, notably Erasmus’s grandson Charles (Foster 2000). Within this paradigm all organisms, including humans, are subject to the laws of nature, a position that fundamentally challenged Judeo-Christian belief systems of the day. According to science philosopher and psychologist Edward Reed, Darwin posited that organisms are a product of their bodies, and these bodies are sculpted by their environment: a notion that challenged fundamentally the placement of a divine creator (Reed 1997).\(^{37}\) These complex yet formulated ideas would later percolate into decisive theories in

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\(^{35}\) Erasmus Darwin's poetic scientific verse was admired by his contemporaries William Wordsworth and Samuel Tayler Coleridge according to Evolutionary theorist Richard Dawkins (2009:399).

\(^{36}\) Foster states, ‘Evolutionary ideas had long been associated with materialism—each implying the other—and were seen as first arising from the ancient materialists Empedocles, Epicurus, and Lucretius. It was in Lucretius that the notion of species survival through adaptation to the environment, and more importantly the idea of the extinction of species that failed to adapt (known as “the elimination theory”), was most clearly stated in antiquity’ (2000:180–181).

\(^{37}\) According to Reed, ‘If life, mind, and feeling are concomitants of the arrangement of organs and of a fluid ether in animal bodies, what role was left for either God or the soul? Erasmus Darwin … argued that the way we act is a function of our upbringing—of social, not divine intervention’ (1997: 15).
the works of Charles Darwin.38

From a science communication standpoint, Darwin’s poem made complex ideas set forth by Carl von Linné (Linnaeus) in *Systema Naturae* (1735) accessible to a larger public: Plants reproduce sexually and can be grouped complexly according to families.39 Although the Linnaean system laid the groundwork for future taxonomists, it was written in Latin and beyond the comprehension of the lay public. Darwin’s poem offered a cultural interpretation and was written in English.40 According to Adrian Plant, Exhibitions Officer at the Shrewsbury Museum (on the Darwin family estate), Darwin, ‘chose to use a creative language imbued with poetic imagery … an incisive way of gaining a more holistic understanding of the ways in which the world works’ (Plant, forthcoming, please see appendix). Darwin portrayed a systemic view that all organisms are fundamentally related at a molecular level as part of a larger environment, and all adapt accordingly—a message that many artists and scientists are still working to get across to the public.

To ensure delivery of his radical concepts to the public, Darwin used sexual metaphor to engage readers. According to scholar Janet Browne, ‘The poem was unabashedly about sex and sexual relations, about the all-pervading drive to find a mate and to reproduce. Such a focus was decidedly controversial’ (1989: 593). Darwin figuratively changed the floral reproductive organs: the stamen into a ‘courting male’ and the pistil into a ‘receptive female’, creating a metaphorical bride and groom (Browne 1989: 596). As Browne (1989) points out, Darwin imparted plants with human sexual identities. Darwin thus personified plants and their life histories, making them more enjoyable and comprehensible to the general public, since people, as sexual beings, could identify with plants through their ‘common behaviour’ (Boyd forthcoming: 56). In addition to sexuality, Darwin also portrayed plants with emotional qualities, another point of access for readers to identify with, using terms such as ‘braves’ (Darwin 1791: 6).

Darwin’s book was a bestseller and successfully reached thousands of people, increasing ecological awareness and even potentially making botany fashionable (Schiebinger 1991). It is true, as Browne posits, that Darwin was not the first to use the seductive language of human sexuality to describe plant reproduction: ‘It is worth emphasizing here that it was Linnaeus who initiated this personification of the sexual relations of plants … personification allowed Linnaeus to write of plant sexuality as a “marriage” and the male and female organs as “husbands” and “wives”’ (1989: 600). Darwin, however, did translate, interpret, and artistically expand Linnaeus’s ideas into the English language, even creating dozens of new botanical terms (Browne 1989). In Darwin’s case, seductive language and progressive undertones could be seen as particularly bold in a time when the Church still had considerable influence on the socio-political dynamics of British society.

Linnaeus and Darwin, furthermore, were criticized for their anthropomorphizing of

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38 Darwin scholar Nora Barlow asserts, ‘Erasmus's cast of mind appears to hold definite heritable qualities ... When we examine the achievements and characteristics of (Charles Darwin’s) forbearers and descendants, the copious mind of Erasmus appears as a vast family aggregate’ (1959: 85).
39 According to scholar Janet Browne, ‘Darwin intended it to be a vindication and explanation, both amusing and instructive, of Linnaeus's classification scheme for plants ... Through his verses we can follow the expression of connections between the ordering of nature and human society ... [in] Darwin's explanation of Linnaeus's scheme’ (1989: 596).
40 According to Darwin family historian and Shrewsbury Museum curator Peter Boyd, ‘[Darwin] formed the Lichfield Botanical Society in order to translate the works of the Swedish botanist Carl von Linné [Linnaeus] from Latin into English’ (Boyd (forthcoming): 57).
plants, which from a current scientific standpoint is considered non-objective and far removed from ecological reality (Browne 1989). As Browne has critiqued, ‘The over-all impression is of an “artificial” world far removed from real life’ (1989:615). In Darwin’s constructed poetic world, plants did not struggle to exist, which is far from evolutionary reality and potentially misleading to the public. According to scholar Desmond King-Hele, although Darwin’s poetry was immensely popular, his theories on evolution had almost no direct influence on the intellectual development of natural history in England (King-Hele 2004:21). Further, Darwin’s writing could be considered guilty of reinforcing social constructs of gender biases whereby ‘women’ flowers fall into cultural stereotypes.41 Regardless of such criticisms, however, Darwin’s The Botanic Garden: A Poem in Two Parts successfully reached readers of his day with powerful ecological messages, even if they did not clearly illustrate a lasting introduction of evolution to the general populace. Darwin’s poetic techniques worked to engage readers, and these are still viable forms of engagement among contemporary practitioners.42

Like Erasmus Darwin, John James Audubon (1785–1851) used dramatic narratives to reach the public with his artworks and associated writings. Audubon was a model example of an early hybrid artist and scientist who raised public awareness of environmental phenomena and contributed knowledge to the field of primary research biology. By focusing on the non-human animal—mostly birds—as individual beings depicted in dramatic and often allegorical works of art, Audubon asked viewers to question their anthropomorphic views on non-human species, even the landscape itself. Below, I will discuss Audubon’s offerings to science and art along with his set of ideas, which fundamentally contributed to the shaping of modern environmentalism.

According to science writer William Souder, Audubon was an avid explorer who contributed vast amounts of knowledge to the field of biology with his descriptions of little known North American birds and mammals (Souder, 2004). As a visual artist and ornithologist, Audubon described and drew greater than five hundred species of North American fauna (Souder 2004). According to art historian David S. Rubin, in 1820, Audubon set forth to depict ‘all the bird species of North America’, which had not previously been done (Rubin 2004:7).43 Audubon meticulously painted birds from physical examinations of specimens he collected in nature. From these paintings, copper etchings were made for mass production and were printed and sold collectively in his seminal The Birds of America (issued in groupings, 1827–1838). In total, this publication, with the accompanying Ornithological Biography (issued in five volumes, between 1831–1839), contributed depictions and scientific knowledge of ‘435 bird species’ (Souder 2004:282).

Audubon’s artworks were scientific descriptions in their own right, often providing information on bird behaviours such as courtship, foraging habits, and environmental habitats

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41 According to Browne, ‘Darwin listed a procession of female images ranging from virtuous brides and tender mothers to attentive sisters, nymphs, and shepherdesses. Laughing belles and wily charmers were followed by queens and amazons’ (1989:615).
42 One need only look at the recent title of science writer Michael Pollan's popular book The Botany of Desire (2001) as an example.
43 According to Souder, prior attempts at describing and depicting the avian fauna of North America had been conducted by artist and scientist Alexander Wilson, who represented about 250 species (2004:286). In addition, English naturalist Mark Catesby published the first large collected account of North American flora and fauna between 1729 and 1747. It was entitled Natural History of Carolina, Florida, and the Bahama Islands, and it included 220 plates.
through visually rich story telling. Audubon’s *Ornithological Biography*, written in part by scientist William MacGillivray, was the first major biology publication on North American birds. According to author Richard Rhodes, *Ornithological Biography* included the common and scientific names of the avian species as well as accompanying plants, insects, reptiles, and other species, specimen collection localities with descriptions of landscape, and varied anecdotal data that greatly benefited science (Rhodes 2004). Audubon’s contribution of seminal knowledge on North American birds was a major contribution to the new science of ornithology and influenced other scientists of his day. As Rhodes (2004) noted, he even contributed to Charles Darwin’s theories of both artificial and natural selection. More than a century after publishing, Audubon’s species summaries are still relevant and appear in varied new editions of *The Birds of America* (Vogt 1946; vi–ix). In addition to these contributions, Audubon gave accounts of several species of birds that are now extinct, providing some of the only information on their behaviour available to science.

Audubon’s contribution to art is also plentiful. Audubon’s artworks were complex, often-dramatic narratives, in which the birds were depicted as individual beings struggling for existence in nature. The artworks themselves were interdisciplinary in nature and represented a ‘harmonious synthesis of empirical observation and inspired idealization’, according to arts scholar Gloria K. Fiero (1990:60). With this ‘idealization’, Audubon often anthropomorphized birds in his paintings in a fashion similar to Erasmus Darwin’s sexualized flowers. As Audubon made his living as a portrait artist for several years, he knew the tools for capturing the individual through art, as pointed out by Souder (2004). To personify his birds as almost human, Audubon often imparted a sense of emotion in his avian subjects (Souder 2004). To heighten visual interest, he sometimes created works where the avian subjects were severely injured. For example in plate 241, ‘Great Black-Backed Gull’ in *The Birds of America*, the individual bird is bloodied from an unknown skirmish and appears to be screaming (Audubon 1840). These scenes are made even more dramatic through their large scale; the birds were printed at actual life size. Audubon’s view of nature was far from idealistic as he ‘knew the natural world was far from suburban idyll’, according to Rhodes (2004:378).

Audubon likewise would sometimes impart near-human empathy in his birds, with visions of parental endearment such as plate 62, ‘Passenger Pigeon’, where an apparently loving mother carefully feeds her young (Audubon 1840). This image is particularly complex and may even present an implied environmental message about the fragility of individuals in

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44 According to Souder: ‘[Audubon] carefully described the bird’s flight, its song, its feeding and reproductive habits, its nest-building, and what the eggs looked like—as well as where and how he had found it, shot it, and probably ate it. At the conclusion of each account, MacGillivray added a scientific description, including precise measurements, plumage characteristics, and taxonomic designations. Close attention was paid to features distinguishing males from females and juveniles from adults. In the cases of new species, Audubon provided both scientific and common names of his choosing … [and] later in the series … included black and white sketches he made of specific body parts and internal organs’ (2004:258). In addition to observations published in *Ornithological Biographies*, his copious journal writings contain descriptions of visited environments, information on varied animal species, and even material on Native American cultures (Rhodes 2004).

45 Rhodes states: ‘Audubon’s careful field observation of courtship rituals and the transitional physical features such as vestigial webbing on the feet of the frigate bird would influence Darwin. The text volumes of *Birds of America*– the five-volume *Ornithological Biography* … would be quoted three times in Darwin’s 1839 *The Origin of Species* … Darwin would quote Audubon even more frequently in two of his later works, *The Variation of Animals and Plants under Domestication and the Descent of Man and Selection in Relation to Sex.*’ (2004: 305–306)

46 Several descriptions of now-extinct bird species are found in *Birds of America*, such as the Carolina parakeet, the passenger pigeon, the Ivory-Billed woodpecker, and others (Rhodes 2004).
nature. Already by Audubon’s time, the passenger pigeon had begun to decline, and he had witnessed first-hand the slaughter of hundreds of thousands of these birds.\textsuperscript{47} Perhaps Audubon’s emotive depiction of this species is a reflective response to the demise of these ill-fated birds. Another emotionally complex pictorial example pointed out by Rhodes is of ‘house wrens nesting in a hat, an image of tender family life that the hat’s startling splash of shit bleaches [of] sentimentality’ (2004:378). Though anthropomorphic, Audubon’s personifications of wildlife appear to be more about representing the behaviour of birds in a compelling way rather than transforming them into humans. As Rhodes observes, ‘Audubon’s supposed anthropomorphism is an attempt to recover meaning, a system for translating the alien experience of a different animal order into human terms and parallels’ (2004: 377–378). This powerful tool of personification, or non-human translation of experience, successfully reached audiences of his day with a message that was fundamentally environmentalist. Likewise his views challenged the popular norm of his time; at this point in history, North America was undergoing enormous ecological degradation and species demise, according to environmental scientist, Stephen R. Kellert.\textsuperscript{48} The technique is still effective; one only need look at the success of the contemporary film Finding Nemo\textsuperscript{49} to see that theatrical tools such as personification are still effective ways to reach audiences.

Although Audubon, much like Erasmus Darwin, never outlined his thoughts into a cohesive philosophy, ideas an overarching idea did emerge from his practice: Non-human animals are individuals, and like us, they struggle to exist in the complex ecosystems of nature. Further, they deserve respect.\textsuperscript{50} Audubon also posited a clear environmental message through some of his species accounts. In the text accompanying plate 128, ‘Catbird’, for example, he discussed farmers eradicating this species on spurious grounds, even suggesting that this could lead to the extinction of the species (Rhodes 2004: 212). In an era of ‘Manifest Destiny’, Audubon challenged the conventions of the Judeo-Christian view of nature by asking readers to think about the depicted birds and their environments: ‘Audubon often invited his readers into his natural history by dramatizing … the behaviour of birds and other animals … he also created a moral lesson to be learned from his representations of the natural world’ (Murphy et al. 1998: 172). Additionally, he imparted important scientific knowledge of numerous species and contributed greatly to the emerging visual arts in early nineteenth-century America.\textsuperscript{51} As is the case with Erasmus Darwin, Audubon utilized the mass production techniques of printing, which allowed him to reach countless readers. Though

\textsuperscript{47} Passenger pigeon populations had swelled to billions because of nineteenth-century agricultural practices, and individual flocks were said to darken the sky when passing over (Rhodes 2004). For further information see Vedder, John James Audubon and the Birds of America (1999: 260–268).

\textsuperscript{48} According to Kellert, ‘Unrestricted hunting in America, however, particularly with the development of modern weaponry, commerce, and transportation, resulted in an extraordinary and unsustainable waste of wildlife. Many species—including various fur-bearing mammals, birds of the forests and plains, marine creatures, large predators, and others—became extinct. The intensity of the slaughter is still hard to imagine’ (1996: 67).

\textsuperscript{49} This film grossed over $900,000,000 and became the second most popular DVD of all time (Boone 2006). Although Disney suggested that the film was inspired at least in part by scientific knowledge of marine ecosystems, Finding Nemo inspired audiences to buy clownfish (Ocellaris sp., e.g. “Nemo”) as pets, causing them to become exploited in the wild. Further ecological damages were caused when pet owners later released these fish into nonnative habitats (Arthur 2004).

\textsuperscript{50} Audubon often referred to his experiences with individual animals and his respect for them. For example, in his account of a living golden eagle, he remarked on the ‘nobility’ of the individual and the deep sorrow he felt for euthanizing the specimen to make art (Audubon 1986: 149–150).

\textsuperscript{51} In the early nineteenth century, North American art lacked any independent, stylistic cohesion and was primarily influenced by European art movements (Gardiner 1990).
motivated at least in part by economic necessity; Audubon published works that successfully, even if unconsciously, imparted his own philosophy of nature and creating the opportunity for ecological awareness. His work continues to be popular and remains an example of how strategies of representing non-human animals as individuals may effectively shape popular perception. Additionally, Audubon’s artworks continue to inspire both the public and contemporary artists: notably Peter Edlund, Walton Ford, Mark Dion, my own work, and many others.

**Section 2.3. Biological Unity as a Philosophical Approach towards Environmentalism**

Similar to the way that Erasmus Darwin and John James Audubon described numerous species and landscapes to science, the acclaimed German scientist and philosopher Alexander von Humboldt (1769–1859) published his observations of the natural history of Latin America, gathered during his travels there. Underlying Humboldt’s writings were a vision of the biological unity found in nature as he observed it during his explorations. According to Gerard Helferich, Humboldt was the prototype of the naturalist as adventurer and inspired numerous other scientists of his time to explore natural systems (Helferisch 2004). Likewise, his robust data sets and descriptions of natural phenomena inspired future generations of biologists, geographers, and even astronomers (Helferisch 2004). Described as a ‘synthesizer’ of knowledge derived from direct experience with nature, Humboldt attempted to find and illustrate the order underlying seemingly chaotic environments, positing a remarkably holistic worldview (Helferisch 2004: xxi). His approach placed man within a larger system of living beings and challenged cultural perceptions of humankind’s separation from nature (Helferisch 2004).

One of many of Humboldt’s publications, *Aspects of Nature in Different Lands and Different Climates; with Scientific Elucidations* (1849), detailed his five-year exploratory journey to the Americas, an account that contributed vast quantities of natural history knowledge to the science of his day. In the preface to this book, Humboldt placed even the human mind in the sculpting hands and all-encompassing environment: ‘Throughout the entire work I have sought to indicate the unfailing influence of external nature on the feelings, the moral dispositions, and the destinies of man’ (Humboldt 1849: ix). According to environmental writer Aaron Sachs, these opinions had a profound influence on the outlook of American and European artists of the period by inspiring their view of humans as a part of a greater community of living beings (Sachs 2006). Sachs even posited that Humboldt’s...
systemic ‘Chain of Connection’ qualified him as being among the first ecologists (2006: 2).

It is quite impossible to fully comprehend Humboldt's enormous contribution to Western science, philosophy, and popular perceptions of the natural world. However, there are three fundamental concepts that arose in his writing: first, the scientific quest for knowledge should be unified to understand the complexity of the universe and made available for all of humankind to understand, a position still argued for in contemporary ideas of transdisciplinarity by E. O. Wilson and Jürgen Mittelstraß; second, human beings are part of a larger community of living organisms, a cornerstone of modern ecology; and finally, human understanding and perception can be enriched through reflective observation of nature, a position I fully share and utilize in my participatory biology programs. According to Sachs, ‘Humboldt stood apart from nature in order to observe its mysterious workings yet also included himself in its realm. He had an almost postmodern awareness that nature and culture are inextricably linked, yet he also felt a profound respect for nature's differentness’ (2003: 119). Such profound philosophical concepts are still very relevant today, as we are facing large-scale environmental challenges such as global climate change, loss of biodiversity, demise of natural habitats, and others. Despite this, many still do not see themselves as part of a larger living environment.

In his final, immensely popular multi-volume publication, *Cosmos: A Sketch of the Physical Description of the Universe* (1845), Humboldt attempted to outline all scientific knowledge of the seemingly chaotic universe, an effort that he felt would supply compelling material evidence for an ‘underlying cosmological order’ (Helferisch 2004: 320). This work functioned as both a popular guide to understanding the material universe through the lens of scientific exploration as well as a philosophical treatise on how to view nature rationally and with respect. *Cosmos* informed thousands of lay readers about natural processes and remains as one of the greatest contributions to Western thought to date (Helferisch 2004).

Humboldt opened *Cosmos* with a philosophically progressive environmental message: ‘Nature is a free domain’ (Humboldt 1849: 23). With these words, he suggested that nature is autonomous and not here solely for humans, an attitude that, according to environmental essayist and activist Jim Mason, was in stark opposition to popular socio-religious, ‘dominator’ models of his day (Mason 1993: 33). Mason posited that as Western societies evolved into the nineteenth century, the presumed right of humans to dominate nature became engrained and even ‘celebrated humanity’s ascent to mastery over nature’ (1993: 33). Mason suggested that Judeo-Christian beliefs promoted environmental degradation through anthropocentric views, or ‘the world outlook into which they were born, which was that nature, the living world, existed for humanity, and humanity should rule over it’ (Mason 1993: 33). If Mason's analysis is accurate, Humboldt’s ideas were certainly visionary, perhaps even revolutionary for the time. According to Sachs, Humboldt even criticized the destruction of natural habitats for agricultural production, placing him among the first environmental activists (Sachs 2006).

As a popular science writer, Humboldt challenged the philosophies of his predecessors Francis Bacon and René Descartes, who, according to Mason, sought to ‘update dominism for the scientific, and ultimately the industrial age’ (Mason 1993: 35). In this sense Humboldt was a radical who found value in nature beyond its economic worth, stating that
the ‘profound conceptions and enjoyments [nature] awakens within us can only be vividly delineated by thought clothed in exalted forms of speech, worthy of bearing witness to the majesty and greatness of the creation’ (Humboldt 1849: 23). Sachs suggests, ‘Ultimately, [Humboldt] hoped his listeners would rebel against the authoritarianism and Christian orthodoxy … and create a society in which every individual could freely experience … the astonishment found in nature’ (2006: 75). Sachs surmised that this sense of awe through experience with the natural world and his belief in truth in nature firmly established Humboldt as a Romantic (2006: 76). His Romantic sensibility, along with his ability to engage his readers through countless tales of adventures of exotic lands, is perhaps the reason his works were so successful among the public and continue to be read today. Additionally, through attempts to direct people towards experiences in natural systems, Humboldt’s ideas are echoed among participatory science programs and environmental educators like Richard Louv, discussed later in this thesis.

A potential problem that arose in Cosmos is Humboldt’s obsessive search for the truth in nature, a characteristic of Romantics (Sachs 2006). Humboldt and the Romantics sought universal truth in nature, believing the natural world was perfect until man altered it, according to Marie Louise Pratt (1997). This view is somewhat naïve, as human beings are a part of nature, as Humboldt suggested, and as such, we and all other organisms shape the environment in some form or another. As I will discussed later in this dissertation, seeking one’s own belief in a singular definition of ‘truth’ can lead to a non-objective, unscientific approach to observation and description of natural phenomenon. Regardless, Humboldt’s scientific findings remain mostly intact, and his extensive observations continue to inform modern science (Helferich 2004). Additionally, Humboldt’s form of ‘moderate’ Romanticism suggested the inherent value of nature itself, a position reflected in the work of future environmental ethicists such as David Henry Thoreau and Aldo Leopold.

Alexander von Humboldt changed the way people in Western societies viewed the natural world. With work informing the emerging fields of biology, geography, and even cosmology, he contributed immense amounts of seminal knowledge to science. As a popular science writer he posited a profound ecological message about the unity of humans beings within a vastly complex universal system. As a revolutionary thinker, Humboldt challenged the prevailing Judeo-Christian philosophy of his day, positing his views on the inherent worth of nature beyond the monetary. Humboldt proved through observation of nature that people can heighten their reflexive perception, an opinion still suggested in some contemporary citizen-science programs involving ecosystem study. As people continue to separate themselves from nature, artists and scientists working today may see Humboldt’s efforts as a source of inspiration with new potentials that can challenge popular perceptions of nature.

German scientist, visual artist, and explorer Ernst Haeckel (1834–1919), like Humboldt, sought unity and truth in natural forms. Like Audubon, he utilized lithography as the method for mass-producing elegant images and texts that transferred his environmental thinking and knowledge of microscopic and other organisms to a larger popular audience. According to art historian and biologist Olaf Breidbach, Haeckel developed a captivating visual art strategy that brought awareness of ‘utterly foreign’ micro-organisms to a lay populace. He often portrayed life forms not normally seen in everyday experience, such as
plankton (Breidbach 1998: 17). Disseminating scientific literacy through visual art, Haeckel produced hundreds of aesthetically compelling lithographic plates picturing a side of nature not usually available to the public. Haeckel’s art also evidenced democratic elements in its broad dissemination, as previously only wealthy individuals who could afford microscopes would have seen such exotic, tiny life forms (Breidbach 2010). Haeckel’s Kunstoffen der Natur (1904) included colourful illustrations as well as ‘readily intelligible commentaries’ addressed to a ‘wide public’, making it one of the first popular art and science books (Breidbach 1998: 11). The continued popularity of Kunstoffen der Natur and other artworks—reproduced widely in art books, science publications, and encyclopaedias, even to this day—is most likely in response to its ‘visual richness’ and Haeckel’s attention to detail (Breidbach 1998: 15).

The physical beauty of organisms first lead Haeckel to science and served as the underlying foundation for his transdisciplinary practice, according to Irenäus Eibl-Eibesfeldt (1998). Haeckel found an unquenchable source for his art in nature, as scholar Max Rieser posits: ‘Ernst Haeckel observed long ago that all artistic forms are derivative from natural forms. This is true of structure, columns, decoration of buildings, the role of “repetition” in a stylistic pattern, etc.’66 (Rieser 1956: 355). Haeckel both utilized and informed the popular stylistic movements of his day, notably the Art Nouveau and Jugendstill schools, which were often inspired by designs found in nature (Breidbach 1998). Breidbach posits that it was through the context of Art Nouveau that Haeckel instructed viewers toward understanding his pictures of nature, perhaps teaching us to ‘see nature the way it really is’, at least, according to his interpretation (1998: 14). Eibl-Eibesfeldt even suggested that human attraction to ‘symmetry’, with its association with beauty, may be another reason that Haeckel's works have continued their popularity (1989: 22–24).

According to Breidbach, Haeckel attempted to make unseen nature visible through his illustrations, which in turn helped the artist better comprehend the science of and connections in nature (1998). Raised to be ‘deeply religious’, Haeckel found natural divinity and order in the ‘design’ of ecosystems (Breidbach 2010: 19, 23). Haeckel’s vision suggested ‘magic’ and ‘perfection’ in organic symmetry, which he further developed into a kind of monism or nature-based spirituality (Breidbach 1998: 13–14). Like Humboldt, Haeckel also published his own theories on a connected universe in several publications, most notably his Die Welträtsel (Riddle of the Universe, 1899). As historian Niles Holt has suggested, an emerging respect for the natural world arises from Haeckel's belief system: ‘[he] used the term “natural religion” in a dual sense: as a deistic counterpart to “revealed” religion and as a general term describing a worshipful attitude toward the “wonders” of nature’ (Holt 1971: 270). One may ponder how Haeckel’s respect toward nature permeated his mass-produced publications, perhaps forming a precursor to popular environmentalism.

Haeckel's view of systemic nature (even holistic, as with Humboldt) informed the complexity of his artworks. There often appeared to be an underlying focus on organisms in relation to one another. For example, in numerous plates in Kunstoffen der Natur, organisms such as frogs, turtles, fishes, and others spatially interrelate and even visually

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66 Max Rieser continues, ‘The original principles of esthetic appraisal are imbedded in the forms of the natural world, as found therein by our senses consciously or unconsciously and abstracted therefrom’ (1956: 355).
compete at times, which perhaps suggested complex species relations in complex ecosystems. As Haeckel was the creator of the modern term ‘ecology’, it would stand to reason that his works of art often convey the complexity of environments and interspecies connections (Breidbach 1989: 14). Through his art, Haeckel envisioned ecology but also constructed a system of belief for how life should work and how it evolved (Ball 2006).

On the other hand, Haeckel’s self-made belief system, consciously or not, led to biases and errors in his scientific theories, according to Philip Ball (2006). Here the artist/scientist theorized that organisms evolved progressively toward greater geometric perfection, a position similar to that of Aristotle and other scholars of antiquity (Breidbach 1998; Ball 2006). In an almost allegorical depiction, organisms portrayed in Kunstformen der Natur climb Haeckel’s imaginary upward ladder, evolving from single-celled diatoms to complex antelopes (Breidbach 1998). Ball states, “[His] extraordinary drawings were not made to support his arguments about evolution and morphogenesis; rather, they were the arguments themselves” (2006, online). This seems to demonstrate the communicative power of Haeckel’s artworks, yet still questions his scientific objectivity, and perhaps even his honesty. The question of objectivity and honesty in regards to contemporary transdisciplinary artworks is an essential one to me, as misinforming the public about biological phenomenon could discredit the entire art-science genre and would be counter-productive to a true analysis of organisms nor their ecosystems.

The degree to which Haeckel utilized his artistic license is still open to considerable debate, although Jerry A. Coyne further supported Ball's opinions, suggesting that Haeckel's beliefs certainly appear to have skewed his view of evolution and analysis of natural processes (Coyne 2001). Haeckel published illustrations of vertebrate embryos that exaggerated their similarity. These illustrations have continued to mislead the public: ‘Some biology books still display these doctored drawings’ (Coyne 2001: 745). As Haeckel was the most prominent German naturalist philosopher of his day and is still popular, the degree to which his work misinforms the public is hard to ascertain (Breidbach 1989).

Haeckel's hybrid art-science practice is an example of the conflict between Romantic ideals and scientific objectivity (Breidbach 1989). As Ball has stated, Haeckel’s artworks ‘are some of the most beautiful illustrations ever made in natural history but it seems clear that now that Haeckel idealized, abstracted, and arranged the elements in such a way that their symmetry and order was exaggerated’ (Ball, 2006, online). Haeckel's persuasive ideas about evolution stressed an underlying order, implying hierarchy and gradual development that strayed from Darwinian principles of species adapting in diverse ways to survive in constantly changing environments (Ball 2006, online). Additionally, historian Daniel Gasman (1998) has asserted that Haeckel's pseudo-scientific ideas on an uneven evolutionary gradient with polygenism among human races fed directly into Nazi ideology. Although the debate on Haeckel’s tendencies towards racial inequality has continued, it is now known that he

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57 According to Breidbach he was the most prominent ‘Darwinist’ in Germany at the time (2010: 19)

58 Breidbach suggested that Haeckel, along with Goethe and other prominent Romantics, shared the belief in ‘truth’ to be found in nature. Haeckel devised a science-based religion and in 1899 published underlying philosophical ideas in Welträtschel—Enigmas of the World (Breidbach 2010: 16). Ball posits, ‘He was a archetypal German Romantic, who toyed with the idea of becoming a landscape painter, venerated Goethe, and was prone to a kind of Hegelian historical determinism that sat uncomfortably with Darwin's pragmatic rule of contingency’ (2006, online).
inaccurately, and popularly, promoted the idea that ‘ontogeny recapitulates phylogeny’ widely during his time (Ball 2006, online). It can therefore be said that Haeckel’s promotion of incorrect biological theories, consciously or otherwise, misinformed the public. *Kunstformen der Natur* nevertheless has remained an exemplary case of how science-to-art hybrid practices work through visually engaging images to effectively reach non-specialist audiences. As Eibl-Eibesfeldt has suggested, the inherent aesthetic in nature’s details engaged Haeckel, which he diligently portrayed and mass-produced to reach countless people (1989). These numerous images captivated audiences of his day and continue to captivate and inspire viewers, further validating the role that visually engaging artworks may have in increased understanding of organisms and their ecosystems.

**Section 2.4. The Value of All Nature: Developing an Environmental Ethic**

As with the scientists discussed above, one cannot fully describe the immensity of Charles Darwin’s contributions to Western science, philosophy, and popular perceptions of the natural world. In his last publication, *The Formation of Vegetable Mould through the Action of Worms with Observations on their Habits* (1881) Darwin set forth an important underlying ethic: that all organisms, no matter their scale, have value to ecosystems. As such Darwin inherently dismissed socially constructed hierarchies among living beings. Additionally he asserted that all living organisms struggle for existence in changing environments, including humans—and worms. According to biologist and popular science writer Richard Dawkins, Darwin’s ideas were deeply opposed to anthropogenic beliefs (Dawkins 1976). As Dawkins summarized, ‘Living organisms had existed on Earth, without ever knowing why, for over three thousand million years before the truth finally dawned on one of them. His name was Charles Darwin’ (Dawkins 1976: 3). Darwin, without doubt, built a philosophical framework that situated human beings among the enormous system of all other living beings through common biological origin. Similar to Humboldt, Darwin’s universality challenged the Judeo-Christian belief system of his day and represented a paradigm shift in popular perception of nature (Ballengée 2004). According to scientist and popular science writer, Steven Jay Gould, these paradigm-altering ideas ‘developed one of the most disturbing [ideas] to traditional views about the meaning of human life in Western History: Natural Selection’ (Gould 2000: 173). Darwin challenged both the dominant Western religious belief system and social norm of his day, as Gould states that Darwin's unparalleled revolutionary ideas positioned him as a ‘philosophical and scientific radical’ (Gould 2000: 181). For many transdisciplinary art and participatory science practitioners, Darwin's philosophy of biological equality and universality have continued to be relevant today.

Darwin was so dedicated to his philosophy of ecosystem inclusion that he spent more than forty years studying earthworms, their interactions, and their value to terrestrial environments. *The Formation of Vegetable Mould through the Action of Worms with Observations on their Habits*, according to Darwin scholar, Tim M. Berra, represented his ‘longest running’ set of observations in nature (Berra 2009: 79). Working with members of

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59 As described by Ball, ‘the so-called biogenetic law which argued that organisms retread evolutionary history as they develop from an egg’ (2006, online).
his family as a research team, he developed a method for measuring movement of substrate by earthworms, amassed influential knowledge on soil, earthworm-to-plant interactions, and evolutionary dependence, and presented one of the first studies in the field of ‘Quantitative Ecology’ (Berra 2009).

**The Formation of Vegetable Mould through the Action of Worms with Observations on their Habits** published Darwin’s long-term observations, contributing insights into the little-known habits of often unseen and certainly under-recognized creatures, earthworms. Gould (1983) suggested that Darwin developed two important scientific contributions about these annelids: First, earthworms shape the landscape considerably over time; second, they are of pivotal importance for the maintenance of healthy terrestrial ecosystems in temperate climates. Utilizing varied field observation techniques, Darwin demonstrated ‘that earthworms bring eighteen tons of finely ground soil per acre per year to the surface, thereby aerating and improving the soil’ (Berra 2009: 79). Darwin also made important observations on annelid behaviour and physiology, having run controlled experiments in flowerpots that demonstrated worms to be photophobic and deaf, but reactant to vibrations (Berra 2009). Such innovative experimental techniques are a source of inspiration for my own studies of complex ecosystem and organism interactions. Likewise they are a key reminder that simple yet ingenious experimental methods may be a successful way to understand ecological phenomena. Additionally, like Haeckel, Darwin, through his writing, gave presence to the unseen (small and microscopic) in complex ecosystems, a noble effort and truly one of the first ecological texts.

As Gould pointed out, Darwin contributed great knowledge to the science of soil ecology and even provided a visionary outlook for today’s organic gardening. According to agriculturist Howard Barry, Darwin’s ideas helped to establish ‘the truth that Nature is the supreme farmer and gardener, and that the study of her ways will provide us the one thing we need—sound and reliable direction’ (1945: 18). Barry suggests that in a field where chemical use has been equated to agricultural advancement, Darwin’s book is ‘the real foundation for the study of the principles underlying farming and gardening’ (Barry 1945: 9–12). The complete life of the soil is an essential focus of Darwin’s work; Gould stated that more than 100 pages are dedicated to the ‘ends of leaves’ to illustrate the terrestrial nutrient cycle (1983: 129). From the death of leaves comes food for worms, which in turn, gives rise to nutrients for future plant growth. Darwin states: ‘Worms prepare the ground in an excellent manner for the growth of fibrous-rooted plants and for seedlings of all kinds’ (Darwin, 1945: 146–147). To a degree this is reminiscent of the holistic ideas in Humboldt’s *Cosmos*, with the linking among species, land, and other organisms in a complex view of ecosystems. Darwin’s message and methods appear to continue to provide a contemporary contribution, as today many transdisciplinary art and science practitioners are working in the fields of ‘EcoVention’ gardening (Spaid 2002).

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60 Gould states, “Darwin made two major claims for worms. First in shaping the land, their efforts are directional. They triturate particles of rock into smaller fragments (in passing them through their gut while churning the soil), and they denude the land by loosening the disaggregating the soil as they churn it: gravity and erosive agents then move the soil more easily from high to low ground, thus leveling the landscape. The low, rolling character of topography in areas inhabited by worms is, in large part, a testimony to their slow but persistent work” (1983. p. 125).


62 Whereby, I attempt to study amphibians in context to their predators and parasites as one of many parts to complex food webs inside even more complex ecosystems.
Darwin was not an outspoken or perhaps even a conscious philosopher, although, according to Gould, he nonetheless posited a complex set of ideas through his outlooks and scientific practices (1983: 132). Darwin stated, ‘A subject may appear an insignificant one, but we shall see that it possesses some interest; and the maxum de minimis lex non curat [the law is not concerned with trifles] does not appear in science’ (Darwin 1881: preface). Darwin suggested that all creatures great and small struggle to exist under constant environmental pressures, as Dawkins later affirmed: ‘It may metaphorically be said that natural selection is daily and hourly scrutinising, throughout the world, every variation, even the slightest; rejecting that which is bad, preserving and adding up all that is good; silently and insensibly working, whenever and wherever opportunity offers’ (Dawkins 2006: 79). Hereby, under Darwin’s philosophy, humans and earthworms can be seen as universal equals in their struggle to exist in constantly changing nature; this offers a profound environmental message.

Several critics of Darwin have used his views on species equality to devalue evolutionary theory. Creationists such as Ken Ham have suggested that Darwin fundamentally removed the role of ‘the Creator’, thus devaluing all species (2005: 39). Interestingly, even though Darwin utilized a research method of scientific observation and fact finding based on material evidence, he studied theology and continued his belief in spirituality throughout his life (Boyd 2011). Through the accumulation of facts from a lifetime of painstaking, careful observations, Darwin presented concrete evidence to demonstrate the theory of natural selection and design by the natural environment. On this subject, Dawkins stated, ‘Thanks to Darwin, it is no longer true to say that nothing that we know looks designed unless it is designed. Evolution by natural selection produces an excellent simulacrum of design, mounting prodigious heights of complexity and elegance’ (2006: 79). In the case of his earthworms, Darwin was able to show that the small have a large significant value to the whole, stating ‘It may be doubted whether there are many other animals which have played so important a part in the in the history of the world as these lowly organized creatures’ (Darwin 1945: 148).

Charles Darwin changed the Western perception of nature. As a scientist he offered a profound environmental message about the unity of all living organisms. This knowledge challenged the dominant Judeo-Christian religious hierarchies of his day that placed man in a dominant position to non-human animals. His last major scientific work revealed that even small, seemingly unimportant species hold value and are key to the survival of larger environmental systems. Darwinian philosophy remains a rich source of inspiration and motivation for my own outlooks and those of numerous other art-science practitioners, to this day.

Influenced by Darwin and Alexander Von Humboldt, hybrid art-scientist Henry David Thoreau was an explorer and poet who also successfully changed popular perceptions of the natural world. Unlike Humboldt and Darwin, who travelled to distant, exotic lands, Thoreau stayed local. He journeyed to a small stretch of forest called Walden Pond, located a short distance from his family home. His travels led him toward what he referred to as ‘contact’, or direct experience mediated through observation of a local environment (Thoreau

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63 According to Gould, Darwin did not write “coherent” philosophical treatise nor provide meta-frame-works for scientific methodology like his contemporaries Thomas Henry Huxley and Charles Lyell (1983: 132).
1864, quoted in Sachs 2006: 32). He would spend two years at Walden Pond conducting scientific experiments, observing natural phenomena, and reflecting on nature and the ecological demise of the North American wilderness during the era of manifest destiny. From this ‘contact’ Thoreau derived a pertinent set of non-conformist values in regards to human placement within and about the natural world; these values were disseminated to the populace through his nature writings and public lectures.

Environmental scholar Daniel J. Philippon stated that Thoreau was ‘inspired by his encounters with the non-human world (nature as external), Thoreau celebrates nature as the true home of humans (nature as universal)’ (2004: 12). This ‘true’ home places human beings among a larger system of living beings, in ways similar to the outlooks of Humboldt and Charles Darwin. Fundamentally, Thoreau’s natural interactions were empirical, sensory-based engagements with natural environments and with animals, either through personal experience or through scientific experiments (Philippon 2004). These engagements resulted in the publication of Walden, or a Life in the Woods (1854) in which Thoreau expressed to larger audiences how nature was shaped and how we are sculpted because of nature. As Philippon (2004) implied, this message reflected a sense of ‘Darwinian struggle’ but used poetry to captivate the public (Philippon 2004). As with the case of Audubon’s artworks, Thoreau’s prose about the Walden landscape often consisted of scientific descriptions, as in his description of the Walden ‘scenery’: ‘The surrounding hills rise abruptly from the water to the height of forty to eighty feet, though on the southeast and east they attain to about one hundred and one hundred and fifty feet respectively, within a quarter and a third a mile’ (Thoreau 1980: 121). The pages of Walden are filled with such scientific accounts; here words are not utilized as poetry or metaphor but instead as a means to disseminate factual information about the Walden ecosystem. This, strategy is particularly important and may still be an effective way to reach contemporary audiences with scientific information on ecosystems. In my own practice, which utilizes direct experience through primary biological research in nature and with animals to create artworks conveying an ecological message, such a tactic has value.

Although Thoreau was not an academically trained student of science, he was an advocate of scientific, rational beliefs and a profound reader of former researchers, notably Humboldt (Sachs 2007). According to Sachs, Thoreau was a known subscriber to the scientific methods utilized in Cosmos, and his entire venture to Walden was a fundamentally ‘Humboldtian’ exploration (Sachs 2007: 94–99). As Sachs suggests, Thoreau found an intellectual ‘soul-mate’ in Humboldt, immersing himself while at Walden ‘in natural science and in nature itself, trying to live according to Humboldt's model of interdependence—identifying specimens, measuring depths, adapting to ever-changing conditions of soil, climate, [and] atmosphere’ (Sachs 2007: 97). Thoreau’s resulting writings revealed a keen understanding of ecological systems and how they function. He advanced fundamental

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64 Nature writing is described by literary critic John Tallmadge as ‘informal, inclusive, intensely local, experiential, eccentric, nativist, and utilitarian, yet in the end not only concerned with fact but with fundamental spiritual and aesthetic truths’ (1994: 119).

65 Thoreau utilized descriptive writing techniques that engaged readers, as discussed by Tallmadge (1994); see above.


67 Nash posited, ‘His journals are crammed with data about how organisms relate to each other and to their environment, and he followed the Linnaean tradition’ (1989: 37).
knowledge about succession rates of North American hardwood forests, made observations of bird behaviour, collected numerous plant and animal specimens for scientific institutions, and, based on his naturalist writings, could be accurately termed an ‘ecologist’, according to environmental theorist Roderick Frazier Nash (1989: 34–37, 166–167). Nash goes on to suggest that Thoreau was such an adept scholar of nature that he was one of the first Americans to perceive environmental degradation and ecological resource exhaustion by man.

It was not just Thoreau's science writing that made Walden a popular and lasting work but also his often-antagonistic philosophical ponderings, which asked readers, ‘What is a righteous way to live?’ (Tallmadge 1994). He critiqued industrialized American culture and its disconnect with nature. His action of leaving society for the woods is both a performative act of social rebellion and an attempt towards reunification with nature whereby he asked, ‘Shall I not have intelligence with the earth? Am I not partly leaves and vegetable mould myself?’ (Thoreau 1854: 121). This strategic combination of didactic information, existential questioning, and engaged writing make Walden a remarkably complex work of lasting popularity, surmised Perry Miller, in his afterword to the 1980 edition. Here Thoreau asks readers to question themselves and their society, even using second person point of view to directly address his audience (Miller 1980: 252). Miller also pointed out, ‘The prose is actually written in the rhythms of public speech. Thoreau is not musing, he is orating’ (Miller 1980: 252). Thoreau, it seemed, had an intention, when drafting Walden, to reach the public at large with his sensibility of ethics and raise understanding of natural phenomena.

Thoreau could be viewed as an ‘environmental abolitionist’ who was ahead of his time (Nash 1989: 211). He asked humans to find their essential wildness through experience with nature, and he expressed the belief that all living things, even the earthly substrate, was made of individuals, and as such had an inherent right to freedom and well being (Nash 1989). Thoreau, according to Nash, ‘expanded community consciousness … (he) began with the axiom “every creature is better alive than dead, men, and moose and pine trees” and went on to question the appropriateness of human domination’ (Nash 1989: 37). This natural community was made up of individuals, human and non-human alike, and all had value in Thoreau’s concept of unity. Much like Audubon's personified birds, Thoreau’s descriptions of animal such as “sunfish and skunks embraced them as 'neighbors' (Nash 1989: 130).

Thoreau's view of the neighbourhood was fundamentally holistic, inclusive of all beings and even the earth itself. As Nash suggested, ‘Thoreau's organicism or holism, reinforced by both science and religion, led him to refer to nature and its creatures as his society, transcending the usual human connotation of that term’, in which ‘There was no hierarchy nor any discrimination’ (Nash 1989: 37). Hereby, Thoreau developed a far-reaching moral system and created a profound early environmental ethic: individual humans, non-human organisms, and even the earth itself have an inherent value and deserve respect, an opinion fundamental to today’s environmental movement.

However, Thoreau’s ethics regarding nature were not entirely selfless or even perhaps for the benefit of the wilderness itself. Rather, Thoreau may have utilized nature as a resource

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68 It is important to note that Walden and other of Thoreau's published writing were utter failures in terms of sales and circulation in his lifetime. So, to be precise, Thoreau did not reach large numbers of readers until after his death (Miller 1980).

69 Thoreau was known to be opposed to slavery and often presented abolitionist statements. According to Nash, Thoreau ‘saw human slavery and the abuse of nature stemming from a common source: ethical myopia’ (Nash 1989: 211).
for both artistic and individual spiritual growth (Nash 1967). Like Haeckel and Audubon, Thoreau saw nature as ‘an inexhaustible fertilizer of the intellect’ (Nash 1967: 88). Without connection to the natural world, ideas and society lost vitality, or as Nash explained, ‘Thoreau believed that to the extent a culture, or an individual, lost contact with wildness it became weak and dull’ (Nash 1967: 88). That being said, Thoreau's interest in nature for the most part went beyond inspiration and sought the spiritual, located in the genre of American Transcendentalism: ‘the existence of a reality higher than the physical’ (Nash 1967: 84–85).

Influenced by their interpretations of Eastern philosophy, the transcendentalists defined man’s place in the universe as ‘between object and essence’ (Nash 1967: 85). Thoreau's search for ‘essence’ involved self-reflection while in the wilderness (Nash 1967: 86). As pointed out by environmental essayist Carolyn Merchant, ‘Thoreau found evidence of vital life permeating the rocks, ponds, and mountains in pagan and American Indian animism’ (Merchant: 100). To this end, Thoreau created his own form of nature-based spirituality. It could be argued that in this sense, Thoreau ‘used’ the environment for his own mystical development. Regardless, it was from this mystical experience that Thoreau asked readers to look inward and act outwards with respect toward nature: an approach that has had a long-lasting influence even on today’s popular perception of the natural world.

Differing from Thoreau, Aldo Leopold was an academically trained conservationist and forestry scientist. He also reached large audiences with an environmental ethic by means of his writing. Like Humboldt and Thoreau, in his writings he extended the concept of community and communal values to include humans, non-human animals, and the landscape itself. Of his environmental values, he simply stated, ‘The land ethic simply enlarges the boundaries of the community to include soils, waters, plants, and animals, or collectively: the land’ (Leopold 1949: 204). By considering other species and natural elements in his concept of ‘the land’, Leopold simultaneously de-centralized humans and placed them into a larger meta-system. Leopold, as a trained forester, would have understood better than Thoreau, in scientific terms, the biological continuity and connectivity all species share. Leopold’s theory, based on empirical evidence, expanded to unite abiotic materials and biotic organisms, a position that is now fundamental to ecology.

In contrast to Thoreau’s ethics on preservation, Aldo Leopold’s land ethic was a framework for a higher level of moral human behaviour toward the land; it underlined pragmatic approaches toward conservation of soils and the mechanisms of ecosystems. Leopold saw the complex interactions between species and their designated ecosystems, and how sensitive these systems often are to human alteration, a position I share with my work on amphibians. Leopold suggested that humans needed to develop an ecological conscience that would encourage us to allow the land to function naturally and toward self-renewal.

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70 As Leopold states: ‘Land, then, is not merely soil; it is a fountain of energy flowing through a circuit of soils, plants, and animals. Food chains are the living channels, which conduct energy upward; death and decay return in the soil. The circuit is not closed; some energy is dissipated in decay, some is added by absorption from the air, some is stored in the soils, peats, and long-lived forests; but it is a sustained circuit, like a slowly augmented revolving fund of life. There is always a net loss by downhill wash, but this is normally small and offset by the decay of rocks. It is deposited in the ocean and, in the course of geological time, raised to form new lands and new pyramids’ (Leopold 1949: 216).

71 “A land ethic, then, reflects the existence of an ecological conscience, and thus in turn reflects a conviction of individual responsibility for the health of the land. Health is the capacity of the land for self-renewal. Conservation is our effort to understand and preserve this capacity” (Leopold 1949: 221)

72 Please see Part II of this dissertation.
Leopold was aware that humans are part of a greater biological system and that with this awareness the populace could learn to conserve land out of love and respect (1949). According to Leopold, morality toward land alteration could come to fruition because actions are ‘right’ when they preserve ‘integrity, stability, and beauty of a biotic community’, and are ‘wrong’ when they prevent the land from self-renewal (1949: 224–225).

Much in the way Charles Darwin did, Leopold utilized empirical evidence to challenge the anthropocentric worldview by placing all members of the biological community in a larger ecological context. Diverging from Darwin, Leopold promoted the idea of land’s intrinsic value, yet did not clarify from where this construct of worth stemmed (beyond ecological terms). This issue is yet to be resolved and currently continues to be debated between two environmental philosophical camps. According to environmental philosopher Clare Palmer, the ‘subjectivists’ believe that intrinsic value is a human creation onto which they place their own lives and the lives of others (1997: 11). The ‘objectivists’ feel that intrinsic value is something that is built into the world and therefore it cannot be a human construct (Palmer 1997: 11). Although worthy of further deliberation, at a point in history when we know we are in the midst of a global biodiversity crisis, should we not focus efforts more towards ecosystem conservation, regardless of the origin of value? According to environmental ethicist Andrew Light (2006) such a level of abstraction in continued philosophic debates has caused environmental ethicists to largely move away from solving actual environmental problems.

Leopold’s proposed ethic positioned humans as active participants in ecological conservation. Under this paradigm we make educated choices about how best to allow the land to function ‘naturally’ (Leopold 1949). Paradoxically, however, such choices may have wide-ranging effects that may even surpass natural evolutionary or ecological phenomena. Mason has criticized the position of humans as stewards because it implies a ‘dominator’ model of control rooted in agrarian, patriarchal systems (Mason 1993: 127, 324). As Mason has suggested, such ‘care-taking’ led to environmental degradation in the first place.

Leopold’s active stewardship was also criticized by Nash (1989) as being culturally biased towards Western belief systems which, position humans as having dominion over the natural world. In defence of Leopold, however, it will take much educated insight and a consolidated active effort to solve the plethora of environmental issues we face at this point in history, according to numerous conservation biologists (Myers et al. 2000; Wilson 2002, 2012; Crowder 2005; Brooks et al. 2006; McCallum 2008).

Under Leopold’s idea of active stewardship, even austere (formerly damaged by humans) landscapes had value and with the proper scientific knowledge should be restored (1949). This position is very different from ideas presented in the writings of Thoreau. According to Leopold it was ethical to not just protect natural habitats but also ‘right’ to restore, to the best of our ability, those that have been degraded. However as ecologist Joy B. Zedler (1999) has pointed out, ecosystem restoration is beyond a simple moral assessment of ‘right’ or ‘wrong’, as environmental doctoring is ethically complex, involving social, economic, and often scientific concerns. Likewise, professor of law Mathew J. Parlow is concerned that the ability to restore ecosystems allows for polluters to more

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73 Leopold referred to such restoration efforts as ‘doctoring’ (1949: 221).
readily pollute them in the first place. This then sets the stage for restoration efforts by the same companies as an act of ‘green-washing’ (2008: 513). In addition, restoration can be scientifically controversial. For example, wetland mitigation seems to lack a thorough system of analysis to ascertain successes or failures, as pointed out by scientists Robert Coats and Phillip Williams (1988). As an amphibian researcher who has worked at environmental remediation sites, I am aware of the importance of this question, as often restored sites still have less biodiversity than sites never damaged in the first place.

Another concern with Leopold’s vision of nature is what appears to be the underlying belief that the ‘land mechanism’ eventually moves toward a greater natural ‘harmony’, suggesting that ecosystems gravitate towards balance (Leopold 1949). However, this is reminiscent of Haeckel’s evolutionary ‘progress’ and closely aligned with utopian views of wilderness, in contradiction to the current scientific understanding that ecosystems are rarely in balance. Such balances or ‘ecological homeostasis’ may actually be a very rare phenomenon, and numerous current scientific studies have demonstrated that ecosystems work in complex fluctuations, more like a pendulum than a pool settling (Yachi and Loreau 1999; McCann 2000). There are numerous changing factors to consider, such as species populations, availability of resources, and environmental disturbances (McCann 2000; Loreau et al. 2001). Some disturbance may actually be beneficial to some species, according to tropical ecologist Jim Kricher (2005). For example, tropical storms may down large trees, making resources available to non-arboreal species. In defence of Leopold, he was a trained forester and knew first-hand how ecosystems may change in abrupt ways. He even referred to plant succession as a ‘war’ (Leopold 1949: 27). So perhaps Leopold’s suggested ‘harmony’ reflects more the approach humans should adapt towards nature and not the actual ecosystems themselves. This opinion is reflected in other writings, where he stated, ‘Conservation is a state of harmony between men and land’ (Leopold 1993: 145).

The originality of Leopold’s ecological ideas has been a subject of criticism by several authors. Nash harshly critiqued Leopold, stating that he ‘nearly plagiarized’ Charles Darwin and only further popularized instead of founding the science of ecology (Nash 1989: 68). Likewise, botanist R. J. Goodland argued that ecology was most explicitly described earlier through the tropical studies of Johannes Eugenius Bülow Warming (Goodland 1975). Regardless, Leopold was able to reach vast numbers of readers through his nature writing, increasing popular understanding of ecological phenomena: something I hope my art and participatory science programs can do. According to the Leopold Foundation, A Sand County Almanac continues in popularity even today, with more than 1 million copies printed, and has also been translated into several languages (Aldo Leopold Foundation 2008). Notwithstanding criticisms, Leopold contributed seminal knowledge to the science of ecology and disseminated this information to a larger public.

Section 2.5. Conclusion

In this chapter I examined examples of historic practitioners who moved beyond the

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74 According to Duffy (2001), A Sand County Almanac and Rachel Carlson's Silent Spring are the two most influential books on environmental thinking in the United States.
disciplines of science to disseminate their understanding of natural history phenomena to a larger public through art. The analysis of these historic works found no evidence of a true fusion between art and science, but instead of transfer of knowledge from one field of examination (scientific study) to creative outputs that were accessible to larger audiences. Each of these historic artist/scientists successfully employed representational strategies or engaged writing techniques to deliver their scientific understanding—and often an underlying environmental philosophy—to the public. Firstly, Erasmus Darwin employed poetic styles with seductive metaphors to describe plant reproduction, which transgressed the Judeo-Christian concept of creationism and informed readers about biological phenomenon. To captivate audiences, John James Audubon theatrically portrayed birds, often giving them dramatic and individual presences in his works of art, which questioned the public view of animals and nature. These historic artistic approaches effectively reached large audiences and increased knowledge and awareness of natural history. Such poetic and dramatic representational strategies may still be very relevant tools for today and are therefore pertinent to the main questions of this thesis.

As representation may be an important strategy for popular engagement, so is the underlying philosophical message it may deliver. The writings of Alexander von Humboldt asked readers to open themselves up to observation and reflection with a unified view of the natural world, with the aim that this would shift their approach towards nature. Ernst Haeckel reached thousands of people through the mass production of lithographs of beautiful and complex organisms, implying a greater ecological connection and biological unity among all species. This suggests that scientific understanding and observation, when distilled into a popular, creative format, have the potential to drive philosophical approaches toward the environment. This is of paramount importance to some transdisciplinary practitioners such as myself, who utilize art to describe the experience of scientific research in an effort to raise public ecological awareness.

Yet a precise set of individual and social values may need to be established for understanding environmental change. Charles Darwin situated human beings among a system including all other living creatures, even focusing his last major work on small and seemingly unimportant organisms as valuable to the function and perhaps survival of larger global living systems. Thoreau and Leopold had strong conceptual ideas about the value of wilderness in post-pastoral America, and popular dissemination their ideas has had a lasting effect on the American perception of the landscape, as reported by art historian Simon Schama (1998). As early activists Thoreau and Leopold philosophically examined human approaches toward nature, laying the foundations for later schools of environmental thought including conservation biology, deep ecology, eco-feminism and environmental ethics. They may have even prepared the social terrain for today’s ‘citizen science’ movement (Orr 1999). Likewise the system of values posited by Charles Darwin, Thoreau, and Leopold are still relevant today, as politics and cultural difference remain problematic influences impeding environmental remediation.

All of these past scientists challenged popular Western perceptions of the natural world and questioned human relationships to nature, sharing these positions through their art. Such hybrid practices may still be an effective means to reach non-specialist audiences,
suggesting strategies that may be useful for contemporary transdisciplinary art and participatory science practitioners who aim at reaching the public with an environmental message. As a contemporary hybrid artist/scientist, I find inspiration in all of the historic examples discussed above, which laid foundations and perhaps established a context for today’s art inspired by biological phenomena and ecological systems. Likewise, the philosophies posited through these historic science-to-art to public practices may inform an underlying approach for contemporary participatory science programs. Although today’s environmental challenges are often daunting and complex, strategies that move beyond single disciplines, along with inherent degrees of environmental ethics, remain relevant in inspiring changes to levels of ecological awareness and understanding among the populace.
Chapter 3. Wetland Conservation and Art: Activating the Community

3.1. Introduction

As this overall research seeks to understand how transdisciplinary art and participatory biology may increase understanding of ecological phenomena for larger audiences, I found it important to examine examples of seminal ecological artworks by Hans Haacke, Patricia Johanson, and Joseph Beuys. These artworks blurred the boundaries between art and environmental activism by increasing public understanding of wetland ecosystems. These artists utilized diverse strategies that moved beyond single disciplines, verging on transdisciplinary practices. Hans Haacke creatively utilized the aesthetic of a public aquarium combined with those of a functioning wet-laboratory to create his work Rheinwasseraufbereitungsanlage, thus introducing the public to the science of water filtration while commenting on the environmental degradation of the Rhine River. Patricia Johanson’s large-scale wetland remediation art project Fair Park Lagoon offered an example of how artists may instigate the restoration of ecosystems and inspire communities with an environmental message. In his performative action Eine Aktion im Moor, Joseph Beuys publically immersed himself into a swamp, raising questions about wetland fragility while challenging popular perceptions of the value of these ecosystems. Surprisingly, these important works are seldom referenced in art history and are almost exclusively omitted from mainstream art theory and criticism. This chapter will discuss the relevance of these practices to art history within the context of art related to ecology as well as examine the means by which these artists disseminated an environmental message to large audiences.

Section 3.2. Rheinwasseraufbereitungsanlage/Rhine-Water Purification Plant (1972) by Hans Haacke

German artist and activist Hans Haacke responded to wetland degradation through the creation of his seminal ecological artwork, Rheinwasseraufbereitungsanlage, or Rhine-Water Purification Plant (1972). This work made three important contributions to cultural discourse surrounding wetland ecology: firstly, it raised public awareness of a localized environmental issue, the pollution of Rhine River water; secondly, as a site-specific installation created for a city museum, Haacke positioned the art institution within his concept of the “Consciousness Industry” to offer a larger critique of municipal funding; lastly, the work visualized a scientific technique for the treatment of degraded water. As with several of the historic transdisciplinary works discussed in chapter 1, Rhine-Water Purification Plant effectively raised public awareness of localized ecological phenomena. The work remains a source of inspiration to my own series of sculptural installations, Eco-Displacements (2003–present, please see appendix), which artistically interpret specific aquatic ecosystems while utilizing scientific methods to sustain organisms within artificial ecosystems.

Rhine-Water Purification Plant increased public awareness of local water pollution in Krefeld, Germany, while positing an environmental message. This was done by two primary
means: firstly, the display, which was composed of unusual materials,75 showed actual water contaminated by a local polluter, the Krefeld Sewage Treatment Plant, made clean through complex filtration; secondly, through an accompanying two-dimensional triptych,76 Haacke presented actual localized environmental data with photography. Collectively, the works77 formed a systemic installation by which polluted Rhine water was purified in front of the viewer before reintroduction into the environment, while didactically demonstrating the underlying source of the degradation. Art historian Barbara Matilsky explained, ‘Contaminated water was pumped into a container where it was filtered … before entering a large rectangular basin housing goldfish … the work itself was conceived by Haacke as a closed ecological system—water was re-circulated and not a drop was wasted’ (Matilsky 1992: 41–42). Haacke told the complex story of specific wetland degradation and concluded with how it can become rehabilitated enough to again sustain aquatic life.

Haacke’s message and ecological intervention78 can be compared to Aldo Leopold’s philosophical treatise favouring direct actions in environmental management toward restoring ecosystems. Like Leopold, Haacke examined natural processes inherent to natural environments and living organisms through a systemic, though not a necessarily scientific approach.79 Diverging from his earlier works, such as Condensation Cubes (1962), which created a natural water cycle80 under artificial conditions, Rhine-Water Purification Plant went further to remediate water through a systemic process. As artist and theorist Jack Burnham affirms, Haacke’s systemic interests, such as those ‘of cyclical processes which manifest evidences of natural feedback and equilibrium’, posit a ‘keenly sensual attitude toward the most ephemeral phenomena’ (1975: 315). Haacke’s underlying artistic philosophy with Rhine-Water Purification Plant and other works can be further comprehended through remarks made in 1965 in his Untitled Statement: ‘… make something, which experiences, reacts to its environment, changes, is nonstable … make something, which cannot “perform” without the assistance of its environment … make something, which lives in time and make the “spectator” experience time … articulate something natural …’.81 Burnham goes on to remark of Haacke’s ideas of natural systems as almost ‘an environmental systems philosophy’.

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75 According to art historian Barbara Matilsky (1992) these materials included: large bottles of degraded, visually repulsive Rhine River water collected from a nearby sewage plant; a large water filtration unit; a large aquarium (placed on the ground instead of the normal household practice of placing aquariums on a stand); living fish; and vinyl hosing that drained water from the Museum into a back garden. Matilsky suggests that the work ‘established a new direction in art, inspiring artists to bring rocks, plants, and water into museums and galleries’ (Matilsky 1992: 41–42).

76 Haacke describes Krefeld Sewage Triptych (1972): ‘This documentation records the level of untreated sewage the city of Krefeld spews into the Rhine annually (42 million cubic meters). The left panel lists data on volume, rate of pollution (official code), breakdown into industrial and household sewage, and fees charged per volume. The right panel lists data on volume, rate of pollution, and breakdown by volume and name of major contributors of Krefeld sewage. The center panel is a photograph taken January 21, 1972, at Krefeld-Uerdingen (Rhine kilometer mark 765.7), where the city discharges its sewage’ (Haacke 1986: 106). According to Haacke, the environmental information presented in Krefeld Sewage Triptych was obtained from ‘official data about the rate and the sources of the Rhine’s pollution within the borders of the State of North Rhine-Westphalia’, which ‘were obtained from the State agency in charge of monitoring them’ (Haacke 2011).

77 According to Haacke, ‘Aside from several pre-existent works, I developed several site-specific new works for the show, most of them relating to the pollution of the Rhine—Krefeld is located on the Rhine—and to the wastewater disposal by the City of Krefeld’ (Haacke 2011).

78 Intervention in the sense that actual polluted Rhine water was filtered and returned to the actual environment (Spaid 2002: 30–31).

79 In his 1967 statement on art and technology Haacke stated, ‘The employment of engineering technology does not establish scientific art. The artist’s application of scientific knowledge is naturally not scientific in itself because it does not intend contributing to the body of knowledge’ (Haacke 1967, quoted in Munoz, Cotter, and Douglas 1999).

80 Condensation Cubes consisted of large, sealed glass enclosures containing air and water. Water evaporated to form condensation, which then dripped back down, creating a cycle.

Again, one can relate this to Leopold’s ideas of complex, changing natural ecological systems.

*Rhine-Water Purification Plant* combined characteristics of Haacke’s earlier kinetic art strategies, which involved changes to water under artificial conditions, with those that involved living organisms such as ants (*Ant-Coop*, 1969) and chicks (*Chickens Hatching*, 1969) under similar artist-controlled environments; the artist introduced living processes to bring ‘Real-Time-Systems’ into art (Ballengée 2004: 305). Hereby, Haacke simultaneously challenged historic notions of the timelessness of visual art by creating something temporary and affirmed the ephemeral, even uncontrollable, process of living art. From my earlier research into Haacke’s “Real-Time” systemic works, he ‘experimented with transforming the gallery or museum spaces with living creatures’, which invited viewers to witness natural processes of life under artificial conditions, including avian birth (Ballengée 2004: 305). Art historian Walter Grasskamp characterizes Haacke’s use of living organisms thus in his earlier ‘Real-Time Systems … concentrated not on the living things themselves, but on the growth process’ (2004: 41). The goldfish in *Rhine-Water Purification Plant* represented a departure from this early focus on growth, instead positioning the living fish as proof of actual water-filtration; the animals lived, which demonstrated that the water had been cleaned.

In *Rhine-Water Purification Plant*, Haacke’s interest in systems moved beyond the natural Rhine River ecosystem itself to include the local civic community. He has described himself and members of the arts community, particularly museums, as part of a growing ‘consciousness industry’ (Haacke 1986:60–72). Haacke suggests that over time, the ‘artworld’ had become increasingly privatized and sensitive to (and largely governed by) economic incentive. These incentives have influenced artists’ ideas and even prohibited art centres from displaying some transgressive works of art. Museum censorship of some forms of ‘consciousness’ became an increased concern for Haacke over time (Haacke 1986: 60–62). In response Haacke increasingly began using art within cultural institutes to critique or at least question institutional funding. For example, *Rhine-Water Purification Plant* was exhibited at Museum Haus Lange, a municipal institution in Krefeld, Germany. Funding for the museum and his project came from the city, which also funded the local polluter of the Rhine River (Haacke 2011). Haacke stated, ‘At the time of the exhibition, the city of Krefeld annually discharged over forty-two million cubic meters of untreated household and industrial sewage into the Rhine’ (1986: 106). The work was created specifically for Museum Haus Lange and the local community of viewers to increase ‘consciousness’ of Rhine River degradation and implicated the local human system that created it. Secondly, museum members and other civic servants collaborated to create the sculpture, additionally delivering a transgressive message. *Rhine-Water Purification Plant*, viewed under this paradigm, was dually an act of

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82 Which, according to Grasskamp, included seagulls, chicks, ants, turtles, and a variety of plants (2004: 41–43).

83 Inspired in at least in part by social theories of German writer Hans Magnus Enzensberger, Haacke used the term ‘industry’ because it ‘cuts through the romantic clouds that envelop the often misleading and mythical notions widely held about the production, distribution, and consumption of art’ (1986: 61).

84 As with the cancellation of Haacke’s solo exhibition at the Guggenheim Museum, which intended to show the economic ties between Museum board members and questionable corporate activity.

85 Haacke stated that several members of the Museum staff helped to develop the work, including technical aspects of the water-filtration: ‘An engineer of the municipal water and wastewater disposal department, whom I had contacted, provided valuable information and other help, without which I would not have been able to develop these works’ (Haacke 2011).
cultural mutiny and environmental activism, attuned with the local focused problem-solving Mode 2 transdisciplinary model suggested by Gibbons et al. (1994).

The local public ‘consciousness’ Haacke raised with his installation was about specific regional degradation and the civic ‘system’ that led to the pollution in the first place; *Rhine-Water Purification Plant* was a direct ‘political and ecological statement’, according to Matilsky (1992: 42). Grasskamp further affirmed Matilsky’s opinion, stating that Haacke’s works were among ‘the first artworks of the twentieth century to articulate an awareness of the environment that goes beyond the merely aesthetic’ and were representative of the artist’s growing concern for ecological and social issues (2004: 43, 53). Grasskamp further discussed the political ramifications of *Rhine-Water Purification Plant*: ‘The work drew attention to environmental pollution in the Rhineland, where the region’s dominant river, once praised and painted by the Romantics, had long since become a stinking chemical sewer for the industries on its banks’ (2004: 53). According to Haacke, the installation was so successful at generating environmental consciousness that ‘In response to the exhibition, a regional newspaper reported extensively on the city’s part in the pollution of the river’ (1986: 106). This media attention then generated public discourse about the Rhine and, according to Haacke, ‘may have contributed to building a political consensus to support sustained efforts in curbing pollution’ (Haacke 2011). Following *Rhine-Water Purification Plant*, Haacke has remained a ‘political artist’ in the view of the art world (Grasskamp 2004: 53). As with the eco-political writings David Henry Thoreau discussed previously, Haacke increased the ecological consciousness of museum visitors while challenging the collective social practices which led to the degradation in the first place.

From a visual standpoint, *Rhine-Water Purification Plant* invoked the sense of a public aquarium, whereby people could intimately view fish. As Ginger Strand stated, such aquariums ‘like adultery, draw us into a shadowy underworld of unspoken sensual pleasure, an engrossing, exotic environment’ (Strand 2005: 25). Responding to John Berger’s seminal essay, ‘Why Look at Animals?’ Strand surmised that the exotic quality of aquatic creatures engages our sense of curiosity, and the intimacy of being only a few millimetres of glass away from them creates a connection; the ‘experience is coded as an exchange of sympathies between two beings’ (2005: 29). The intention of inducing sympathy and ‘awe’ for the unfamiliar aquatic world, along with imbedding social messages, is common practice among today’s increasingly successful commercial aquarium industry (Strand 2005: 23–36). From this vantage point, Haacke’s goldfish became central protagonists by which viewers could find a tangible reason to clean the water. Haacke, intentionally or not, set up a complex psychological experience and moral message for viewers by using the living fish he ‘saved’.

Although a seminal ecological artwork, *Rhine-Water Purification Plant* raised a number of bio-ethical and environmental concerns. The use of non-native, domestic goldfish (*Carassius auratus*) to represent aquatic fauna of the Rhine sent a mixed ecological message. Goldfish, native to eastern Asia, are a known invasive species and have been widely introduced from the domesticated pet trade to freshwater ecosystems globally (Hubbs and Lagler 1974: 77). Introduced goldfish have been known to compete with native fishes, to be vectors for disease (carrying domestic illnesses to wild stocks), to alter water visibility (by “mudding” water) and are even known to increase water pollution by feeding on aquatic
plants that impede eutrophication. By using this particular species, Haacke may have inadvertently sent a message of acceptance for such goldfish introductions. Haacke said of the choice in fish, ‘It was relatively easy to get goldfish since they customarily are the choice of fish to stock ponds in people’s backyards’ (Haacke 2011). The upside might have been that people who viewed *Rhine-Water Purification Plant* certainly would have been familiar with this species and more inclined to want to ‘save’ them. Additionally, Haacke has said that by using fish people kept in their pools, the work ‘also associated [the fish] non-polluted waters’ (Haacke 2011). From this vantage point, the artistic gesture reinforced the overall environmental message of concern for the Rhine River ecosystem. Nevertheless, it was not without fault in its execution.

In his earlier poetic gesture, *Ten Turtles Set Free* (1970), Haacke released animals from the pet trade into the natural environment, thereby potentially endangering wild populations of native turtles and other wildlife. Pet store species are known vectors for various diseases when released into the wild. Furthermore, the animals referred to as ‘turtles’ were actually tortoises, most likely native to northern Africa of the genus *Geochelene* (Iverson 1986), which Haacke released in the St. Paul de Venice region in southern France. Matilsky described the action as ‘a metaphorical work, a symbolic gesture, that called into question human interference with the freedom of animals and their imprisoned status as pets’ (1992: 52). In actuality this gesture, in ecological terms, could be considered harmful to the local wildlife and potentially fatal to the tortoises themselves, which most likely did not survive the temperate climate of southern France. Matilsky concluded, ‘By liberating the turtles [sic], the artist engaged in a ritual of respect that acknowledged their value and addressed a fundamental principle of environmental ethics—that all life has a right to exist for its own sake’ (Matilsky 1992: 53). Herein lies an enormous conflict between ‘good’ artistic intentions, with an implied sense of environmental ethics, and ecological realities based on scientific knowledge of biological phenomena. This issue is very relevant today, as increasing numbers of artists have been working directly with living entities and in ecosystems. An ethical framework for such actions has yet to be standardly applied or even established. This must be considered and is urgently needed, as artists with virtuous intentions but without enough scientific understanding may do more harm than good to individual organisms and ecosystems.

Section 3.3. Leonhardt Lagoon (1981–1986) by Patricia Johanson

Patricia Johanson, like Haacke, responded artistically to the issue of wetland degradation in urban environments. As a visual artist and architect, her monumental work *Leonhardt Lagoon* (originally titled *Fair Park Lagoon*) was created as a large scale, public wetland remediation project for the city of Dallas, Texas. Working with a pre-existing, degraded body of water, Johanson’s work achieved actual environmental restoration as a form of public urban art.86 With this project, an opportunity for transdisciplinary collaboration among scientists, artists, and the public occurred, reminiscent of the philosophies of

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86 Johanson stated about the work, ‘The renovation of the Fair Park Lagoon should be seen not simply as another project that provides “cultural uplift”, but rather as an attempt to create a new kind of environment where man and nature are interwoven’ (1982:1).
Mittelstraß. As a site-specific remediated urban ecosystem, *Leonhardt Lagoon* became a functional, communal space for both humans and non-human animals.\(^{97}\) As with several of the historic works discussed previously, *Leonhardt Lagoon* raised awareness of ecological phenomena and challenged popular perceptions of biological communities.

Johanson, like Haacke, was among the first wave of Land artists\(^{88}\) to consciously involve natural processes into her artwork. Originally a large-scale minimalist painter, Johanson became ‘dissatisfied with making art for museums and galleries’, according to art historian Caffyn Kelley (2006: 3). Moving into the landscape, Johanson’s first large outdoor sculptural installation, *William Rush* (1966), was a 200-foot long steel horizontal line, painted red, which visually changed in the environment as varied amounts of daylight and forest debris impacted its surface, ‘continually reflecting changes going on around it’, according to Johanson (quoted in Kelley 2006: 50).\(^{89}\) According to Kelley, ‘Johanson was thrilled by the interaction of nature with the sculpture’ and the idea that works could change and become part of a larger environmental system\(^{90}\) (2006: 49). Navigating an artistic terrain mostly occupied by male contemporaries,\(^{91}\) Johanson’s attention to small animals was refreshing, compared to the normal destructive environmental processes associated with much of Land Art.\(^{92}\) Also, Johanson moved against the concept of permanent, ‘timeless’ art she had been taught,\(^{93}\) beginning to design works that incorporated environmental interactions and natural transformation into her working process. This is similar to Haacke’s interests in ‘Real-Time Systems’, as both artists developed keen interests in natural processes and the idea that works of art could change,\(^{94}\) like living organisms. These interests led Johanson to the concept of large-scale, ecological remediation and environmental design works.

Natural processes and cyclical change became fundamental to Johanson’s ideas of working in the natural environment. Following her large outdoor minimalist sculptures, Johanson went on to create over 150 drawn designs and writings for environmental works that integrated her ecological concerns with the aesthetic of an artist.\(^{95}\) Through some of these

\(^{87}\) Johanson stated, ‘All of my projects are site-specific, so each location is the key to my design. Even though I work with living beings, my aim is that their descendants will continue on into the future within that specific place’ (Johanson 2011).

\(^{88}\) ‘Land Art . . . encompasses any work that activates the land, however temporary’ (Spaid 2002: 10). Art historian Gilles A Tiberghien states, ‘The term “Land Art” also has the advantage of being broad enough to include very diverse works . . . it is clear that all the artists affiliated, to some extent, with Land Art prefer to utilize the element earth, even if some of them choose other media—air, water, fire’ (quoted in Tiberghien 1995: 13).

\(^{90}\) Johanson recalled: ‘Immediately debris from the trees fell on the sculpture in different patterns. You would find a grasshopper, a frog, or a snake sitting there’ (quoted in Kelley 2006: 49).

\(^{92}\) According to Kelley, Johanson ‘began to explore the possibility of creating a living art that would grow and change in time, shaped and enhanced by the natural world, instead of art that had to be protected and maintained in an ideal state’ (2006: 49).

\(^{93}\) Art historian Suzann Boettger stated, “The earliest contemporary Earthworks environments were not only produced by artists who were male, but also the sorts of physical activities performed to create them, and often in wilderness terrains, required aggression, strength, and stamina—characteristics of a traditional male type of overt power that was termed *macho*” (2002: 148).

\(^{94}\) One only need to think of land artists like Robert Smithson and his work *Spiral Jetty* (1970), which heavily altered an aquatic ecosystem.

\(^{95}\) Johanson stated, ‘When I was first studying art, people used to say “If it can be changed in any way, then it is not art”. There is an idea of art as a series of perfect, ideal objects’ (Kelley 2006: 51).

\(^{96}\) Exploring perceptual change of an otherwise static art object, Johanson created *Stephen Long* (1968), a 1,600-feet long horizontal steel work painted three colors (red, yellow, and blue), which visually changed in response to different outdoor light. Johnson stated in 1973 of this work that it ‘was more of a color experiment . . . the painted colors were constantly in flux due to changes in the color of natural light’ (Kelley 2006: 50).

\(^{97}\) These works began in 1969 when *House and Garden* commissioned the artist to create a garden design. Diverging widely from traditional gardens and fountains, none of her designs were implemented at that point. Although unrealized, the ideas were fundamental to her later works and included, according to Spaid, ‘plans for water gardens (made from flood basins, dams, reservoirs, and drainage systems), ecology gardens, ocean-water gardens, dew ponds, municipal water-garden lakes, and even highway gardens’ (2002: 65).
designs, Johanson sought to make ‘environmental problems visible’, and even proposed to add harmless dyes to aquatic pollutants so people could know what had spilled into their drinking water, according to Kelley (2006: 25). Also included in these sketches were interventionist plans ‘that envisioned the transformation of degraded environments’ (Matilsky 1992: 60). Hereby Johanson diverged from most other land artists by showing interest in austere landscapes and their remediation, and even suggested they could be made ecologically functional again over time, through art. Matilsky stated, ‘Johanson was one of the first artists to think of art as a means to restore habitats’ (1992: 60). Remediation of wetlands as a form of artistic practice expanded upon Haacke’s symbolic Rhine-Water Purification Plant by moving into actual large-scale ecosystems. These visionary designs (though purely conceptual) sought to implement numerous future ecological art interventions.

Her visionary designs for environmental remediation were first realized over a decade later with Leonhardt Lagoon. At the request of an art institution, over a six-year period Johanson implemented a large-scale wetland restoration artwork that offered a solution to a pre-existing degraded lagoon. The project functioned on multiple levels, reminiscent of the fundamental characteristics of Gibbons et al. (1994) Mode 2 Transdisciplinarity: firstly, in ecological terms as an actual restoration of a large urban wetland and reintroduction of native species; secondly, as a trans-species communal space that offered habitat for wildlife while simultaneously it creating areas for the urban public to immerse themselves in a natural environment; thirdly, as a community oriented collaborative art and science project, people with diverse backgrounds participated in the environmental restoration process; and lastly, as a pragmatic urban infrastructure solution to flooding and erosion in a city parkland. In its entirety Leonhardt Lagoon sought to improve the ecological functioning of a wetland while raising public understanding of such ecosystems and the organisms that inhabit them.

Recalling Leopold’s vision of the complex system of land with its interconnected inhabitants, Johanson has said Leonhardt Lagoon was ‘a fusion of aesthetic form, functional infrastructure, and living ecology, where every element is part of a larger system whose parts are intricately related’ (quoted in Kelly 2006: 27). The work focused attention on an urban wetland and its wildlife inhabitants within the larger eco-social system of a city, an area not normally addressed in conservation at the time. According to art curator Amy Lipton, Leonhardt Lagoon ‘was practical and aesthetic; she wanted to remediate and reshape a functioning though out-of-balance aquatic community using ecological and sculptural ideas’ (Ballengée and Lipton 2005: 95). These ecological concepts included the utilization of aquatic plant species to filter water, which in turn helped to remediate against excessive······

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96 Among Land artists, Robert Smithson is probably the most recognized for his attention to and use of austere landscapes. In addition he was critical of environmental remediation attempts by artists of his day, believing that such works ‘cosmetically camouflage the abuse’ (2002: 53–54).
97 Kelley stated, ‘Johanson notes that confronting environmental issues means seeing past the conventional cultural of nature. “I want to confront people with the world as it exists” … This means accepting the full scope of environmental problems’ (2006: 25).
98 According to Matilsky, Leonhardt Lagoon (first titled Fair Park Lagoon) ‘was commissioned in 1981 by Harry Parker, then director of the Dallas Museum of Art, to commemorate the sesquicentennial of the state of Texas’ (Matilsky 1992: 60).
99 Matilsky stated, ‘inviting Johanson to propose a solution to the declining condition of the lagoon … This work sets an important precedent for an art institution playing an activist role in environmental remediation and community education and is a model for other communities to emulate’ (Matilsky 1992: 60).
100 From the author and Lipton’s prior research, wildlife and even habitats in urban landscapes have ‘traditionally been dismissed and often exterminated’, yet ‘non-human life is present and needs to be addressed’ (Ballengée and Lipton 2005: 92).
eutrophication.\textsuperscript{101} Spaid stated that native emergent plants were used ‘to reduce turbidity (clear up the water) and stabilize the shoreline … at selected points around the lagoon to act as a mat on top of the silt and to provide a buffer between water and shore’ (2002: 67). Through careful, scientifically informed planning (and planting), which included creating functioning inner and outer shorelines, Johanson’s remediation with plants brought life back to a derelict wetland.\textsuperscript{102} Additionally, the vegetation created essential littoral habitat for larger wildlife such as fish, amphibians, reptiles, and birds, which in turn helped to return the lagoon to a functional, complex food web.\textsuperscript{103} These actions invoked the philosophy of Darwin in relation to Johanson’s vision, where all things living are interconnected.

As a trans-species communal space, \textit{Leonhardt Lagoon} offered a wildlife habitat while simultaneously creating an area for public immersion in a natural environment. According to Kelley, ‘Johanson designed huge forms based on native plants’ which helped the aquatic system function in ecological terms but also aesthetically appealed to the public (2006: 20–25). Inspired by the Texas Fern (\textit{Pteris multifida}) and the Delta Duck-Potato (\textit{Saggitaria platyphylla}), Johanson created enormous, organically shaped sculptures from a porous form of concrete called gunite, which interweaved the wetland to create direct public access to water and important wildlife habitats (Kelley 2006: 20–25). The artist has said, ‘The sculptural forms control bank erosion, serve as paths and bridges over water, and create microhabitats for a wide variety of plants, fish, turtles, and birds … offer[ing] a functional and aesthetic framework in which ecological communities can evolve, life in all its messy complication can proliferate, and creation continues’ (quoted in Kelley 2006: 25). As compelling forms based on nature,\textsuperscript{104} the interactive sculpture encouraged exploration of the wetland and, as Johanson has stated it, ‘affords people access to this environment, so they can find out how wonderful a swamp really is’ (quoted in Kelley 2006: 25). Just as Haeckel brought the microcosmically unfamiliar to the public, Johanson’s enlarged ‘plants’ engaged visitors while pragmatically offering important areas for physical engagement with a wetland.\textsuperscript{105} In this way and others, \textit{Leonhardt Lagoon} effectively contributed to wetland ecology and raised public environmental awareness.

\textit{Leonhardt Lagoon} is an example of a large-scale, transdisciplinary art project where people with diverse backgrounds collaborated with the artist to experience a restored

\textsuperscript{101} According to the author and Lipton, ‘Her plan helped to eliminate the over-population of algae through planting native vegetation at selected places to serve as a buffer between water and shore, and she provided several aquatic species to help restore the ecosystem’ (Ballengée and Lipton 2005: 95).

\textsuperscript{102} Spaid stated of the prior condition of the wetland, ‘The lagoon had died because its food web was out of balance. Aquatic insects, snails, some crustaceans, and other middle food-web species were not present, largely due to the absence of a littoral zone, which is composed of vegetation and supports 75% of a pond’s life’ (2002: 66).

\textsuperscript{103} Kelley stated that Johanson ‘researched food and habitat requirements for different animals, realizing that specific plants would attract wildlife … The lagoon was planted with emergent vegetation that roots in shallow water, and further out with floating plants. Along the shore, Johanson planted tall grasses to provide shelter and food for small animals and birds’ (Kelley 2006: 20).

\textsuperscript{104} Reminiscent of Haeckel’s inspiration in natural forms, Johanson stated of the sculptures, ‘I chose two native Texas plants as models … the Delta Duck-Potato (\textit{Saggitaria platyphylla}) had a mass of twisted roots … built as five-foot wide paths that people could walk on, while thinner stems rose out of the water and became perches for birds. Leaves further out in the lagoon became islands where animals could rest. Other leaves along the shore became step-seating and overlooks. The second sculpture … was based on a Texas fern (\textit{Pteris multifida}). The fern functions as a bridge—not a direct pathway over the water, but a network of crossovers, islands, and stopping points. Individual leaflets are twisted to create the kinds of spaces I wanted’ (http://patriciajohanson.com/fairpark [September 2011]).

\textsuperscript{105} Kelley stated, ‘Once visitors are lured out over the water by twisting paths, the sculpture disappears as the focus shifts to a dragonfly, a fairy shrimp, a spawning fish, or a water-lily. The lagoon is a living landscape that is always changing. It contains all the myriad of details that allow such landscapes to evolve and survive … Fair Park Lagoon is a nurturing, living world; it is also a popular and entertaining place. Children play alongside the insects, reptiles, birds, and mammals that live there’ (Kelley 2006: 25).
wetland. As Haacke collaborated with members of the Krefeld municipality to create the Rhine-Water Purification Plant, Johanson worked with local scientists, educators, engineers, city-planners, parks department staff, and others (Kelley 2006). Matilsky stated, ‘before preparing her remediation plans, Johanson researched the natural history of the area … in collaboration with Walter R. Davis II and Dr. Richard F. Fullington of the Dallas Museum of Natural History, the artist selected and introduced native plants, fish, and reptiles’ (Matilsky 1992: 60). Together the team revitalized the wetland food chain with localized species to become a living outdoor science exhibition. Having developed knowledge of the science of ecosystems, Johanson generated a further list of suggested bio-remedial actions with the local Parks Department. These included a full list of native species to be introduced, actions for the removal of non-native invasive species, and policies to limit nutrient pollutants running into the lagoon (Spaid 2002). Together the team implemented these actions, which helped the lagoon function more naturally, and even saved money on shoreline maintenance (Spaid 2002). Upon completion, Leonhardt Lagoon was a successful restoration project and functioning transdisciplinary collaboration, as Walter Davis II states: ‘Today the lagoon teems with life. Those that understand the intricacies of a functioning ecosystem find particular satisfaction here’ (quoted in Kelley 2006: 23). Although both Haacke and Johanson successfully collaborated with scientists and municipal workers for their creations, Johanson’s attention to native aquatic species is an important distinction; in the author’s opinion, it delivered to the public a much more accurate view of natural wetlands.

Johanson’s Leonhardt Lagoon offered a pragmatic solution to the problem of flooding and erosion in a city park. According to Matilsky, the lagoon, over five city blocks wide, was initially constructed in the early half of the twentieth century to alleviate flooding. Since this time, the wetland had steadily declined to become a ‘solid mat of algae, suffocating other forms of life’ (Matilsky 1992: 60). Through her large plant sculptures, along with the planting of real aquatic vegetation, the project controlled erosion and stabilized water levels to serve as a functioning flood basin (Matilsky 1992). Johanson stated, ‘The entire five-block-long lagoon … serves a municipal flood basin, thus familiar forms and paths of travel are frequently altered by fluctuating water levels’ (quoted in Kelley 2006: 25). Additionally,

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106 Johanson stated, ‘I have always learned about things by experiencing them, and that is the only strategy I use. When people have an opportunity to experience wetlands plants and animals, as they do on the paths at Fair Park Lagoon, they usually form a powerful bond with nature and become advocates for wetlands on their own’ (Johanson 2011).

107 Walter R. Davis II, Associate Director of the Dallas Museum of Natural History described in detail the collaboration: ‘The weeks following your arrival were exciting to the scientific staff of the museum. There were lengthy discussions of the water quality of the lagoon and the missing links in its deteriorating food chain. The environmental needs of turtles fish, birds, and a host of native plants were outlined. Years of field-work in Texas now paid off, as lists were compiled of the localities where native aquatic plants could be collected and transplanted into the refurbished lagoon’ (http://patriciajohanson.com/fairpark (September 2011)).


109 Kelley surmised that the artist came to better understand environmental processes and evolution through a self-driven study of botany, biology, and ecology over the course of her career (2006: 108).

110 Spaid stated, ‘She recommended they trap the problematic Asian Ducks and remove them to another location, and stop fertilizing strips of grass around the lagoon … Johanson even provided the park a complete list of recommended species for the restored ecosystem including: 1) fifteen bank and emergent plant species, 2) four kinds of floating plants, 3) three different submerged plants, 4) eleven fish species, 5) five types of turtles, and 6) several kinds of ducks. To reduce the number of sunfish, she suggested officials encourage fishing with the stipulation that the fisherman not throw the fish back’(Spaid 2002: 67).

111 The flora and fauna were chosen with the idea of developing a food chain, reducing turbidity, and minimizing park maintenance. They were all local species that would colonize the lagoon once food was available, or arrive on transplanted vegetation or the feet of birds, with the exception of a few fish that were ceremoniously dumped into the water at the dedication’ (Johanson 2011).
Johanson, like Haacke, challenged the concept of ‘timeless’ art. She also rebelled against the idea that art would ‘serve’ when offering a utilitarian function in civic or ecological terms. Kelley referred to Johanson’s integrated working process as ‘large-scale public projects that realize her radical, yet utterly practical vision … with engineers, city planners, scientists, and citizens’ groups to build her art as functioning infrastructure for modern cities’ (2006: 3). Such cooperative solutions, moving beyond single disciplines, are consonant with the underlying philosophy of transdisciplinary practices of Mittelstraß and others. Under Johanson’s approach, urban sites, reclaimed and otherwise, can be designed to function both in ecological and social terms while simultaneously being works of art. As Kelley stated, they offer ‘a new vision for public land, where … functional landscapes are designed as both art and habitat’ (2006: 39). Leonhardt Lagoon functioned pragmatically to manage water and also functioned socio-ecologically as it raised public awareness of ecological phenomena. As such, it is a model example of transdisciplinary art and ecology.

**Section 3.4. Eine Aktion im Moor/Bog Action, (1971) by Joseph Beuys**

Like Haacke and Johansson, German artist, activist, and teacher Joseph Beuys expressed his concern for wetlands through art. With his 1971 performance Eine Aktion im Moor (Bog Action), the artist conducted an important (though seldom referenced) action to raise public awareness of loss of wetland habitats. Eine Aktion im Moor contributed three significant ideas relevant to today’s transdisciplinary art with ecology: firstly, that a complex natural aquatic ecosystem itself (in its entirety) can be a material for sculpting; secondly, that such places may be utilized for ritual and contain metaphysical value among shamanic or holistic belief systems; Lastly, that such actions are forms of environmental protest falling within the canon of more radical forms of ecological activism. Each of these principles will be discussed below. Additionally, Eine Aktion im Moor has been a source of inspiration for my own series of participatory biology Eco-Actions (1999–present, discussed later), which attempt to connect local communities with specific ecosystems.

To better understand how Beuys could conceptually transform a natural bog into an environmental sculpture we must first examine the artist’s ideas of sculpture and approach to materials. Beuys primarily identified himself as a ‘sculptor’, and similar to Haacke and Johanson, he often worked to create ephemeral (or at least changing or transforming) three-dimensional objects and installations, many of which challenged ideas of the timelessness of art. Beuys stated of these pieces, ‘My sculpture is not finished. Processes continue in most

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112 Robert Morris describes this concern in his seminal 1980 essay, ‘Notes on Art as/and Land Reclamation’ whereby he posited, ‘A number of issues, or perhaps non-issues, are raised by this possible ménage à trois between art, government, and industry. One of these is not an issue, and that is the objection to art’s “serving” as land reclamation, that it would somehow lose its “freedom” in doing so. Art has always served’ (quoted in Kastner 1998: 254).

113 Kelley stated, ‘Every facet of a Johanson project is designed to perform multiple functions: cultural, social, infrastructural, and environmental’ (2006: 3).

114 According to art historian Joachim Pissarro, Beuys ‘… was interested in matters of process, production, transformation, creation … His work does not depict, allude to, or evoke nature; but it emulates natural forces, natural growth processes in as many forms as he could put in his hands on various materials, and their possible permutations’ (Pissarro 2010: 12,14). For example, in many of his ‘vitrine’ works, materials such as fat were used that would change under varying environments or alter chemically over time, according to Rosenthal (2004: 13–15). It is also important to note that Beuys studied science before moving into art, instilling in him a lifelong, analytical interest in zoology and botany, according to art historian David Adams (1992: 26–27). In his 1980 interview with Kate Horsefield, Beuys stated, ‘I had a kind of laboratory all the time until fifteen years of age, when I developed really and factually a laboratory which was involved with physics, chemistry, zoology, botany, and such things, and I decided to study...
of them: chemical reactions, fermentations, colour changes, decay, drying up. Everything is in a state of flux’ (from undated statement in Harlan 2004: 9). Beuys’s material choices were visually unusual and evoked processes similar to those in natural ecosystems; as art historian Mark Rosenthal opined, ‘Beuys’s frequently stated desire to push beyond the constraints of art conventions through his use of organic, unaesthetic materials ... set into motion and give a lifelike force’ (Rosenthal 2004: 13–14). In this way, works by Beuys referenced changes that occur constantly in nature, paralleling thoughts in the works mentioned above by Haacke and Johanson.

Diverging from Haacke and Johanson, Beuys rigorously hand sculpted materials, leaving physical traces of his own ‘presence’. His materials were often viscerally manipulated, described by Rosenthal as being ‘variously handled, bitten, eroded’, which embedded a sense of the artist’s hand (or teeth) in the process of creation. Beuys hereby created the role of central protagonist for himself, a process Rosenthal refers to as ‘staging sculpture’ (2004: 14–17). Beuys later became so invested in ‘theatricality’ that he departed from object making (mostly) and instead moved toward performing sculpture and sculpting society as his preferred medium.\footnote{Beuys’s underlying artistic philosophy can be further comprehended through his remarks: ‘The concept of sculpting can be extended to the invisible materials used by everyone: Thinking Forms—how we mould our thoughts—or Spoken Forms—how we shape our thoughts into words—or social sculpture—how we mould and shape the world in which we live’ (Beuys, quoted in Harlan 2004: 9).} He sought to expand his idea of sculpture to include Aktionen, or actions, where ideas were publicly delivered by performance in an attempt to intervene directly in the way people, often students, thought. According to Rosenthal, transforming or activating society through ideas, sometimes called ‘Social Sculpture’, became a central component to Beuys’s work later in his career (2004: 48).

Eine Aktion im Moor was a sculptural interaction with a wetland whereby Beuys ‘jogged through a bog, bathed in mud, and eventually swam through this swampy pit’, according to Spaid (2002: 22). Photographic documentation by Gianfranco Gorgoni depicts Beuys with his head barely out of the water, coated in plant matter, detritus, and directly experiencing an actual aquatic ecosystem. According to art historian David Adams (1992), Beuys believed this direct experience or connection moved beyond the retinal experience normally attributed to the environment and was a foundation for altering our perception and relationship to it. With this Aktion, we see a marriage of Beuysian ideas: the visceral material engagement (sculpting mud, water, plants), combined with the concept of social sculpture—the way this action and the subsequent photographs altered public perception of wetlands (Adams 1992). Beuys’s attention turned to physical interaction (immersion) with both living and abiotic materials, differing radically from Haacke’s almost autonomous artistic approach in Rhine-Water Purification Plant, where the physical hand of the artist was intentionally absent. Similar to Johanson’s Leonhardt Lagoon, the wetland (an entire ecosystem) in Eine Aktion im Moor was conceptually transformed into a material at an environmental scale. Like my own Eco-Actions, wetlands themselves are the stage for public experiential ecological learning, and Eine Aktion im Moor is a continued inspiration to me.

Beuys believed materials had both a symbolic and universal metaphysical value,
which diverged sharply from approaches by Haacke and Johanson. For example, to Beuys, animal fat or lard was symbolically associated with his own near-death experience and was associated metaphysically to warmth and eroticism. According to art historian Joachim Pissarro (2010), Beuys considered sculpting, speaking, and even thinking were actions on a metaphysical level—each emulated the creative energies of the universe found within the artist, which recalled holistic beliefs and early German Romantic ideology. On this level all actions were creative; even the process of living itself was a larger spiritual or shamanic journey. Materials, words, and ideas were sculpted, as they were ‘alive’ with universal meaning and connected in a cosmological system (Pissarro 2010). Pissarro concluded that Beuys’s philosophy ‘directly echoes Wilhelm von Humboldt’s definition of poetic language’, which ‘must not be regarded as a dead product of the past but as a living creation’ (2010: 15). Here we can also see Beuys’s underlying holistic philosophy, which paralleled Humboldt’s idea of interconnection among all things in the cosmos.

In Eine Aktion im Moor, the bog became a sacred place for performing rituals of connection, cleansing, and healing. One may be reminded here of the necessity for the return of the sacred as discussed previously in the ideas of transdisciplinarity by Nicolescu. Beuys viewed bogs as mystical places of alchemy, evolution, and regeneration: as the ‘storing places of life, mystery, and chemical change, preservers of ancient history’ (Beuys, quoted in Tisdale 1979: 39). Through his performance Beuys attempted to become one with the environment and part of its natural processes. According to Beuys, such spiritual experiences could transform individuals who could then alter society’s approach, philosophically and spiritually, toward nature. Adams surmised, ‘He saw this as necessary to replace the current ecology-destroying tendencies embodied in consumerism, patriarchy, statism, and capitalist growth’ (1992: 26). Beuys embedded metaphysical value in the bog, and the experience of being within it challenged Judeo-Christian belief systems much as Henry David Thoreau did with his own immersion into the wilderness. Beuys’s holistic belief system may have encouraged awareness and respect for ecosystems: an effective way of increasing popular environmental stewardship, or what Adams referred to as a ‘deep-rooted change’ in individuals and society (1992: 29).

Beuys, like Thoreau, spiritually valued and sought to promote equality for animals. For example, in Coyote, I Like America and America Likes Me (1974), Beuys lived in a New York gallery with a live coyote for several days, suggesting trans-species intimacy, connection, and perhaps even transcendentalism. Matilsky stated, ‘Beuys’s posture was archetypical, conjuring a world where animals, human, and spirit were one’ (1992: 54). Yet to be truly beyond an anthropogenic paradigm, one must wonder how the canid felt about this
experience. One might also question the fate of the animal and other animals, following Beuys’s heavily documented performances. Although *Eine Aktion im Moor* did not explicitly involve metaphysical interaction with individual non-human animals, it did deliver a strong message of human connection to a larger biological community. In this way, Beuys’s self-developed eco-spirituality, even if not clearly defined, may be an effective strategy for transdisciplinary art practitioners to utilize for increasing ecological appreciation among a populace that views itself as disconnected from nature.

During *Eine Aktion im Moor*, Beuys underwent a shamanic act of ‘transformation’ to symbolically become a semi-aquatic organism, much in the way he ‘became’ a stag in his earlier *The Chief-Fluxus Song* (1964), where Beuys made deer calling noises in an attempt to ‘speak for the animals who could not speak’ (Adams 1992: 30). Even though a symbolic individual animal was absent in *Eine Aktion im Moor*, Beuys did state that bogs were the ‘liveliest elements in the European landscape ... from the point of view of flora, fauna, birds, and animals’ (Beuys, quoted in Tisdale 1979: 39), giving them a particular sense of importance. Throughout his performances and writings, Beuys does not offer an easily definable system of beliefs. He does, however, invoke a sense of value beyond material resource to non-human animals and the landscape, which recalled the earlier environmental ethics proposed by Leopold and Thoreau.

In addition to holistic and sculptural intentions, *Eine Aktion im Moor* was an environmental protest. Performed in proximity to the heavily environmentally compromised Ijssel Lake (formerly Zuiderzee Bay) in the Netherlands, Beuys brought attention to such bogs, which according to Spaid ‘were under threat of being drained to form low-lying land masses’ (2002: 22). Spaid went on to state that the majority of freshwater wetlands had declined in environmental quality, and in Europe, such bogs had become increasingly ‘endangered’ by the time of this performance (2002: 22). Beuys’s scientific understanding and concern for habitat protection were manifested in *Eine Aktion im Moor*; he stated that wetlands ‘are essential to the whole ecosystem for water regulation, humidity, ground water, and climate in general’ (Beuys, quoted in Tisdale 1979: 39). By drawing public attention to wetland decline, Beuys socially ‘“sculpted” popular ideas, thus activating civil responsibility towards such ecosystems.’ In this way, *Eine Aktion im Moor* and other conceptual works invoked Haacke’s ideas of actively increased public ‘consciousness’ of Rhine River degradation and also Johanson’s concept of making environmental problems visible through art.

It is through his performances, or *Aktionen*, that we most clearly see Beuys’s

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119 In addition to interactions with living animals, Beuys also employed dead animals in his performances, such as in his 1965 *How to Explain Painting to a Dead Hare*. Bioethical questions arise about the origin of the rabbit used. In the spring of 2012 I discussed the fate of these animals with Beuys’s art dealer Ronald Feldman, and he says that the hare came from a butcher’s shop and that the coyote came from a wildlife trainer.

120 According to Spaid, ‘Such interventionist schemes demonstrate the artist Joseph Beuys’s (1921–1986) notion of “infiltration”, which he likened to an oil stain spreading across a filter. “This is the other side of the filter: a new, refined essence, the spreading of ideas to the different forcefields of human ability, a kind of inspiration that takes effect through physical process of capillary absorption: psychological infiltration, or even the infiltration of institutions”’ (Spaid 2002: 22).

121 Dedicated to sculpting society through infiltration of ideas, Beuys even performed lectures (active teaching) where he demonstrated art theories and social and political concepts through diagrammatic renderings on blackboards. Rosenthal says, ‘Blackboards were, in effect, “calls to actions” by which Beuys ... would induce a state of contemplation, imaginary possibility, or a desire to change the world’ (Rosenthal 2004: 48). For Beuys, the act of teaching students and the public was sculpting at a societal level.
concerns for the environment expressed and his most successful contributions toward raising public ecological awareness. Rosenthal stated that by the 1970s Beuys ‘would often leave the narrowly defined field of art in favour of political action, and he would declare that his art objects were, in fact, meant to epitomize ideological/political concerns’ (Rosenthal 2004: 17). In Eine Aktion im Moor and many of his other actions, Beuys’s concern for and social connection to the environment were expressed. These actions included involvement with the founding of the German Green Party; bringing attention to deforestation through public demonstrations; delivering philosophical discussions that entailed re-thinking humanity’s anthropogenic placement ‘outside’ nature; large-scale tree plantings; and others, according Adams (1992). Eine Aktion im Moor and his action of the same year, Überwindet endlich die Parteiendiktatur (Overcome Party Dictatorship Now), sought to show appreciation for under-acknowledged ecosystems, leading to their protection. This, Adams (1992) concluded, is activism, placing Beuys within the canon of the Radical Ecologist movement. Adams posited that Beuys was a ‘pioneer investigator of the role of art in foraging radical ecologist paradigms for the relationship between human beings and natural environments’ (1992: 26). Although the effect of most of these actions on society and the environment is difficult to ascertain, some individual performances did successfully protect specific ecosystems or led to the increase of flora populations in urban areas. As such, these actions would align with Leopold’s idea of what is morally just in ecological terms.

In spite of Beuys’s accomplishments, many inconsistencies arose in his mythology, such as the validity of his near-death experience, which led to larger questions about his honesty and credibility throughout his practice. Synonymous with Beuys is his previously discussed ‘myth of origin’, which may or may not have happened at all. In fact, photographs and texts from varied catalogues actually contradict Beuys’s story; Beuys is pictured in relatively fine health, posing next to a ‘slightly damaged’ plane (Buchloh 1980: 69). In a further dramatization, Beuys stated his co-pilot, referred to as his ‘friend’, was ‘atomized’ upon impact in the severe crash, yet this ‘friend’ mysteriously vanished from all other described versions of the story the author was able to find (Beuys, quoted in Buchloh 1980: 69). Instead of having one version of the story, Beuys appeared to have developed and altered this account throughout his career, leading Buchloh to term it frankly as a ‘neurotic lie’. If Beuys misinformed the public about such a personal experience, we must also question the

122 According to Adams, “An approach worthy of the epithet ‘radical’ is one that does not limit its concerns to ecological systems within the natural world. Radical ecology also see these in connection with larger patterns of human life: social forms; economic theories, practices, and interests; political and legislative history and method; control of information and communications media; and, indeed, the underlying philosophies and teleologies of Western civilization” (1992, 26).

123 Beuys’s 1971 Überwindet endlich die Parteiendiktatur (Overcome Party Dictatorship Now) took place in the wooded area of Grafeenberger Wald in Düsseldorf, Germany. This forest was threatened by the proposed expansion of tennis courts, following the performance, where Beuys and the public swept forest floors and painted trees with white crosses, the recreation Club decided not to deforest the area according to Davis (1992, 26, 34). In his seminal ecological artwork, 7,000 Eichen, Beuys and his students planted trees in Kassel, Germany for the “Documenta 7” exhibition. Hereby, through artist-led action, trees were planted throughout an urban area which increases nesting and arboreal habitat for some animals and aided in climatic factors such as absorption of greenhouse gasses (Steiner, 2007: 133). Additionally, Beuys posited a strong environmental message of reforesting the city, Beuys also dramatized the need to revitalize the urban ecology” (1992: 50).

124 Buchloh stated, ‘Beuys’s “myth of origin”, like very other individual or collective myth, is an intricate mixture of facts and memory-material rearranged according to the dynamics of the neurotic lie: that myth-creating impulse that cannot accept for various reasons, the factuality of the individual’s autobiographic history as such . . . As in every such retro-projective fantasy, such a narcissistic and slightly pathetic distortion (either dramatization or nobilization) of the factually normal contradictions (made more traumatic or more heroic) of the individual’s coming into the world, the story told by the myth’s author reveals truths, but they are different from what the author would want them to be’ (Buchloh 1980: 38).
credibility of his actions of environmental stewardship in terms of ecological science.

Actions by Beuys that directly involved live animal interactions and environmental intervention need also to be questioned in ecological and animal welfare terms. For example, in his often cited, Coyote, I Like America and America Likes Me (1974), the origin and ‘return to the wild’ of the live coyote is not well documented. In fact, I found that the animal itself was not wild in the first place, but instead loaned from a wildlife trainer. This knowledge can change the fundamental perception and interpretation of the work. Works involving live animals, such as this and Haacke’s Rhine-Water Purification Plant, whereby the artist does not explicitly divulge the organism’s fate, send a mixed ecological message and may even reinforce popular material tendencies for use and discard of natural resources among consumers. Was the coyote ideologically ‘used’ and disposed of as a temporal artistic material? This raises important bio-ethical questions as well as questions about the validity of several past interpretations by art historians of Coyote, I Like America and America Likes Me (1974).

Other issues arise in Beuys’s 7,000 Eichen (7,000 Oaks), in terms of ecology. With this work, the artist chose species of trees (European Oaks) that had culturally symbolic value to Germany instead of planting a mixed group of species, which would have produced a more significant, biologically diverse contribution. In a recent interview, artist Newton Harrison recalled thinking of the project, ‘This guy is nuts! Oaks don’t belong in Beech country! There is a Beech forest all over the place, why are they talking about this Beuys in terms of ecology?’ (Harrison 2011: 52). Likewise, Dia Art Foundation has continued 7,000 Oaks in the spirit of Beuys, planting non-native European Oaks in New York City: a posthumous gesture that may have negative long-term environmental consequences, as such introduced exotic species are known to compete with native flora. The actual positive and negative environmental effects of 7,000 Oaks may take decades to fully understand.

Lastly during his performance, Eine Aktion im Moor, Beuys physically interacted with a sensitive bog ecosystem, potentially causing localized ecological disturbance. Such bogs consist of layers of organic debris intricately maintained by a delicate balance of slow-growing mosses and other plants, anaerobic bacteria, and detritus (dead plant and animal materials), creating a complex nutrient cycle that can take decades, even centuries, to form. Physical disruptions (as with Beuys’s swimming, jogging, and bathing) of such slow developing layers can lead to chemical imbalances, as one layer is moved above or below the natural order of accumulation. Again, there is no documentation of the after-effect to the bog following Beuys’s performance.

Nevertheless, even if somewhat problematic, Beuys’s underlying ecological concern is felt in Eine Aktion im Moor and is a source of inspiration for my participatory biology programs, Eco-Actions (discussed later), often conducted in wetlands to monitor the health of amphibians and other aquatic organisms, with public participation.

Section 3.5. Conclusion

Haacke, Johanson, and Beuys raised awareness of wetland ecosystems by activating

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125 Discussion with Ronald Feldman, spring 2012.
The community through ecological art. Such practices, in the case of Johanson’s and Haacke’s collaboration with scientists and community members, transcended disciplinary boundaries and are attuned with ideas of transdisciplinarity as characterized by Mittelstraß and Gibbons et al. (1994). Furthermore, these projects sought solutions to real-world, localized environmental problems—in the case of Haacke, symbolically, while with Johanson, actual remediation of an ecosystem. Both artists, along with Beuys, drew public attention to wetlands and the environmental threats many face in order to disseminate better understandings of ecological phenomena.

However, some artistic choices made in these works raise ethical considerations that need to be addressed. Haacke may have accidentally harmed a greater ecological community through his vision of what is right (freedom) for a few individual non-human life forms. By sanctifying Haacke’s action through art history, Matilsky (1992) and others may have further propagated an anthropogenic position whereby the artist acts upon an interpretation of what is just versus what in scientific terms would be considered irresponsible and potentially dangerous to a greater organismal and ecological community. This viewpoint is dangerously common in discourses surrounding art involving biology and ecology and may be symptomatic of underlying art-world naiveté or overall ignorance of the natural sciences. When questioned about the fate of the fish utilized in *Rhine-Water Purification Plant* following the exhibition, Haacke did not respond (Haacke 2011). However in all fairness, awareness of issues such as the impact of introduced species were far less commonly known in the 1970s than they are today. One only needs to look at modern seafood markets with their piles of declining species or the aquatic pet trade to understand that little has changed since the time of Haacke’s work in regards to social values attributed to aquatic life. Regardless of criticism, however, *Rhine-Water Purification Plant* did raise awareness about pollution in the nearby Rhine waters.

Johanson, like Haacke, created an artistic response to wetland degradation. Going beyond Haacke’s symbolic work, her monumental *Leonhardt Lagoon* implemented large-scale environmental remediation as a form of public urban art. Conducted in collaboration with diverse communities both human and non-human, Johanson, according to Kelley, advocated ‘for a new culture of nature that can integrate people and the non-human world’ (2006: 35). Like Charles Darwin and Aldo Leopold, Johanson gave equal attention and merit to all wetlands organisms and the ecosystems themselves, to ‘dissolve the hierarchies and get everything on the same level—the art, the people, the plants, the soil, the water’: a profoundly holistic message she shared with the public (Johanson, quoted in Kelley 2006: 40).

Additionally Johanson blurred the boundaries between art and natural phenomena: a bold message of ecological integration. According to Lippard, her ‘public art offers a rare sense of being present at the vortex of culture and nature’ (quoted in Kelley 2006: vii). Johanson’s *Leonhardt Lagoon* is an ideal model of a successful transdisciplinary art project that effectively involved collaboration with scientists to raise public understanding of an ecological phenomenon while it actually solved a real-world problem.

Beuys’s *Eine Aktion im Moor*, although problematic regarding a number of related issues (see above), did effectively raise awareness of wetland loss. Photographic documentation of the performance acts as a reminder of Beuys’s ecological concern and has
been a source of inspiration for my own Eco-Actions. Also, the enigmatic understanding of Beuys and his practices reminds us that for art projects involving living organisms and direct involvement in ecological systems, special measures of responsibility need to be addressed beforehand and afterward, insuring the safety and continued welfare of involved organisms and the ecosystems themselves. Otherwise, such artistic gestures, when not informed by science, may in fact mislead the public and potentially negatively impact ecosystems and biological communities. As with my own work with amphibians involving the public directly in wetland research, these concerns are very relevant and must be considered throughout the working process.

All of these works crossed single disciplinary boundaries and to varied degrees are attuned with interpretations of transdisciplinarity, as discussed previously. Haacke worked with scientists and members of the community to create art combined with activism to spread knowledge of wetland degradation to a larger populace, reminiscent of Gibbons et al.’s (2004) Mode 2 form of transdisciplinarity. Johanson teamed with scientists and locals to restore an actual ecosystem, making a positive contribution to both the local human and wildlife communities, an action that solved a real-world problem through a cooperative, multidisciplinary approach in line with the philosophies of Mittelstraß. Beuys found the sacred in an endangered wetland and used his performance as a combinatory form of activism, education, and spirituality: a method more aligned with Nicolescu’s views on transdisciplinary practices. All to a degree could be characterized as Transdisciplinary Art with Ecology.

All of these practices were active forms of inquiry beyond a single disciplinary lens, focused on finding solutions to real-world, localized ecological issues. To varied degrees they all posited pragmatic solutions to these complex challenges: Haacke actually filtered polluted river water; Johanson remediated a large-scale wetland; Beuys’s actions led to the protection of habitats. Likewise all of these works disseminated to larger audiences understanding of wetland ecosystems and the challenges they face. As such, each is a relevant example of transdisciplinary art about ecology. My hope is that because of the works by Haacke, Johanson, and Beuys, future generations of ecological artists and others inspired to study and protect wetlands will be similarly successful in addressing the milieu of ecological problems we and other species currently face.
Chapter 4. Biological Research as Art Practice

4.1. Introduction

The primary goals of my dissertation research sought to increase understanding of ecological phenomena among non-specialists and to explore how transdisciplinary art and participatory biology could achieve this. Additionally I found it important to consider whether such practices could contribute new knowledge to the field of primary research biology and also to consider the way in which these findings could be disseminated. To address these questions, I found it necessary to analyse important artworks by Helen and Newton Harrison, Mel Chin, The Tissue Culture and Art (TC&A) Project, and Cornelia Hesse-Honegger. For the creation of these artworks the artists utilized research biology as a form of artistic practice, transcending disciplinary boundaries. Each in their own way contributed new understanding to the field of biology and additionally increased understanding of ecological phenomena to larger, non-specialist audiences. The following aspects will be considered for each work: background of the project; the process by which artistic exploration and scientific research became entwined and the practical results of the artwork in furthering the field of biological research; and the philosophical-aesthetic implications of the artwork. In their seminal work *The Lagoon Cycle*, the Harrisons sought to develop a source for sustainable food, which resulted in the development of scientific methods for breeding a rare species of crab in captivity. Mel Chin in his collaboration with scientist Rufus Chaney challenged ideas of public art and aided to establish the scientific field of phytoremediation. While acting as artist protagonists, TC&A generated a new method in the field of tissue-engineering science while questioning the larger biomedical industry. In the last section, Cornelia Hesse-Honegger’s research into the impact of radionuclides on insects captivated the public and pushed the scientific community towards further studies. Each of these artists crossed disciplinary boundaries through their creative research to generate new understandings of biological phenomena and contributed in their own ways to the scientific community: as such they verged on transdisciplinarity. The varied models of approach to their creations will be discussed, as will the biological discoveries the works yielded and how these findings were disseminated to larger, non-specialist audiences.


American artists Helen and Newton Harrison responded to the issue of declining biodiversity, loss of wetland habitat, and maintaining sustainable food supplies through the creation of their seminal work, *The Lagoon Cycle* (1974–1984). The Harrisons effectively developed a new scientific understanding of captive breeding of a declining species of a crustacean, the Indopacific Mud crab (*Scylla serrata*) while simultaneously increasing public awareness of disappearing mangrove ecosystems. The work also developed an aquaculture method for growing these crabs in captivity as a potentially sustainable food

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126 Phytoremediation, or phytoaccumulation, uses plants or algae to remove contaminants from soils, sediments, or water. The plants or algae can be harvested, improving damaged environments (Meagher 2000).
127 According to the Harrisons, funding for the project ‘required a taxonomic identification which had not been a previous matter of public record’. (Harrison 2013).
source for increased human populations. Lastly, the work raised complex bio-ethical questions about the use of non-human life forms within works of art as well as the often dichotomous relationship we as consumers have with the animals we eat.

The Lagoon Cycle evolved from an earlier series of works by the artists entitled Survival Series, described recently by art historian Linda Weintraub as ‘Strategies to Sustain Life’ (Weintraub 2012: 74). As installations, Survival Series transformed public exhibition spaces into working laboratories that experimented with sustainable food production. Cultural venues became utilitarian hosts for portable citrus orchards, hog pastures, and shrimp and fish farms from which food could be harvested and served to museum visitors (Ballengée 2010, 2012; Weintraub 2012). In a 2010 interview, Newton Harrison stated that an underlying motivation for the work was that the ‘earth is being wrecked globally’ (Ballengée 2011: 45). Even as of the late 1960s (presumably the environmental damage began along with the Industrial Revolution), Newton wondered what people could do to fix these issues.

In addition, Survival Series sought to answer a larger fundamental question: ‘What is earth?’ (Ballengée 2011: 47). The artists experimented with the creation of viable healthy soils through traditional farming practices, answering this question with the statement, ‘It’s where everything grows’ (Ballengée 2011: 47). As such, the Survival Series works were not intended specifically as scientific or ecosystem research, but rather as creative solutions to ‘introduce self-sufficient farming techniques to feed an overpopulated world’ (Spaid 2002: 34). Over time and through practice, a method of hands-on, ‘do it yourself’ approach to science and techniques for creating the manageable and productive environments within artificial conditions developed.

The Harrisons were very much a product of the 1960s and 1970s avant-garde art movement and in many ways recalled the optimism of the movement at this time. Newton Harrison’s work in the 1960s was categorized as ‘Technological Art’ yet embraced this genre simply for the sake of a new canvas. In defiance of the larger art and technology movement was the Harrisons’ attitude toward utilizing technology and science as a means to an end for real-world problem solving; this deviated from most other art and technology works of the era, which often sought the aesthetically spectacular use of new techno-media (Ballengée 2011: 46). The Survival Series was more proactive, as the Harrisons (now working together)

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126 In their early stages the Lagoons were still being classified by the artist as Survival Pieces (Harrison 1974).

127 The Survival Series included: Hog Pasture, Survival Piece # 1 (1970–71); Shrimp Farm, Survival Piece # 2 (1971); Portable Fish Farm, Survival Piece # 3, (1971); Portable Orchard, Survival Piece # 5 (1972–73) and others (Weintraub 2012). The Harrisons have suggested that these works moved towards backyard farming and ‘putting food production back into people’s own hands’ (Harrison 2012).

128 Although the Harrisons do not identify themselves as activists, their work has increased public understanding of environmental issues (activating the community) and often has sought to find solutions to real-world ecological challenges, a position that is eco-activist, in my opinion (Ballengée 2010; Harrison 2012).

129 When interviewed, Newton Harrison stated he was influenced as much by the Soviet launch of the Sputnik satellite as his artist contemporaries: ‘I said to myself: “I understand that the Sputnik is not a scientific thing at all, in fact, it’s an act of technology”. Then I thought: “It is a global performance that is bigger than the globe. What am I doing making sculptures, trying to recapitulate these old masters?”’ (Harrison 2012).

129 Newton was among the artists involved in the 1960s and 1970s art and technology movement and exhibited in the now-famous 1970 ‘Art and Technology’ exhibition at the Los Angeles County Museum of Art (Ballengée 2011: 45).

132 However, in Beyond Modern Sculpture (1968) Jack Burnham observed of Technological Art that many of the practitioners were seeking to bridge the widening chasm between art and technology. In a section on the Experiments in Art and Technology (E.A.T.) group and their ‘9 Evenings’ performance series in 1966, he wrote, ‘Beyond its many shortcomings, E.A.T. represents the desire to create a professional and social rapport between artist and engineer more complete and more realistic than anything attempted in the past’ (Burnham 1968).
began considering ways to create projects utilizing technology and science to solve actual environmental issues rather than creating standard objects of art—a position that rebelled against art-world trends of non-utilitarian fine art prevalent from the 1970s until today (Ballengée 2010). As such, the decision by the Harrisons to utilize the tools of art combined with the methods of technology and science to pragmatically solve complex problems aligns with transdisciplinary approaches as described earlier by Mittelstraß and Gibbons et al. (2004).

According to the Harrisons the Survival Series followed the road of ‘using aesthetically minded science to address the depredations of irresponsible science and technology’ (Ballengée 2010). Yet the work illustrated that both the ‘natural’ and ‘technological’ worlds—though different—are part of the same reality. Through Survival Series, the Harrisons gave a voice to many of the ideas of the art and technology movement by confronting broad issues of degradation and conservation of the natural environment and animal species, including the renewal of urban and rural environments, the depletion of resources, and global warming. As Helen Harrison stated, ‘We explored other ideas about using viable earth ... such as making bio-fuels’ (Ballengée 2011: 47). The Harrisons began to create artistic experiments that utilized the scientific method: suggesting hypotheses; anticipating outcomes; making experimental trials; analysing results; and answering questions about natural phenomena. The difference between their work and standard scientific practices, according to Newton Harrison, was not the analytical questions or methods or even, in some cases, the outcomes, but instead the intention. To paraphrase, as artists they wanted ‘A’, while scientists would have desired ‘B’ (Ballengée 2010). The potential fusion between art and science in the Harrisons’ practice appears clear; however, as they have said, their core aims differed from those of primary research scientists. Additionally the Harrisons have identified themselves as artists, not as scientists, and as such, their hybrid practice crossed disciplines to offer a novel form of art practice generated through scientific methods.

Through approaching art making as a means of scientific research and scientific methods as a means to realize art, the Harrisons reframed questions of how art may be utilized to contribute to larger social and environmental issues. The artists’ environmental message in the Survival Series did not always come through clearly, however. For example, when Portable Fish Farm, Survival Piece # 3 was exhibited in London in 1971 it was widely misunderstood by the public as a sensationalist artwork, because farmed fish were euthanized by electrocution. However, commercial fish farmers typically used electrocution to quickly harvest the animals (a technique deemed as humane by the American Society for Prevention

134 Burnham (1968) noted technological artists were interested in substituting the art object for a system of actions or processes. Though affiliated figures such as John Cage and Deborah Hay would come to be associated with ‘the arts’ in a more traditional (if experimental) sense, these happenings set early foundations for collaborations between art and science in the postmodern, post-industrial age.

135 A position seemingly at odds with later ideas of transdisciplinarity as posited by Nicolescu, discussed previously in chapter 1.

136 As Burnham (1968) and some of his contemporaries broadly suggested, the science-minded were often prejudiced against art and the humanities as irrational and impractical, while the artistic community viewed the science community as soulless, ecologically irresponsible, and pragmatic to a fault. But even as the two viewpoints drifted further apart, it remained that many in the world at large believed that ‘dehumanized scientific technology cannot help but destroy itself and the world around it’ (Burnham 1968). In a sense, these collaborating artists and engineers sought to put ethics into technological development.

137 As art critic Arlene Raven asked ‘Can such art just sit there, surrounded by nature? Or hang in galleries in the art environment and simply refer to ecological issues?’ (1988: 24).
of Cruelty to Animals, as some fishes can struggle out of water for hours before death). By focusing on the welfare of the individual fish being killed, the environmental message and artists’ designs for a method of sustainable aquaculture was perhaps overshadowed, as Helen Harrison noted: ‘Everybody ... was looking at the fish farm as a gigantic sensational thing by a mad Californian artist’ (Ballengée 2010).

However it can be argued that the controversy over the piece only served to further engage audiences with questions about ecology, humane treatment of animals, and the morality of food production. Likewise, viewed abstractly, harvesting animals for food by private farms, companies, or individuals is a public benefit, but when the public is confronted by the need and practice of actually killing individual fish for food, the conversation takes on an emotional and a larger bio-ethical dimension. In all truth, the Harrisons did not present overly novel techniques in Portable Fish Farm, Survival Piece # 3 or their earlier aquaculture piece Shrimp Farm, Survival Piece # 2 from the same year (other than scale and the use of an art museum space); most, if not all, of their methods were already in common use by the food industry. Yet, by display, the artists brought attention to the death inherent to commercial food production.

Pursuing questions raised by the fish and shrimp farms, the Harrisons began to develop The Lagoon Cycle. In conceiving the project, the Harrisons researched hardy aquatic species that could survive under a wide variety of conditions, considering the species’ nutritional value and cost of maintenance (Raskin 1994). The team studied existing scientific literature and interviewed biologists. Newton Harrison stated, ‘We wanted catfish to breed in the tanks dealing with the life-cycle of the catfish, but it didn’t work out in Fish Farm. We then began working with our Sri Lankan friend, Ranil Senanayake, who was a herpetologist as well as an ecologist. Ranil had invented “analog forestry” from what we had done earlier as an analog lagoon. We wanted a living creature that could breed under museum conditions. He said: “Listen, I have a creature for you. It’s a crab. Because in my world, these crabs can live in both small ponds and grow in large lagoons”’ (Harrison 2012). Following this, the artists engaged in a scientific study of Sri Lankan crabs and their habitats, even travelling to study them in their natural habitats. This culminated in First Lagoon, essentially an artificial replication of Sri Lankan lagoon conditions in a large aquarium with natural materials brought from Sri Lanka (Raskin 1994).

Following the successful building of First Lagoon, they received funding from the Scripps Institute of Oceanography, leading to the work Second Lagoon: Sea Grant. Second Lagoon represented a much more in-depth recreation of the mud crab’s habitat, albeit a completely man-made version. Cinderblocks and pottery were included to allow the crabs individual hiding places, and the tank conditions were altered to emulate tidal, seasonal, and weather conditions, including changing the specific gravity and nutrients in the water to compel the crabs to mate (Ballengée 2011). Diverging from the earlier Survival Series works, which focused mostly on the development of methods for sustainable food production, the Lagoon works had multiple intentions. These included finding a method to replenish a species being depleted in the wild; creating an exhibition where something lived; adding to the scientific body of knowledge; telling a story; and using a holistic or whole-system approach
within experimental science, which differed from the reductionist approach\textsuperscript{138} often used in research biology (Murray 1993; Ballengée 2011).

As the intentions and methods developed, the artists went on to create five more room-sized \textit{Lagoon} installation over several years, completing the cycle of \textit{Scylla serrata} (Ballengée 2012). To realize the work, the Harrisons researched and modified existing aquaculture technologies and in some cases, invented new methods. As \textit{The Lagoon Cycle} continued, it eventually grew into a 350-foot long installation that included photographs, collages, performances, and poetry (Matilsky 1992). As the project developed, two characters began to narrate a story; ‘The Lagoonmaker’ and ‘The Witness’ are introduced to the audience, evidencing conflicting editorial voices that may represent the artists’ own voices (Adcock 1992). As the cycle progresses, the Lagoonmaker begins to craft a grandiose plan for using \textit{The Lagoon Cycle}’s scientific findings to craft food-producing ponds in the Salton Sea of the Colorado Desert (Harrison and Harrison 1984). The work self-consciously points out that the Lagoonmaker’s ‘art-hubris’ in planning this increasingly extravagant\textsuperscript{139} project that would create a negative result for the Gulf of California ‘very like the one that disrupted the Sri Lankan ecology by substituting tractors, rigidly specialized devices, for the environmentally versatile water buffalo’ (Ratcliff 1985: ix). As art historian Carter Ratcliff suggested, perhaps this was also a comment on the human tendency to use technology and science to play God; as the Lagoonmaker ‘remake[s] himself in the romantic-modernist model of the artist’ (1985: x). Likewise it also presents a metaphor for the isolated modernist individual who, like Prometheus (or Blake or Byron), aspires to knowledge or status above his understanding, believing his genius entitles him. There may also be an underlying warning here, recalling the Greek titans, Milton’s Lucifer, or Doctor Frankenstein, whose creative pride preceded inevitable falls; ‘The Witness’ closes by asking, ‘who will flush the gulf, who will flush the sea?’ (Ballengée 2012).

At the same time, \textit{The Lagoon Cycle}’s editorial voice (‘The Witness’) cautions against human hubris in assuming it is possible to improve or emulate millions of years of natural evolution without complications (Harrison and Harrison 1984). When interviewed, Helen Harrison illustrated the point with a quote from the project’s text: ‘Where we go very simply is: the tank is not a lagoon nor is it a tidal pond, neither does the mixing of fresh and salt water make it an estuary. Filters are not the cleansing of the tides, water from the hoses is not a monsoon, lights and heaters are not the sun, and crabs in the tank do not make a life web’ (Ballengée 2011: 56). To the Harrisons, underlying this statement is a much larger debate between a whole-systems way of approaching ecosystems versus a reductionist paradigm that seeks to separate individuals (even to the nano-molecular scale) and often control them (Harrison 2010). Although the Harrisons do not identify themselves as transdisciplinary practitioners and their works preceded much of the writing on transdisciplinarity, their approach echo ideas discussed previously in this dissertation by Gibbons et al., Nicolescu, and Mittelstraß.

\textsuperscript{138} Such a critique of reductionism is attuned to ideas of transdisciplinarity by Nicolescu and a potential call for reformation of larger structures in science.

\textsuperscript{139} Which, according to the Harrisons, would have involved ‘transferring the polluted water of the Salton Sea’s 350 square miles to the pristine Gulf of California, then bringing the pristine waters of the Gulf of California to the Salton Sea’ (Harrison and Harrison 2012).
The Lagoon Cycle positioned the artists as political storytellers, creating works that improved public understanding of ecological phenomena through the framing of environmental issues (Lippard 2010). The case in point here was the conservation of the Sri Lankan crab species *Scylla serrata* and its protection from overfishing by Russian and Japanese fleets. It also offered a method and message of hope with a primary objective of being able to return viable females born in captivity (in an artwork) to their native Sri Lankan lagoon ecosystems. This message in turn created the potential for public outcry over ecological calamity, which may have aided in the pressuring of politicians to take action on such environmental issues (Matilsky 1992) and give power (knowledge) to the public to conserve this species through breeding in captivity. This overall approach is attuned to positivist thoughts by the late art theorist György Kepes, who suggested that artists could utilize new technology to benefit society and create environmental change (Bijvoet 1997).

Additionally, the narrative in *The Lagoon Cycle*, ‘ends with a long reflection on the greenhouse effect’, noted art historian Craig Adcock (1992), which suggested that the Harrisons were not only thinking large-scale on many socio-ecological levels, but also pondering changes to the global biosphere.

To critique the Harrisons, one could classify *The Lagoon Cycle* as overly idealistic or solely an activist work of art. However, Newton Harrison has stated, ‘We don’t think about activism at all. We think of ourselves as responsible people responding to a circumstance’ (Ballengée 2011: 58). This perspective invokes the proactive stewardship ideas of Aldo Leopold, and is certainly congruent with characteristics of Mode 2 transdisciplinary thinking suggested by Gibbons et al. *The Lagoon Cycle* is a practical response to a real-world environmental issue. It can be argued the project itself created a new way for artists to work with living materials for practical uses that benefit both humans and a species that is diminished in the wild. If nothing else, *Lagoon Cycle* was revolutionary in being able to actually perform the scientific process, replicate ecosystems, and breed living organisms within the context of a work of art.

Pragmatically, *The Lagoon Cycle* designed successful indoor enclosures for the Sri Lankan crab (*Scylla serrata*), where specimens survived up to 18 months and reproduced for the first time in captivity. According to the Harrisons, the crabs were also a viable food source for future aquaculture, growing quickly ‘from one ounce to one pound in about 11 months” (Harrison 2012). Secondly, the work yielded the discovery that this species of crab has a 12-hour circadian rhythm that must be maintained for long-term survival in captivity: a new scientific insight. Thirdly, the research also revealed that this species of crabs could be successfully induced to breed by lowering the specific gravity of the water in the tank from 1.025 to 1.022, which mimicked a natural lunar tide cycle. Finally, it proved that these crabs reacted differently to varied forms of artificial habitats and that social behaviours were driven through a dominant-male social structure. All of these insights posited new knowledge to the field of research biology and were shared with the larger scientific community through a report published by the University of Hawaii.\footnote{Harrison, N. 1975. “Development of a Commercial Aquaculture System for the Crab *Scylla serrata.*” Sea Grant Advisory Reports for the University of Hawaii.}
It is important to remember that the scientific dimensions of this work were
deliberate, but employed by artists. In a sense the Harrisons became do-it-yourself scientists,
and *The Lagoon Cycle*, as a work of art, produced research science and inspired further work
in this field. As art historian Tom Sokolowski pointed out, ‘this work ... is reminiscent of a
true scientist’s inquiry’ (1987: xi). Additionally, though carrying through the plan to the
extent suggested by the fictional Lagoonmaker would be problematic, the project still
suggests further areas of research and improvement in cultivating sustainable food sources
and in engineering suitable artificial habitats while simultaneously bringing this newfound
knowledge to the public in story form. As such, *The Lagoon Cycle* is a seminal example of an
artwork that should be characterized as transdisciplinary, even if the creators may not view
their work as such. This work utilized scientific methods within artistic practice to generate

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141 As the Harrisons pointed out, their view on transdisciplinarity, ‘implicit in the lagoon cycle derives from a very simple choice
that we made early on which had to do with listening to the environment in the largest sense of listening, seeing, feeling, knowing. This meant if we were going to grow something, for instance a life cycle, we would have to learn
how to design one. For instance, we had to face a bioregional problem of some magnitude in Holland. Therefore we
had to invent our own version of bioregional planning, which required a different kind of research. Each problem we
took up required that we gain sufficient expertise to engage and in some cases actually solve real-life problems. This
lead to our thinking about what leadership would need to become if we were to survive well. Rather than the
specialist’s pure cause-and-effect thinkers of the twenty-first century, we needed to become generalists comfortable
enough in our intellectual skin to take on new issues and problems as they arose and have the competence for the
research and study of any discipline in sufficient depth to work with it. We actually believe that the term “trans-
disciplinary” may miss the point or may be a subset of what we may call the inspired generalist’ (Harrison and
Harrison 2012).
new knowledge and disseminated these ecological understandings to both scientific and larger, non-specialist audiences.

**Section 4.3. Revival Field (1990–present) by Mel Chin and Rufus Chaney**

In this section I analyse the seminal ecological artwork *Revival Field* by artist Mel Chin and scientist Rufus Chaney. There are many similarities between *The Lagoon Cycle* by the Harrisons and *Revival Field*, as both projects are the result of collaboration between individuals with different backgrounds. This creative ‘team’ approach is a departure from traditional means of art creation based on individual authorship (Krug 2006). Both artworks also offered creative yet concrete solutions to complex, real-world environmental problems, an approach that is sympathetic with ideas of transdisciplinarity posited by Gibbons et al. and Mittelstraß. Additionally, both artworks generated new scientific knowledge as well as increasing public understanding of ecological phenomena. One significant difference between these teams is how pragmatically they went about the creation of transdisciplinary art projects that generated science. The model employed by the Harrisons could well be described as ‘do it yourself’, having trained themselves to conduct scientific experiments, analyse results, and share findings with a larger audience. In the case of Chin and Chaney, Chin, as an artist, facilitated scientific research by Chaney, a scientist, through a large-scale, outdoor hybrid sculpture and science experiment. Although the methods utilized by these teams were very different, they both created art that generated science, works that had substantial economic and environmental impacts.

In the 1980s, conceptual artist Chin became inspired by hyperaccumulator plants and their ability to absorb and hold large amounts of minerals and metals in their vascular systems. Chin saw this as an analogy for sculpting, with biotic absorption equating to a chisel used to carve the earth (Finkelpearl 2000). Hyperaccumulator plants were particularly attractive to Chin, as they could potentially ‘sculpt’ the soil to remove heavy metal pollutants left from industrial wastes, a process called phytoremediation (Spaid 2002). Phytoremediation further inspired Chin to conceptually move beyond earlier ‘earth’ artworks (by Robert Smithson and others) in the restoration of landscape, rather than just its manipulation (Finkelpearl 2000).

As an artist Chin did not have a background in plant sciences and began making inquiries of local botanists (Finkelpearl 2000). Chin’s initial idea was to extract metallic

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142 In the case of the Harrisons, Newton is a trained sculptor and Helen is a literary academic (who specialized in the works of Geoffrey Chaucer) and former public school teacher. In the second team, Chin is a conceptual artist and professor, while Chaney is a Ph.D. scientist and senior research agronomist for the United States Department of Agriculture (USDA).

143 The Harrisons were concerned with species decline, sustainable food production, and loss of estuary habitats. Chin and Chaney focused on remediation of soils and terrestrial ecosystems contaminated with toxic materials.

144 Since the Harrisons published their research on successful methods of rearing *Scylla serrata* in captivity, the species has become increasingly popular in aquaculture in Africa and Asia (Hill 1980; Heasman and Fielder 1983; Prasad and Neelakantan 1989; Ying-liang et al. 2004; Hai-fu et al. 2005). Likewise with Chin and Chaney, the first *Revival Field* (1990–93) established a research precedent for the now-global use of phytoremediation (Chaney et al. 1997; Salt et al. 1998).

145 At the time Chin was rethinking his medium in the wake of an expensive and personally exhausting sculpture show mounted in Washington, DC. Chin has stated, ‘I discovered something in the Whole Earth Review about Terence McKenna, who is a psilocybin expert. He’s into this whole mushroom cult idea . . . His article mentioned something about plants cleaning up waste fields, but he was focusing on *Datura stramonium*, which is known as Jimson weed. “Well, there it is”, I thought, “Jimson weed . . . it’s plants, I see it as a sculpture”’ (Finkelpearl 2000: 391).
pollutants from soil using Jimson weed (*Matura stramonium*) as a kind of ‘modern metallurgical/alchemic project’ (Finkelpearl 2000: 391). As his research and communication with scientists continued, he was referred\(^\text{146}\) to Dr. Rufus L. Chaney, a senior USDA agricultural research scientist working in Maryland. Chaney had previously researched the idea that planting a polluted area with hyperaccumulator plants might aid the recovery of soil viability and, in turn, local ecosystem rehabilitation.\(^\text{147}\) Chaney ‘had proposed phytoremediation … as early as 1983, but never implemented a field test’ (Spaid 2002: 9).

When Chin contacted him, Chaney suggested that Jimson weed\(^\text{148}\) was not an appropriate plant. In an interview, Chaney stated: ‘In our first conversation I told him that he had a good idea, but the specific approach ... was a dead end . . . the first thing that he’d read about was actually a cell culture, a *slurry* of cells’ (Finkelpearl: 410) that could possibly trap radioactive isotopes and some toxins\(^\text{149}\) but would not extract metal. So Chin began thinking of other species and pushing Chaney toward collaboration.\(^\text{150}\)

Over time Chaney recommended readings to Chin, such as Robert Richard Brooks’s *Biochemical Methods of Prospecting for Minerals*, in part to test the artist’s sincerity and ability to learn enough science to make a collaboration possible (Finkelpearl 2000). As Chaney stated, he was very sceptical: ‘I think the thing that worries a scientist in this kind of collaboration is that the artist won’t understand the science and will embarrass the scientist’ (Finkelpearl: 405). As Chin’s understanding of the science grew, Chaney began to become secure with a collaborative project but made it clear that under the conservative Reagan administration (whose policies flowed smoothly into George H. W. Bush’s presidency) there was no available funding for phytoremediation research, and as a result his work in this area had been shelved (Finkelpearl: 405).

Undaunted, Chin applied for and received funding for the project from a cultural rather than a scientific institution, the United States National Endowment for the Arts (NEA). Spaid (2002) posited that ironically, Chin’s NEA funding for the collaborative research was also nearly denied, because conservative senators and elements of the same Reagan and Bush administrations that had shelved Chaney’s research created a series of controversies regarding NEA grants from 1989 through the 1990s (Finkelpearl 2000). Though recommended by the grants panel, Chin found his proposal denied by newly appointed NEA chairman, John Frohnmeyer, as he deemed *Revival Field* more of a science project than an artwork (Spaid 2002). Chin rebutted the decision by Frohnmeyer through a letter-writing campaign to museums and arts organizations. Chin stated, ‘I heard [that] Frohnmeyer was livid … All he had wanted to do was make a political statement for John Sununu and President Bush. He thought it would be simple. He found my piece questionable enough from his perspective, and he hated the words “invisible aesthetics” that I used to describe my work’ (Finkelpearl 2000: 395). Eventually, Chin was able to meet with Frohnmeyer to ‘articulate the project’s artistic

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\(^{146}\) Kirk Brown from Texas A and M University referred Chin to Chaney (Finkelpearl 2000).

\(^{147}\) This does not necessarily represent an immediate return to the species that were indigenous at the time of pollution, but at minimum using natural biological means to extract toxins from the site and returning it to a state that could prove habitable for a broad range of species (Chaney et al. 1997).

\(^{148}\) Jimson weed is better known as a hallucinatory plant that can sicken and kill cattle (Finkelpearl 2000).

\(^{149}\) Subsequent research indicates slurry cells are effective in remediating other types of pollution. See, for example, http://www.microbialcellfactories.com/content/7/1/5 [17 October 2014].

\(^{150}\) According to Chin, Chaney ‘expected seven years to get a site and wasn’t even going to budge forward until something real was in sight’ (Finkelpearl 2000: 399).
merits’, and funding was restored (Spaid 2002: 9).

Simultaneously, Chin sought an appropriate location for Revival Field, a task that also was not without obstacles. Chin found the Pig’s Eye Landfill in St. Paul, Minnesota, to be an appropriate polluted environment; additionally, the project could be supported by the Walker Art Center in Minneapolis. St. Paul authorities, however, were not initially in favour of acknowledging an area as polluted, much less highlighting it for public display (Finkelpearl 2000). However, the city of St. Paul eventually granted Chin and Chaney permission to proceed with their hybrid art/science experimental sculpture.

Once the site was secured, Chin and Chaney (and a team of students and other volunteers) planted 96 plots to conduct varied experiments on how effectively the plants could absorb pollutants (Chin 1992). The shared science and art concept with the project was ‘detoxifying a 60-square-foot section’152 of landfill, with the artist working in the field with the scientist to conduct primary research. The plots were assessed on the ability of six species of plants, such as sweet corn (Zea mays), bladder campion (Silene cucabalis), and others to absorb varied metal pollutants from the soil (Matilsky 1992; Krug 2006). Chin, his students, and other volunteers regularly monitored changes in soil quality. When harvested in the fall, plant, soil, and earthworm samples were carefully prepared, bagged, and sent to Chaney for further analysis (Chin 1992).

During the first year of installation, Revival Field had setbacks,153 but by the second season, there were signs of noticeably positive changes to the soil and the overall ecosystem (Finkelpearl 2000). Chin’s assistant and students noted that insects and worms were repopulating in the soil. The artist commented: ‘Initially ... there were very few worms. It was not good soil. It had a monoculture on top—but this plant was not accumulating anything. It had just adapted to this hostile climate’ (Finkelpearl 2000: 402–403). Over time Chaney’s experimental plants took hold, and the landscape began to visually change, as the team noted. Chaney’s specimen tests later confirmed that the plants were effectively absorbing the metals from the contaminated soil, allowing it to return to a less toxic state (Finkelpearl 2000).

The pragmatic results of Revival Field were that Chin and Chaney created the first large-scale phytoremediation experiment, pioneering new techniques for reclamation of polluted land. Secondly, this science experiment (as artwork) demonstrated that the usage of varied species of plants for phyto-extraction could effectively remove metals from soil, creating a viable new field of environmental industry (Chaney et al. 1997). Thirdly, from this initial successful experimental trial, the team were able to expand to additional sites with new successes.154 Lastly, Revival Field pioneered a completely new and economically viable155 technology of ‘green remediation’156 that is now an accepted, common practice at the US Department of Energy and EPA.

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151 Cities, including St. Paul, were concerned that attracting national attention to toxic sites would be bad publicity (Finkelpearl 2000).
152 http://www.satorimedia.com/fmraWeb/chin.htm
153 During the first year vandals broke through the fence and some plants were eaten by animals, but by its second year methods had been further refined and a greater yield occurred (Finkelpearl 2000).
154 The project is ongoing as of the 2000 interview with Finkelpearl with several installation sites: Revival Field, St. Paul, MN, 1990–93; Revival Field II, Palmerton, PA, 1992–98; Revival Field III, Soldier Field, MD, from 1996; Revival Field IV, Germany, 2000.
155 According to Spaid (2002), New York Times analyst Andrew Revkin predicted that by 2005 the new phytoremediation industry would become a $400 million business.
156 http://www.epa.gov/superfund/greenremediation[17 October 2014].
This science of remediation and the use of such plants has become an increasingly used tool among other artists following *Revival Field*, along with other novel tools for restoration that Spaid has referred to as ‘EcoVentions’.157 As Matilsky further asserted, the project created new media (polluted soil) for sculpting, ‘to carve the landscape through the use of hyperaccumulators’ (1992: 211). As the artist himself stated:

Conceptually, this work is envisioned as a sculpture involving the reduction process, a traditional method used to carve wood or stone. Here the material being approached is unseen and the tools will be biochemistry and agriculture. The work in its most complete incarnation (after the fences are removed and the toxin-laden weeds harvested) will offer minimal visual and formal effects. For a time, an intended invisible aesthetic will exist that can be measured scientifically by the quality of a revitalized earth. Eventually that aesthetic will be revealed in the return of growth to the soil (Chin 2003).

This transdisciplinary art project appropriated scientific tools and protocols as a new form of conceptual artistic process, with the view of the restored landscape as an innovative aesthetic development. Underlying these methods was a strong cooperation between disciplines as well as outreach to the public and students to volunteer as researchers, a position that both reflects approaches of transdisciplinarity by Gibbon et al. as well as some forms of participatory science espoused by Irwin and others, as discussed in chapter 1.

Another important practical result of *Revival Field* was that science was allowed to develop and operate to some degree outside the demands of fiscal sponsorship,158 precisely because it was contextualized, in the case of *Revival Field*, as an artwork. As art theorist Stephen Wilson noted, this flexibility is often invaluable:

Free from the demands of the market and the socialization of particular technical disciplines, artists can explore and extend the principles and technologies in unanticipated ways. They can pursue lines of inquiry abandoned because they were deemed unprofitable, outside established research priorities, or strange (Wilson 1995: 3).

The fact that this work received (and almost lost) funding from the NEA is of historic importance and demonstrated that a tremendous amount of valuable research can come from modest funding159 and can set precedent for future, similar ecological art practices. It is also important to consider a counterpoint offered by Earth artist Robert Morris, who expressed his concern for artists doing such remediation works that are cost-effective to the industry that polluted the environment in the first place, as quoted in Matilsky (1992: 12):

… art was going to cost less than restoring the site to its ‘natural condition’. What are

157 The term ‘Eco-Vention’ (ecology + invention) was coined in 1999 by Spaid and in part described an artist-initiated project that employs an inventive strategy to physically transform or restore ecosystems and/or ecological communities towards more natural levels of function (Spaid 2002).

158 As the majority of scientifically funded research projects seek specific results or at least to prove a specific hypothesis for further research funding or peer review, *so Revival Field* was free to fail in this regard if it did not work. However it did work, and Chaney published several peer-reviewed articles as a result of the research conducted as *Revival Field* (Chaney et al. 1997).

159 As Spaid (2000) suggested, $10,000 is a very limited budget for either a large-scale artwork or a major scientific research project.
the implications of that kind of thinking ... that art should be cheaper than nature? Or that siteworks can be supported and seen as relevant by a community only if they fulfil a kind of sanitation service?

This opinion is shared by art theorist Marga Bijvoet (1997), who feared that artists might be exploited under such conditions, because they tend to work more idealistically, charging less for environmental restoration projects than commercial reclamation companies. This position, at least to some degree, concerned Chin during the creation of Revival Field.\footnote{As Chin commented, ‘It’s going into privatization, opening up this whole field of technology. A lot of people are going for plant patents, trying to make money (…). Well, that’s real-world dynamics, and I just want to see the field. I want to see four square miles transformed. Our industrial past can have one more possibility for regrowth through these managed systems’ (Finkelpearl 2000: 404).}

So under this paradigm it seems to be a question of what the artist deems ethical (e.g. the right thing to do for the ecological community, reflective of Leopold’s morality) and can afford to do in the sense of surviving in a society.

Outside of these issues, such environmentally restorative artworks may look good for those that allowed them. Chin believed that the Minnesota authorities finally relented and gave permission to use the landfill site when they decided that the work could be good for public relations and the municipality’s image (Finkelpearl 2000). Thus, artists working in this realm need to be cautious, as there is a risk that unknowingly they may help to ‘green-wash’. However, in the case of Revival Field, it is evident that remediation successes far exceeded any publicity efforts on the part of local municipalities.

Larger philosophical implications arose through this analysis of Revival Field. Firstly, even an austere landscape can be remediated, and such an action is morally just, an approach reflective of the land ethic discussed earlier by Aldo Leopold. Art became a functional tool to facilitate remediation science through cooperation, offering an ecological benefit to society at large. This method that parallels thoughts by Kepes (as discussed earlier), who suggested that art could evolve into a utilitarian ‘good’ tool for real-world social and environmental restoration. This opinion is exemplified in the practices of Patricia Johanson and Chin, who viewed polluted ecosystems as something to be shepherded and repaired to the best of our abilities,\footnote{The idea of repairing and self-repairing landscapes as well as species naturally and through human assistance appears frequently in the ideologies presented by scientists and science philosophers James Lovelock and Edward O. Wilson.} but it is in sharp contrast to the earlier ‘Earth Art’ movement.\footnote{See the work of Robert Smithson, regarded by some as ambivalent to ecology (as discussed in a previous chapter). Smithson was not opposed to ecology but at the same time commented that efforts to reclaim polluted sites through art might only serve to obfuscate and superficially cover over significant environmental damage (Bijvoet 1997).}

Additionally, through such a creative cooperation between an artist and a scientist, a real-world problem (soil degradation) could be addressed and a solution offered. This is an underlying reasoning for transdisciplinary projects in the first place, under the definitions offered by Nicolescu, Mittelstraß, and Gibbons et al. Such art practice combined with primary research could be made participatory through the aid of volunteers and students, reminiscent of methods applied in citizen science programs as discussed previously by Pliz, Irwin, Bonney, and others. As Irwin had stated of such environmental problems in the first place, ‘Their origins … are thoroughly social problems, problems of people’, and it will take public awareness of these issues and their participation to solve them (1995: 168).

Chin and Chaney’s seminal transdisciplinary artwork, Revival Field, facilitated and generated new scientific knowledge while planting the seeds for the international application...
of phytoremediation science and industry. In addition, *Revival Field* increased non-specialist understanding of the ecological phenomenon of soil degradation and offered a solution to remediate such environments.

### Section 4.4. Pig Wings (2000–2001) by Tissue Culture and Art Project

As with *Revival Field* and *The Lagoon Cycle*, the influential biological artwork *Pig Wings* by Oron Catts and Ionat Zurr (Tissue Culture and Art Project: TC&A), was the result of combinatory methods in art and science. *Pig Wings* furthered scientific knowledge through the integration of product design methods with biomedical techniques employed in tissue engineering. This work, as with those discussed previously, increased understanding of environmental issues; in the case of *Pig Wings*, the work embraced ethical concerns about proprietary ownership and ecological impacts of biological materials utilized in the commercial biomedical industry.

Differing from the macro view (whole organism or ecological system) presented in the living works by the Harrisons and Chin and Chaney, TC&A focused on the manipulation (harvesting and growth) of corporeal material at a cellular level. Tissue Culture and Art Project (TC&A) began in 1996 when Oron Catts and Ionat Zurr, both designers and artists, became interested in the potential for interaction between biology and design (Catts and Zurr 1999). While working with Professor Miranda Grounds at the University of Western Australia’s Department of Anatomy and Human Biology (Perth), TC&A began to explore these ideas with initial experiments (Catts and Zurr 1999). This research, along with the artists’ training in tissue engineering, continued during a 2000–2001 residency by research fellows at the Massachusetts General Hospital Tissue Engineering and Organ Fabrication Laboratory of Harvard Medical School (Boston). Working in the famous Harvard laboratory of Dr. Joseph Vacanti, TC&A continued to refine tissue-engineering techniques and expand the concept of their works to create ‘a platform for the rethinking of our relationship with life’ (Catts and Zurr 2002: 2).

During this period, *Pig Wings* was proposed as *Wings Detached: The Good, The Bad, and the Extinct*, a nearly commissioned artwork for a genetic-themed exhibition at the Wellcome Trust gallery Two10 in London (Zurr and Catts 2005). After much debate between the artists and the curator (which the artists later made public), the Wellcome Trust rejected the proposal for the work and reneged on potential funding. (For a full account of the nearly five-year debacle, see Zurr and Catts 2005). Undaunted, the artists proceeded at the Harvard laboratory to create three sets of tissue ‘wings’ from mesenchyme stem cells collected from pig bone marrow (Catts 2012). Once collected, the cells were inoculated for growth onto

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163 Although the Harrisons’ work primarily focused on whole species or ecological systems, Newton Harrison experimented in the 1960s with tissue culturing plant cells in the work *Life and Death of a Lilly Cell* (1969) and even planned to culture cells from his own liver for consumption, a work he conceived would be a form of cannibalistic art (Harrison 1974).

164 According to Oron Catts, he was ‘trained as a product designer; Ionat was doing photography and media studies at the time’ (Ballengée 2012). Catts’s thesis had explored the idea of biologically designed objects.

165 Vacanti is considered one of the founders of contemporary tissue engineering science and was one of the leading scientists working on the famous mouse with an ear grafted onto its back (Zurr and Catts 2005).

166 According to Catts, ‘The exhibition was supposed to celebrate the so-called completion of the first draft of the human genome project’ (Catts 2012).
three-dimensional, digitally rendered (3-D printed) scaffolds\(^{167}\) shaped like three types of wings, a method still novel to bio-medical science at that time (Zurr and Catts 2005). Wing shapes were informed by natural evolutionary designs (from three types of flying or gliding animals) and metaphorically represented cultural perceptions or attributes of flight.\(^{168}\) Once fully ‘grown’, or in this case, covered\(^{169}\) with cells, removing them from life-supporting bioreactors ritually killed the bio-sculpture wings. Following death, the wings were gold-leafed and displayed in ‘cheap jewellery boxes’ along with photographic documentation of the process (Zurr and Catts 2005).

According to Catts, Pig Wings have since been recreated (grown again) twice, and they exhibited the original preserved (dead) wings with documentation several other times internationally (Catts 2012). On the two occasions\(^{170}\) when they have grown the living wings, a working laboratory within the art museum context has been established. Reminiscent of the Harrisons’ installed lagoons, museum visitors could see the process by which the art was created or, in both cases, grown. Fundamental to the display elements of both the TC&A and Harrison installations were life-support systems, functioning bioreactors (‘artificial wombs’) for sustaining living cells, and large filtration units for maintaining communities of crabs, respectively. The artists themselves physically were part of both the Pig Wings and Lagoon Cycle installations, performing daily maintenance such as nourishing cell cultures with nutrient solutions, paralleling the Harrisons feeding their crabs within aquaria. Beyond the performative qualities, the actions of the artists as ‘care givers’ added another layer of meaning to both works.

The role of artists as providers of life support is multifaceted in Pig Wings and The Lagoon Cycle. In the Harrisons’ work, complex artificial ecological systems were designed to support aquatic life. In the case of TC&A, complex micro-scale environments had to be established utilizing bioreactors to support the life of cells disassociated from an organic body. Learning such ‘care’, these artist groups made numerous experimental trials using complex and repeatable scientific methodologies that resulted in both successes and failures, an inherent part of the scientific research process. Death was also a fundamental component to both Pig Wings and The Lagoon Cycle; in Pig Wings, ritualized opening of the bioreactor ceased life-support and allowed for infection of cells\(^{171}\); in The Lagoon Cycle, adult crabs were harvested and consumed. Actual life cycles were inherent to the process of both The

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\(^{167}\) Each wing was made of ‘biodegradable/bio absorbable polymer (PGA, P4HB) and sized at 4cm x 2cm x 0.5cm each, and allowed to grow for approximately nine months inside a rotary (zero-gravity) cell culture incubator reactor’ (TCandA 2001).

\(^{168}\) In their artists’ statement, TCandA express that in religion and folklore, hybrid winged bodies or chimeras, both human and animal, are often attributed with moral values or status. The bird wing represents ‘good/angelic’ status, the bat wing represents ‘evil/satanic’ status. The third vertebrae wing formation, a pterosaur wing, was deemed by the artists to be largely free of cultural baggage but also was extinct and so may recall the recent scientific quest to bring back lost species (TCandA 2000; Zurr and Catts 2005).

\(^{169}\) According to Catts, ‘In this case we actually were able to get a significant replacement of the polymer by the tissue and the extra cellular matrix—we differentiated the mesenchyme stem cells into bone and ended up with bony structures in the approximate shape of the original 3D printed scaffolds’ (Catts 2012).

\(^{170}\) Pig Wings was shown twice ‘live’ in bioreactors for the ConVerge, Adelaide Biennial of Australian Arts, Art Gallery of South Australia, and Biofeel Biannual of Electronic Arts Perth, Perth Institute of Contemporary Arts, in Perth, Australia, both in 2002 (Catts 2012).

\(^{171}\) In the artists’ account, the wings were maintained alive for the first 10 days of the show, but without anyone able to care for the wings (to ‘feed’ and maintain them under sterile conditions), they had to be ritually ‘killed’ by the artists before returning to Perth. This killing involved taking the semi-living sculptures out of containment and allowing the audience to ‘touch (and be touched by) the sculptures’. Fungi and bacteria existing in air and on the viewer’s hands overwhelmed the fragile cells (Catts and Zurr 2007: 239).
Lagoon Cycle and Pig Wings: induced breeding in crabs/cell harvesting from pig bone marrow; crab egg laying/inoculation of stem cells to scaffolds; birth of hatchling crabs//cellular differentiation; larval growth/somatic formation among cells; harvesting adults//harvesting tissue ‘bodies’. This inclusion of life processes, though not common today in contemporary art, is reminiscent of works by Haacke and Johansson, as discussed previously in chapter 2.

Connections can also be made between Pig Wings and Revival Field. As with Chin, TC&A offered a new means of artistic production, in this case sculpting at the cellular level. An immediate parallel can be made between TC&A's process of seeding cells for tissue generation and Chin’s concept of sculpting earth through plant growth. Likewise the tissue scaffolds (micro landscapes) in Pig Wings are carefully designed with formalistic decisions, recalling the careful layout for the plantings of Revival Field. Additionally, both TC&A and Chin utilized living matter as media but allowed the final result (growth) to be governed by the material itself: cells compared to whole plants, respectively. Although this method is reminiscent of Eastern practitioners of bonsai, it is novel for Western modernists to open the control of art production to the ‘chance’ that occurs in living processes.

On a practical level Pig Wings may have furthered knowledge within the scientific community, though it is much more difficult to gauge than The Lagoon Cycle or Revival Field. Firstly, as research fellows at the Harvard laboratory, TC&A introduced the concept of utilizing CAD/CAM (computer aided design and manufacturing) into the tissue engineering process. Here Catts’s skills as a product designer enabled the team to experiment and create novel shaped scaffolds (substrates on which to grow tissue). The wing designs were rendered virtually in the CAD/CAM program, then output using a rapid prototype printer (Catts and Zurr 2002). Secondly, by diverging from standard product design methods, the artists used biodegradable and/or bio-absorbable resins to make the three-dimensional prints, to insure that tissues could survive on them (Catts and Zurr 2002). The artists developed these methods from their own research and experimentation, independent of other researchers who were working in a similar area, and later published their findings (e.g. Sun and Lal 2002). As Catts has stated, ‘This kind of work had been developed in parallel in other labs around the world, so I can’t claim exclusivity or particular novelty of this approach” (Catts 2012). Although TC&A has stated that one of their aims was to research such technologies, and though they did publish their results in a peer-reviewed science journal, they have positioned themselves as artists, not scientists or bio-technicians, and they use their experiments to create art, not for the intention of advancing biomedical science (Catts and Zurr 2002; Zurr and Catts 2005). However, it is impossible to imagine that their highly publicized work did not in some way influence and potentially advance tissue-engineering science.

Pig Wings, The Lagoon Cycle, and Revival Field all are works created through

172 Specifically, according to Catts, ‘differentiation from mesenchyme stem cells into bone tissue/cells … the maturation of stem cells into more/terminally differentiated cells’ (Catts 2012).
173 According to Catts, ‘as early as 1997 I was working with CAD/CAM and 3D scanning and printing for tissue engineering in Australia’ (Catts 2012).
174 Use of biodegradable and bio-absorbable materials was an already established method employed by tissue engineers (Mikes and Temenoff 2000), but their use in rapid prototyping was a novel approach at the time. These combined methods are now used often in the field of tissue engineering (Sun et al. 2004; 2005).
175 Catts et al., 2000 in Tissue Engineering Vol. 6 No. 6 December.
technological innovation and research instigated by artists, yet artists can retain important critical distance, as Wilson suggested:

Artists can establish a practice in which they participate at the core of this activity rather than as distant commentators or consumers of the gadgets, even while maintaining postmodern reservations about the meaning of the technological explosion (1995:1).

In Wilson’s case, the conflux of art and science was in information technology and artificial intelligence. However, the goals of artificial intelligence research and biotechnology are not always dissimilar, as in both cases researchers may be attempting to create life, defined either as a self-aware machine or as a lab-engineered semi-organism. TC&A embodied Wilson’s category of ‘art as research’, and Pig Wings were dually objects of art and voucher specimens from primary experiments (Wilson 1995: 2).

As with Wilson’s AI works, the system or process of creation is often an important element of the work. As such, Pig Wings and the practice employed by TC&A appeared to be an interpretation of Jack Burnham’s ideas176 that sculpture would evolve from static art objects to systems of art involving complex processes and interactions. Rather than encompassing a specific single medium (stone, clay, metal), these sculptures could instead be characterized by a set of relationships, responding both to internal mechanisms and external conditions177 (Burnham 1968; 1971; 1975). There are several such sets of relationships in Pig Wings: firstly the internal mechanisms within the living tissues utilized as media in relation to the artificial environments (bioreactors) required to sustain their ‘life’; secondly the system of knowledge (the biomedical field), in which the artists had to become embedded in order to create the works in the first place; finally, the role the bio-sculpture artefacts themselves have with audiences to generate discourse about the biomedical industry when publically exhibited to audiences of non-specialists. These layers of complexity place Pig Wings within the genre of transdisciplinarity, as they overlap and potentially move beyond the single disciplines of art, science, technology, and activism.

To create Pig Wings, TC&A (Catts and Zurr) had to work within a biomedical facility, normally inaccessible to non-specialists, and receive specialized training in organ and tissue engineering as research fellows. As art theorist Jens Hauser (2008) has discussed, TC&A are an example of artists who conducted a “wet” artwork while embedded within the field of biotechnology. As such they followed the same procedures and protocols as the primary biological researchers they worked with. Yet, as artists, their intention and outcomes were divergent from their laboratory colleagues.178 Although TC&A became biotechnologists, they retained a critical distance as artists in order to pose complex moral questions about the use of animal materials in such research practices and the complex ethical implications of manipulating life at a molecular level.179 Through exhibiting Pig Wings publicly, the biomedical

176 As discussed in Chapter 2 in relation to the works by Haacke and in this chapter in relation to works by the Harrisons.
177 As seen in works previously discussed by Haacke, Johansson and the Harrisons in this dissertation.
178 As artists, the group were able to experiment freely without the pressure of having to generate the proof of findings that their laboratory peers would have needed for their work. This scenario is similar to that of Revival Field, and as discussed earlier in this chapter by Spaid (2002), can lead to new developments.
179 TCandA state of this ethical questioning in the work, ‘We wanted our work to be, among other things, pitiful (to borrow Virilio’s term), and to emphasize the compassion and care one has to exercise in regard to other (and The Other) living (and semi-living) beings’ (Catts and Zurr, 2005: :2).
industry was implicated, and laboratory results not normally open to public could be viewed by non-specialists in order to generate discourses about such experimental procedures.

Additionally, one of TC&A’s stated purposes was to create ‘semi-living’ sculptures, questioning the definition of what constitutes life within the context of living cells disenfranchised from an organism (Catts and Zurr 2002). Such disembodied tissues are the foundation for modern tissue engineering science, yet in occidental cultures we have yet to ethically or legally establish a standard guideline of governance for such objects or the research practices that bring them into existence (Trommelmans et al. 2007). Likewise, from an ethical and legal standpoint, we have not yet defined if such cells sustained in vitro are ‘living’ beyond the biological sense, and they certainly transcend what we would normally define as ‘life’, at least in our traditional, corporal definition.180

As such, tissue engineered ‘entities’ can be culturally understood, at best, as ‘others’ and often are morally identified as evil or unnatural, like Mary Shelley’s monster in *Frankenstein* (Zurr and Catts 2003; Catts and Zurr 2003). Paradoxically, such cultured entities are not cognitive,181 at least not in our traditional understanding of sentience, as they lack the complex neural systems we believe necessary for consciousness (Zurr and Catts 2003). So one must ask, how is an entity evil if it lacks the conscious ability to reason between right and wrong? TC&A has suggested instead that such artificial entities, though at least partially composed of natural living material, belong to a new taxonomic group, the ‘semi-living’,182 the existence of which we as a society have yet to come to moral or even rational terms.

*Pig Wings* raised timely questions on the nature of what it means to be human from a biological standpoint at a moment in history characterized by rapid biomedical advances. Such entities are living evidence of artificial/natural hybridity183 and hold the potential for future human/non-human, chimerical outcomes. Already, research has been conducted to grow tissue-engineered organs for potential human transplant (Zurr 2002). In various artists’ statements, TC&A comment on the actualization of ‘Deleuze and Guattari’s metaphor of “becoming animal” until there is no longer man or animal’.184 There are many potential, though not well-understood implications of tissues from varied species becoming interchangeable. This would certainly cause barriers between humans and other species to become blurred beyond singular species definitions and could redefine what it is to be human (Zurr 2002). Such human and non-human hybridity is becoming closer to biological reality, and advances will surely challenge current cultural belief systems (Zurr 2002; Catts et al. 2002).

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180 According to Zurr and Catts, ‘Growing parts of an organism independent to it complicates notions of what are life, self, and identity” (2003: 5)

181 As Zurr and Catts have stated, ‘Our understandings of neural tissue as a “thinking” unit, and as the place where consciousness resides, made its manipulation more difficult. Questions in regard to the “understandings” and sentence of the tissue that we hardly understand but manipulate made it ethically challenging. Epistemologically, the idea of future “intellectual” communication with a neural tissue, which is grown independently from a body, raises many inspirations for better understandings of the different levels of life’ (2003: 8).

182 As Zurr stated, “‘Semi-Living’ is a new class of objects/beings that is at once similar and different from both human-made objects and selectively bred domestic plants and animals (both pets and husbandry)” (2002: 63).

183 As the artists state of this molecular blur between the natural and artificial, ‘With the aid of our newly acquired knowledge of life processes—from ecologies to molecular biology—we can exercise an ever growing degree of control over the manipulation of living biological systems to the extent that the techno-sphere (human made) and the biosphere (nature) are increasingly indistinguishable’ (Zurr and Catts 2003: 1).

184 Catts et al.,2002:15.
Furthermore, TC&A has raised complex bioethical and environmental questions about the use of non-human animals (often-sentient\textsuperscript{185}) organisms in the fields of art and biomedical research. With their later work *Disembodied Cuisine* (2003),\textsuperscript{186} the artists grew ‘victimless’ or ‘in vitro’ meat as an ironic statement. On one hand the piece presented the possibility of future foods manufactured without the suffering and death of animals, yet in irony the cells need tremendous amounts of growth nutrients derived from animal materials (the bone marrow of developing calves) and energy to produce them. As the artists have stated:

[C]urrent methods ... require the use of animal-derived products as a substantial part ... of various tissue culture procedures. This point about tissue culture seemed (until recently) to go unnoticed by the advocates of its use as a replacement for animal experimentation ... For example, as a rough estimate (based on our experience with growing in-vitro meat), growing around 10 grams of tissue will require serum from a whole calf (500 ml.), which is killed solely for the purpose of producing the serum (Catts and Zurr 2008: 132–133).

Likewise, Margaret Mellon, senior scientist with the Food and Environment Program at the Union of Concerned Scientists, has suggested the environmental impact of growing such meat may be much more environmentally destructive than traditional farming methods, even if only the transportation and processing of such biomedical materials is taken into account (Levine 2008). Regardless, the commercial pursuit of such ‘victimless meats’ has continued, with several researchers claiming significant advances (Edelman et al. 2005; Datar and Betti 2010; Welin et al. 2012).

TC&A increased public understanding of environmental (and other pertinent) issues by generating the provocative artwork, *Pig Wings*, which questioned the biomedical industry and our collective comprehension of the rapidly changing field of tissue engineering. TC&A immersed themselves into the practice and process of the very biomedical field that they questioned and as such, deviated from the strategies employed by Chin or the Harrisons. Instead, TC&A acted as artist protagonists, a position in modernism seen in others such as Gustave Courbet, Marcel Duchamp, or more recently, Ai Wei Wei. As protagonists, the artists actively engaged the public by asking fundamental questions about what it means to be human and what constitutes life at this point in history and the near future. They also made inquires into what role the artist may have in utilizing such advances in biotechnology.\textsuperscript{187} Such strategies recall what art critic John Gruen posited of artists during the 1960s Art and Technology movement as they ‘reach into the unknown and produce art works that will

\textsuperscript{185} The ambiguous definition of ‘sentience’ speaks directly to the core of TC&A’s discourse. Defined as ‘1. Capacity for feeling or perceiving; consciousness; 2. Mere awareness or sensation that does not involve thought or perception’ (Webster’s New World College Dictionary/dictionary.com) the term’s usage varies in different contexts. The fields of biology and artificial intelligence research often view sentience in terms of self-awareness, reflecting the Cartesian concept, ‘I think, therefore I am’, as discussed in chapter 1. As follows, (non-human) animals may be considered sentient in terms of feeling and perceiving (which is significant to the animal rights movement, as it implies the ability to suffer), however not necessarily in the sense of consciousness—common belief separates them from humanity in that any capacity for organizational intelligence, self-awareness, and complex emotion is subject to debate.

\textsuperscript{186} This project was also began during their residency at Harvard University but would not be realized at an exhibition until 2003 when it was shown in the exhibition L’Art Biotech in Nantes, France (Hauser 2003).

\textsuperscript{187} Art theorist Jens Hauser has suggested that this position moved beyond prior systems of relations by transgressing procedures of representation and metaphor through the manipulation of life itself as a means of artistic expression (Hauser 2002).
combine the most advanced technological discoveries with the most daring, the most outrageous creative ideas an artist may be capable of dreaming up’ (quoted in Bijvoet 1997: 3). TC&A upped the ante by creating such outrageous works, which posed an important question to society: ‘If this is possible, should we go down this path?’ (Catts and Zurr 2002: 366). TC&A utilized their combined creativity (as an artist and a designer) while utilizing scientific methods to conduct research and in so doing crossed several disciplines to address socio-ecological issues of the biomedical industry in what could be referred to as ‘clustering of disciplinary rooted problem-solving’ for Mode 2 transdisciplinary outlook (Gibbons et al. 1994: 29). By contextualizing their research as art rather than science, TC&A retained a critical distance on biotechnological practices and were able to generate public discourses on the larger biomedical industry, one that has grown so rapidly and become so large in recent decades that it is impossible to surmise its potential scale of impact on organisms, ecosystems, and even our own species, which is precisely the message TC&A disseminated to larger audiences.


The long-term field research of Swiss artist Cornelia Hesse-Honegger, conducted on over 16,000 true bugs exposed to radionuclides, is another model of art and science hybridity (Hesse-Honegger and Wallimann 2008). Differing from the Harrisons, Chin, and TC&A, the artist became a trained observer of anatomical deviations in insects exposed to environmental degradation and published her findings, which challenged the opinions of the scientific community. Additionally, by presenting her findings publically through art exhibitions and the popular press, she also increased understanding of a pertinent environmental issue, in this case the harmful effects of low-level radiation on arthropod insects.

Hesse-Honegger apprenticed at an early age as a scientific illustrator at the Zoologischen Museum der Universität Zürich with geneticist and professor Hans Burlap, and later worked drawing marine animals in France and Italy. From these experiences Hesse-Honegger discovered her life-long passion for invertebrates and became fascinated with Heteroptera in 1968 (Hesse-Honegger and Wallimann 2008). Hesse-Honegger was later employed at the Zoologischen Museum to illustrate mutated and other fruit flies (Drosophila subobscura) in the laboratory of Professor Burlap. Hesse-Honegger ‘learned how to draw flies precisely, either their whole body or parts thereof, and also how to catch, authenticate, and prepare insects for collections’ (Hesse-Honegger and Wallimann 2008: 500). The artist soon began her own art works outside her professional requirements as a contracted illustrator for scientists.

Hesse-Honegger’s artistic output until that point was primarily illustration for scientific papers, and she has referenced the drawings and observations of naturalist Maria

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188 ‘True’ or ‘typical bugs’ refers to insects of the suborder Heteroptera of the order Hemiptera (Tree of Life 2005).
189 The developmental malformations were laboratory-induced by exposure to toxins (such as tetrachlorodibenzodioxin) that mimicked the effects of Agent Orange and other defoliants being used by the United States military during the Vietnam War. In later studies, mutations were induced by exposure to gamma radiation from X-rays (Hesse-Honegger and Wallimann 2008: 500–501).
190 The artist stated, ‘For work I only had to make drawings; the paintings that I made were of my own accord’ (Baldwin 2008).
Sybilla Merian as a major influence (Aloi 2009). Yet the poisoned flies of the Zoologischen Museum inspired the course of her work and also evoked a strong environmental ethic for understanding human impacts to the environment. She has stated, ‘Sensing that Nature was more and more endangered, I gradually developed the notion that mutated laboratory flies were physically rendered prototypes of our destructive behaviour, materializing the future of Nature’ (Hesse-Honegger and Wallimann 2008: 501). Inspired and perhaps shocked\textsuperscript{191} by the dramatic effects of human activity on organisms, she began to develop her long-term investigation of sculpted insects collected from radionuclide-contaminated environments by carefully documenting them through precise drawings and paintings.

Her field investigations began in 1987, a year after the Chernobyl (Ukraine, former USSR) nuclear plant disaster. Although she had been assured of the safety of post-Chernobyl low-level radiation by scientists,\textsuperscript{192} she questioned the long-term impact on insects and other wildlife, particularly in generations whose parents had been exposed to radionuclides. To begin, Hesse-Honegger collected small numbers\textsuperscript{193} of true bugs (suborder \textit{Heteroptera}) and other insects in Gyssinge, Osterfärnebo, and Gävle, Sweden (sites heavily exposed to Chernobyl contaminants) and ‘was shocked by the deformations’ (Hesse-Honegger and Wallimann 2008: 512). As ‘pilot studies’, these malformations were recorded but not analysed further to know overall deformation rates.\textsuperscript{194} However, these initial surveys, along with controlled breeding experiments\textsuperscript{195} inspired further studies of the radioactive fallout in Italy, Switzerland, and eventually in proximity to the Chernobyl reactor itself between the years 1987 and 1994. In a 1990 survey of 55 individual \textit{Heteroptera} collected from Pripjat and Seljony Mys (within 30 km of the Chernobyl reactor) 22\% showed obvious signs of deformation (Hesse-Honegger and Wallimann 2008).

In addition to sampling true bugs in sites highly contaminated by the Chernobyl disaster, Hesse-Honegger began examining \textit{Heteroptera} in proximity to nuclear power stations and other sources of low-level radiation, first near her home in Zürich, then expanding out to Aargau (Switzerland), La Hague (France), Gundremmingen (Germany), Sellafield (U.K.), Three Mile Island (USA) and others (Hesse-Honegger and Wallimann 2008). As the range of her investigations expanded, so did her methodology; she would collect more robust numbers of insects at study sites and began comparing their overall deformity rates with those collected at sites deemed less impacted by radiation. In total Hessee-

\textsuperscript{191} Hesse-Honegger stated, ‘I knew from then on what it meant to look at a deformed insect. I also knew what humans were capable of doing to nature’ (Quoted in Baldwin 2008).

\textsuperscript{192} Of this experience the artist stated, ‘I imagined that my beloved true bugs, especially those living in contaminated areas, could suffer body deformations. I discussed this disturbing idea with Professor Ralph Nöthiger, geneticist at the University of Zurich, but he was convinced that the radiation in Europe was far too low to have such an effect on \textit{Heteroptera} or other creatures’ (Hesse-Honegger and Wallimann 2008: 500).

\textsuperscript{193} As for the small sampling size of insects, she has stated, ‘In these places, I collected relatively small numbers of true bugs … because I was mainly working as a painter, without having yet the intention of starting a systematic study’ (Hesse-Honegger and Wallimann 2008: 517).

\textsuperscript{194} However at a least one of her study sites (Gävle, Sweden; see Saura et al. 1998) later confirmed that genetic mutation levels in \textit{D. subobscura} were significantly higher in comparison with those of other European marginal \textit{D. subobscura} populations.

\textsuperscript{195} In addition to field studies of insects in Sweden, Hesse-Honegger also conducted breeding experiments of the fruit fly \textit{Drosophila melanogaster}. Of these experiments she explained, ‘One year after Chernobyl, I started my studies in Sweden and the Canton Ticino. It was autumn as I worked in the Canton Ticino; I thought I could collect \textit{Drosophila melanogaster} and breed them in my kitchen … I borrowed some bottles with food from the zoological institute where I worked. … In the Canton Ticino, a town called Rancate was one of the most affected places from the fallout of Chernobyl in Switzerland, and I collected three pairs of \textit{Drosophila melanogaster} and bred three different lines. One pair did not have any children; the others I bred up to the fourth generation. I can say that I am the only person who did such a breeding project with flies from a Chernobyl-contaminated area’ (quoted in Aloi 2009: 34).
Honegger examined more than 16,000\textsuperscript{196} field-collected \textit{Heteroptera} and produced more than 300 detailed illustrations, documenting malformations (Hesse-Honegger and Wallimann 2008). The researchers’ overall findings demonstrated that at some study sites with above-natural background levels of radiation, as many as 22% to 30% of \textit{Heteroptera} had some form of obvious abnormality compared to those collected at control sites where the deformity ratios ranged from less than 1% to 3% (Hesse-Honegger and Wallimann 2008). By focusing on the small (insects) Hesse-Honegger, like Charles Darwin with his study of earthworms, found important insights into larger ecosystems: in the case of the true bug study, that malformation rates correlated with degrees of contamination at field sites.

Hesse-Honegger’s hypothesis for this statistical increase is that the diet of true bugs (mostly phytophagous, feeding on plant sap) makes them more susceptible to pollutants absorbed by plants. As she has stated, ‘True bugs extract liquid from the plants they live on … So if the plant is contaminated, they take a lot of radioactivity into their bodies’ (quoted in Biba 2010). In this case contamination took the form of radionuclides such as tritium (\textsuperscript{3}H), carbon-14 (\textsuperscript{14}C), or iodine-131 (\textsuperscript{131}I) released by nuclear power and nuclear-reprocessing plants, as well as cesium-137 (Cs-137) and other long-lived isotopes from nuclear disasters like Chernobyl and bomb-testing fallout. In addition Hesse-Honegger also believed that since true bugs are physically small (such as leaf bugs, one of the artist’s favourite subjects) and have limited ability to fly, they are not likely to leave even contaminated habitats (Biba 2010).

The process of Hesse-Honegger’s true bug investigation retains traditional aspects of scientific illustration combined with primary research entomology\textsuperscript{197} such as detailed observations or specimen morphology utilizing a microscope. Even larger \textit{Heteroptera} specimens still required magnified examination, as many of the morphological deviations she recorded were invisible to the naked eye (Hesse-Honegger and Wallimann 2008). Hesse-Honegger has described her tedious precision when documenting by using a ruler inside of microscope oculars to draw in exact proportion; she then reduces this drawing to ‘one precise line’ on transparent paper (Aloi 2009: 32). Using graphite paper, the transparency is copied onto watercolour paper, and watercolours are added in gradual layers. The process is slow; she asserts that it can sometimes take more than a month per insect portrait (Aloi 2009). Similarly she states the cost of material and research time posed a challenge: ‘I pay for the costs involved in the research, all the travelling, and the painting time . . . it is rare that people who use my work for publication pay . . . and books don’t really bring a lot of money either’ (quoted in Aloi 2009: 32). In addition to creating her personal artwork she has also continued work full-time as a scientific illustrator and as a silk textile designer, just to keep her environmental investigations funded (Aloi 2009).

Although photographs could record these malformations more quickly, Hesse-Honegger’s intent is not merely scientific documentation but instead highly detailed works of fine art created by traditional drawing and painting. She has even named Jan Vermeer, Piet Mondrian, and the minimalist works of Kenneth Martin among her artistic inspirations (Aloi 2009). However, the precise quality of Hesse-Honegger’s art in this case has worked as a disadvantage, as she has stated: ‘Everybody thinks that my works are scientific illustrations,\textsuperscript{198}

\textsuperscript{196} In Baldwin (2008) she stated a total of 16,367.
\textsuperscript{197} As Hesse-Honegger was trained in the proper preservation of actual insects, she maintains a large collection of voucher specimens from her greater than two decades of field-work (Hesse-Honegger and Wallimann 2008).
they do not ascribe them with the value of art’ (quoted in Aloi 2009: 32). Additionally, because of the time involved for production, the sale costs of the works is high, so the works ‘rarely sell’ and remain ‘part of my research’ (quoted in Aloi 2009: 32). However, it is precisely because they are exhibited and reproduced in popular publications that they have reached a large audience with an environmental message of how sensitive organisms, even insects, may be to radiation.

When initially presented, Hesse-Honegger’s research findings generated significant scientific controversy. The commonly held scientific belief during the post–World War II era largely viewed low-level radiation as safe, and Hesse-Honegger’s findings were in opposition to this belief (Aloi 2009). When she first published her conclusions in 1988,198 ‘They thought my findings were ridiculous’ (quoted in Lloyd 2011). Even her fellow researchers at the Zoologischen Museum dismissed the initial results of her Chernobyl study. Of this experience she has stated, ‘The scientists of my university were not happy at all and claimed (without having done their own research) that the fallout from Chernobyl could not possibly cause deformations, since the radioactivity was below the threshold of the background radioactivity’, a position that was held by the larger scientific community199 (quoted in Aloi 2009: 34). Yet Hesse-Honegger’s mission was at least in part to have scientists start to look at the threat of low-level radiation exposure more closely, as she has stated: ‘I had to make these paintings to show the scientists that it would be important to start research in fallout areas’ (quoted in Baldwin 2008). The act of her art creation, grounded by her use of scientific field study methods, was intended to provoke the larger scientific community into action.

This artistic strategy had important practical outcomes. Firstly, since Hesse-Honegger publically presented her findings in 1988, numerous other scientific studies have further demonstrated the impact of low-level radiation on insects and other wildlife (a phenomenon now referred to as ‘The Petkau Effect’), and this understanding has spread internationally to larger audiences of non-specialists (Hesse-Honegger and Wallimann 2008; Aloi 2009; Decamous 2011). Secondly, Hess-Honegger’s impact on the scientific community has become increasingly prevalent, as her 2008 paper (with Wallimann, which summarized her research from 1987 to 2007) has been cited at least nine times (Google Scholar search 10, December 2012) since published in the peer-reviewed scientific journal Chemistry and Biodiversity. Hesse-Honegger’s research has even been cited in a new study of butterfly malformations in the wake of the Fukushima Daiichi disaster (Hiyama et al. 2012). In this way, Hesse-Honegger’s biological research as artistic practice not only impacted the scientific community by positing new findings,200 but also broadened the very course by which

198 According to the artist’s website, portraits of malformed insects were published in 1988 in the magazines Tages-Anzeiger Magazin and Chancen. Additionally a film on her work debuted on the German television station NDR (http://www.wissenskunst.ch/uk/aktuelles/contemporary/[13 May 2012]) .

199 This position was reflected internationally by the United Nations Scientific Committee on the Effects of Atomic Radiation: ‘Lives have been disrupted by the Chernobyl accident, but from the radiological point of view and based on the assessments of this Annex, generally positive prospects for the future health of most individuals should prevail’ (UNSCEAR 2000; see http://www.unscear.org/docs/reports/annexj.pdf [17 October 2014]).

200 Hesse-Honegger and Wallimann (2008) stated three important implications from her research: ‘The present work has two different implications: on one hand, it calls for more systematic studies to address a series of poorly investigated issues; on the other hand, it confronts us with ethical questions regarding Nature and Life in general. From the scientific point of view, it is necessary 1) to investigate the long-term effects of low-level artificial radiation; 2) to look at the radionuclide-specific effects on plants and animals; and 3) to reconsider the current threshold values for radioactive emission. From an ethical and aesthetic standpoint, we should value and preserve both the beauty and highly important function of the large class of insects. Thereby, true bugs, especially Coreus marginatus (Coreidae), could serve as sensitive “bio-indicators” in future studies’ (Hesse-Honener and Wallimann 2008: 537).
specialists are now considering low-level radiation as an environmental problem.

From a theoretical perspective, Hesse-Honegger’s practice intertwined the disciplines of fine art, scientific illustration, entomology, teratology, and activism. Differing from the Harrisons, Chin, and TC&A, Hesse-Honegger’s primary intention was to directly provoke the larger scientific into studying an environmental problem she identified and to disseminate her findings to large audiences through media and exhibitions. It could be said that her practice correlated to some degree with transdisciplinary approaches described previously by Mittelstraß and Gibbon et al., as she employed specialized knowledge from different disciplines to identify and address a real-world, complex problem at specific locations, collecting findings that she shared with the scientific community and, importantly, to a larger populace (those without specialist training in entomology or nuclear physics).

Hesse-Honegger’s works opened a necessary discussion about the ethics and environmental impact of worst-case nuclear accidents as well as everyday waste products, nuclear testing and warfare, radioactive munitions, and even safely operating energy facilities. In the wake of the Fukushima Daiichi disaster, these investigations of environmental impact and debates about perceived cost-over-benefit analyses of nuclear power are more relevant than ever. As in the works discussed previously by the Harrisons, Chin, and TC&A, Hesse-Honegger’s scientific research as art brought an environmental message to a larger populace while simultaneously offering new insights on ecological phenomena.

4.6. Conclusion

The artworks discussed above raised increased understanding of ecological phenomena for both the scientific community and larger, non-specialist audiences—such as in the case of the Harrisons’ and Hesse-Honegger’s concerns for the global threats to biodiversity. In relation to Hesse-Honegger, works by Chin spotlighted pollution in degraded habitats. TC&A critiqued the ethical and ecological impact of the biomedical industry and went further to pose a fundamental question about what it means to be human at this point in history. Likewise, they questioned the very definition of life, just as the Harrisons earlier reflected upon the life of a species deemed as a potential food-source. Hesse-Honegger challenged the scientific community itself by publishing her results first in public venues, which forced a reaction. Each of these creative strategies posed questions to audiences about real-world, complex ecological issues and as such, increased popular understanding of such phenomena.

In addition, these artists all intertwined scientific methods (whether biomedical, ecological, or zoological) into the artistic process, which crossed disciplines and thus created a genre of art process through primary research means. Likewise, each in his or her own way contributed knowledge to the larger scientific community, even if this was not the artists’ stated intention. Whether this was a new means to aquaculture crabs, to design tissue scaffolds, to sculpt with plants to remove environmental pollutants, or to score insects to understand the health of ecosystems, each offered a new discovery. Each of these artists was an explorer, offering new ways to think about the role of the artist as a contributor to a larger
social and ecological context. This is important, as increasingly artists are creating works inspired by science, yet it is seldom that they are engaged in scientific research processes such as laboratory or field monitoring techniques.

It is perhaps even more rare that artists have directly contributed to science through the sharing of new knowledge through scientific publications. The above-mentioned practitioners do, and in this way they offer important examples of what may someday prove to be a larger trend for artists: to genuinely become engaged and practicing within the field of science, perhaps even with a new form of transdisciplinary art with ecology. As with my own work, this genuine fusion of artistic creation utilizing scientific methods of inquiry is paramount and also an important strategy for reaching the public with an environmental message. Perhaps, if we are fortunate, future generations of science-informed artists will continue discovering, challenging, and offering solutions to the complex, real-world environmental problems our planet is experiencing.
Chapter 5. Case Study I. Malamp: The Occurrence of Deformities in Amphibians—Transdisciplinary Artworks

5.1. Introduction

In the works discussed in chapter 3, artists engaged audiences to draw their attention to wetland ecosystems and the problems specific ecosystems faced. In chapter 4, artists utilized methods of science to create their own form of hybrid practices, again putting forward an environmental message. In this chapter, presented as a case study, I will analyse my own practice, which has focused on the demise and deformation of amphibians for almost two decades. Such works have been presented in an effort to raise public awareness about the global plight of amphibians.

To begin with I will discuss how this Malamp project came to fruition through collaboration with several other biologists as well as the development of various aesthetic strategies over time to reach audiences. Within this context I will address by what means my transdisciplinary art project, Malamp, disseminated information about amphibians to a larger public. This long-term body of work consisted of three distinct forms: Styx, a sculptural series; Malamp Reliquaries, a photographic series; and Un Requiem pour Flocons de Neige Blessés, an ephemeral film. Each will be discussed in detail, including the methods of creation along with my underlying artistic intentions for each body of work.

Additionally, data from questionnaires to art professionals who organized exhibitions of the Malamp works will be analysed to ascertain if such transdisciplinary art can increase understating of ecological phenomena, specifically in this case, amphibian malformation and global population declines.

5.2. Background to Malamp

In my long-running project Malamp: The Occurrence of Deformities in Amphibians (1996–current), I find myself in a hybrid role as fine arts practitioner, environmental educator, and biologist. This required developing a new methodology that reconfigured art practice with participatory biology to conduct scientific research with an integrated performative aspect. I thus intended to engage the public through environmental education (Eco-Actions, discussed in the following chapter). Additionally, I had to develop new ways of expressing my concerns for amphibians through art objects, adding experimental approaches to image making, installation and video (figure 1)—a factor that not only channelled my creative expression but also allowed for dissemination of amphibian research findings to the public.
Impetus for this project began in 1995, when a group of Minnesota school children found numerous severely malformed frogs during a class field trip. The story went viral in the media within days (Souder 2000; Helgen 2012). At this point I was a young artist just out of art school, and newspaper images of these frogs and what they could mean environmentally horrified me. Prompted by these thoughts, I made contact with the Minnesota Pollution Control Agency and scientists around the United States who were studying malformed amphibians.

During 1996 and 1999, I travelled to numerous labs and affected wetlands around the United States, interviewing scientists and making artworks about the deformed frogs I witnessed. These initial artworks were individual painted portraits of the malformed frogs on repurposed paper (figure 2). This body of work continued until 2000 and consisted of over three hundred individual portraits, most of which were washed away in a studio flood some years later.

Collaboration with other biologists has always been fundamental to the Malamp project. For more than a decade and half ecologist Pierre Raymond Wariny (New York State Museum) and I have sampled wild anuran populations in the greater New York region for above-natural levels of abnormalities. Since 2000, with Dr. Stanley K. Sessions (Hartwick

In 1995 I repurposed all of my old flat artworks (bonding them together using rabbit skin glue and found latex paint) to create a large surface (50 by 50 feet). I then cut small piece of this ‘paper’ into small pieces, which could be carried in my backpack on field trips and to labs. Onsite I would ‘paint’ the deformed frogs encountered using watercolour brushes and a solution of pond water (where the frog was found) or ethanol/formalin for laboratory specimens, mixed with tobacco ash and leftover coffee.

These small paintings were silhouette-like portraits expressing my concern for amphibian extinction and the loss of that individual frog’s life. On the other hand, I wanted the materials to conceptually make a connection between amphibians, myself, and all organisms interconnected biologically and sculpted by their environments: the liquid the frogs inhabited and the materials inside of me from my own consumption of nicotine and caffeine. Each was a small reliquary made from ‘dead’ art.
College, USA), we have sought underlying developmental explanations for limb malformation in anurans and caudates (salamanders and newts). Between the years 2001 and 2003, Dr. James Barron (Ohio University) and I led field surveys, examining anuran deformation ratios in central Ohio. We submitted a paper to the United States Geological Survey’s North American Reporting Center for Amphibian Malformation (NARCAM). A similar deformed amphibian study, *Malamp UK* (2005–2008, discussed in later chapters), began as an invitation from the Arts Catalyst (London) and Yorkshire Sculpture Park (Wakefield), and later was joined by British naturalist Richard R. Sunter (Yorkshire Naturalist League). Such collaborations broadened my understanding of amphibian ecology and natural history, but also inspired numerous artworks of the amphibians we witnessed.

Through these research experiences and in an attempt to engage non-scientists with a message of amphibian conservation, the methodologies for the *Malamp* artworks grew from paintings to a variety of other media. For example, in 2001 I began utilizing high resolution scanning to portray the deformed amphibians, which would later become the photographic series *Malamp Reliquaries* (2001–present). In 2007 I began exhibiting the actual cleared and stained deformed individuals in the sculptural series entitle *Styx* (2007–present). More recently I have begun experimenting with video to express the complex sensations derived from finding malformed animals in nature with the work titled *Un Requiem pour Flocons de Neige Blessés* (2009–2011). Each of these methodologies will be discussed below in detail, as well as the results of questionnaires, which sought to gauge the potential benefit of such art-science projects in reaching a popular audience with an environmental message through visual art.
Figure 4. Various Malamp drawings, 1996–2000. Polluted pond water, ash, and leftover coffee on artist-reconstituted paper.
Sizes varied. Artist’s collection, New York, NY.

5.3. Malamp as Transdisciplinary Art with Ecology

Transdisciplinary Art with Ecology (TAE) consists of several characteristics: firstly, art as means of investigation that moves beyond singular disciplinary approaches; secondly, that such artistic investigations should strive towards real-world problem solving; thirdly, that the primary goal of transdisciplinary art is not the creation of artefacts, but an active form of inquiry (however, if such objects are generated, how may they aid in solving the real world problem being investigated?); as well as, that such transdisciplinary art projects reference a
specific space not only in geographic terms but also space as defined by community—social, biological, or ecological—and attempt to engage with that community towards solving a larger, real-world problem.

*Malamp: The Occurrence of Deformities in Amphibians* (1996–present) involved an active form of inquiry about the real-world problem of developmental malformations in frogs, toads, salamanders and newts. Further, the project addressed the lack of public awareness of the global plight of amphibians. To address these issues, methodologies of primary scientific research, visual art studio practices, and environmental education were intertwined into a holistic cycle of inquiry and means to action.

*Malamp* as an artistic investigation integrated tools of science with visual art techniques: laboratory procedures such as chemical clearing and staining (please see appendix for protocol, Ballengée and Green 2010b) with high-resolution imaging to make fine art prints for the series *Malamp Reliquaries*; natural history specimen display with experimental sculpture for *Styx*; and scientific specimen documentation with experimental video as installation in *Un Requiem pour Flocons de Neige Blessés*. At a fundamental level *Malamp* intertwined scientific methodologies with visual art practices, blurring boundaries between disciplines.

Within *Malamp* an underlying cycle of inquiry caused a ‘feedback loop’. The process of scientific research and direct experiences with deformed animals became the inspiration and subjects of visual artworks, and during the pragmatic creation of the artworks, further scientific questions arose. For example, while conducting high-resolution imaging of deformed toads for the creation of fine art prints, lack of scar tissue was noticed in English specimens, which inspired future laboratory healing studies in developing anurans. Likewise, while creating art I reflected on field and lab studies asking questions in a less results-oriented (non-quantifiable) way, which led to new thoughts about what the scientific data might suggest. Art creation in this way was an instigator for future studies and offered a form of reflective insight into prior scientific research experiences towards solving the problem of malformed frogs.

*Malamp* as a transdisciplinary art project references a specific location (in geographic and eco-regional terms) and community in an attempt to engage them with information about local ecological health. During the studio process, I considered how the specimens as subjects of art would be perceived by audiences, and, more importantly, how a conceptual connection (bridge) could be built between the subject (an individual deformed frog) and a larger civic community that on one hand played a part in the creation of such a malformation and simultaneously will be required to conserve such amphibians. Varied methodologies (discussed below) were utilized to engage viewers, such as scale of amphibian subjects in images for prints and sculpture proximity between viewer and actual preserved specimen. Again, the underlying goal of these works is not the production of static objects, but instead

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203 While imaging specimens for an art project, I noticed both the laboratory-induced and wild-found deformed English toads lacked obvious signs of prior injury. This was the inspiration to closely study scarring in the following year’s Canadian studies, which resulted in the observation that the majority of anuran larvae injured during predatory attacks lack scars at the time of metamorphosis (Sessions and Ballengée 2010a; Ballengée and Green 2011).

204 This occurred during the Canadian studies. While video-documenting live predator specimens for an art film, it dawned on me that some specific tadpole predators appeared to be found in higher numbers at degraded sites than at more pristine wetlands. When I checked the field data this appeared to be the case. This information influenced the direction of the following summer’s research.
active objects that captivate and inform viewers.

While exhibiting such works I was conscious of where these specimens came from and what finding them might mean about the ecology of those wetlands and the surrounding region (discussed in further detail in chapter 8). This awareness of a particular ‘place’ and relaying this information to the audience is a fundamental aspect of in my definition of transdisciplinary art. When displayed in exhibitions, the location where the deformed amphibian was found is always included in the textual information, to make audiences aware of localized ecological phenomena and also to show how widespread the issue of amphibian malformation is. Additionally exhibitions of the Malamp works have become a platform to recruit citizen scientists into participatory biology amphibian field studies at nearby wetlands, achieving greater dissemination of knowledge about localized ecological phenomena.

**Malamp** does not attempt to outline a philosophy for the creation of transdisciplinary art but instead offers an example of a pragmatic and novel strategy for creating scientifically informed artworks that deliver an environmental message to non–science specialist audiences. Finding new strategies to reach popular audiences and inspiring them towards conservation may be paramount to the survival of numerous amphibians and other organisms and perhaps even to our own long-term survival as a species (Kriger 2010).

### Section 5.4. Malamp Reliquaries

The artworks collectively entitled *Malamp Reliquaries* are unique digital prints of chemically cleared and stained, terminally deformed amphibian specimens found in nature. My underlying goals for these works are to engage viewers and increase their awareness about the fragility of organisms that share our planet. In this sense, the works are meant as a bridge between the individual viewer and the specific organism portrayed. Further, they are a way for me as an individual to express my complex sentiments at finding terminal malformations among amphibian populations. They also offer a way for me to expand my research findings and the experience of investigation outside the realm of professional science.

This series began in 2001, when I was awarded a Rockefeller Foundation Fellowship for a residency at the Institute for Electronic Arts at Alfred University (USA). I later brought in a collaborator, Dr. Stanley K. Sessions, so we could continue our collaborative studies of deformed amphibians. Here we utilized high-resolution scanning equipment to image specimens looking for parasites, but we also explored the art-science interface by creating works of art. I was attracted to the idea of the direct-imaging process as referenced the tradition of photograms in natural sciences by Anna Atkins and others: works that are both aesthetically compelling but provide scientific insight into organisms. While in residence at IEA I also had the opportunity to make a singular unique Iris[^205] print of a cleared, stained, multi-limbed frog as a work of art, titled *DFA 83: Karkinos* (figure 3.), which was to become the first of the *Malamp Reliquaries*.

[^205]: An Iris printer is a large-format color inkjet printer that utilizes molecular droplets of watercolor ink.
Over the next decade, I developed a pragmatic method for creating the *Malamp Reliquaries*. First, severely deformed metamorphic frogs and toads found already dead or dying during field surveys are chemically cleared and stained. Clearing and staining is a

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chemical process, which means staining bone and cartilage with brightly coloured dies while digesting surrounding tissues to transparency (for detailed process, please see Ballengée and Green 2010b, in appendix). From the scientific standpoint, this affords a way to see subtle abnormalities in morphology that could be easily missed prior to chemical treatments. Yet, the cleared and stained specimens are incredibly interesting from an aesthetic standpoint, and they often inspire the individual works of art collectively titled Malamp Reliquaries. By further looking and thinking about the individual specimens during art production, I find myself asking more questions which, in turn, inspires further scientific studies.

From the artistic standpoint, clearing and staining obscures direct representation of the individual specimen, as I do not want to exhibit large images of ‘monsters’, which would be frightening and also exploitative of the organism. Chemically altered specimens, however, look almost like x-ray images, which enables a level of abstraction or distance and simultaneously reveals the complex configuration of malformed development. Aesthetically, the colours of the dyed tissues are vibrant, in direct contrast to the skin, which is semi-transparent and meant to appear ephemeral.

The clearing and staining process is followed by high resolution scanning of individual specimens. Here a small temporary aquarium is built directly on the imaging bed of a Scitex Ever smart® Supreme scanner (manufactured for scanning film negatives) then filled with glycerine. The specimens are then gently placed into the aquarium and laboratory-grade cotton is added to create a background. Digital recording (up to 18 hours per specimen) ranges between 8,000 to 12,000 dpi—approximately 25 times the output of a typical home or office scanner. The appeal of the process is the astonishing detail that can be recorded in a digital file. These files can then be used to generate both scientific research images as well as works of art. Referencing here the engaging artworks of Ernst Haeckel, I believe captivating audiences with highly detailed images is still an important strategy for capturing the imagination of viewers.

Digital files are then edited in Adobe Photoshop for colour corrections and scale. Each individual frog is centered, appearing to ‘float’ in what looks to be clouds (cotton). The files are scaled so that the frogs appear approximately the size of a human toddler, in an attempt to invoke empathy in the viewer instead of detachment or fear. If they are too small they will dismissed, but if they are too large they could seem monstrous. Again the intention is move the viewer towards wanting to help amphibians rather than casually walking away or becoming frightened. This viewer-to-animal subject relationship at the one-on-one level has been informed by the environmental ethics ideas of Henry David Thoreau and Aldo Leopold; humans learn to care through empathy and understanding.

The finished digital files are printed in watercolour ink (either through an Iris or Ink Jet printer) on cold press watercolour paper sized 46.5 by 34.5 inches (118 cm by 88 cm). This method and scale is meant to recall the bird portraits of John James Audubon, which still captivate audiences. Also like Audubon’s original paintings, each print is unique and never editioned, which I believe would be exploitive. As Lippard has stated, this non-editioning is ‘respectful of its specific and local individuality’ (2010: 16). By being unique the final work is meant to recall the individual animal and become a reliquary to a brief, non-human life. The
experience for the viewer is intended to be one-on-one with the impacted amphibian.

The titles employed for Malamp Reliquaries are binomial (recalling the naming utilized in science developed by Linnaeus, and utilized by Darwin, Humboldt, and scientists currently). For example in DFA 23: Khárôn (figure 5) or DFA 86: Hades (figure 6), the first name refers to the scientific specimen identification number (DFA 23 meaning ‘Deformed Frog, Group A, Number 23’). To reinforce the otherworldly quality of the finished artworks, the second name refers to a Greek mythological character. For example, in Greek myth, Khárôn was the ferryman who carried the souls of the recently deceased across the river Styx. This Malamp Reliquaries naming system reflects the collaborative nature of the overall project, whereby in scientific studies I, along with other biologists, name or give identification numbers to the specimens we collect so that we can record the data about them. The second names (mythological) also come from collaborations, except in this case with other artists (poet KuyDelair, sound artist Andrew Diluvan, and others). The titles reflect the divergent but intersecting points between art and science inherent to the process of creation behind Malamp Reliquaries.
Figure 6. *DFA 23: Khârôn*. 2001–2007. Unique digital-C print on watercolour paper. Cleared and stained Pacific tree frog collected in Aptos, California. In scientific collaboration with Stanley K. Sessions. Title by the poet KuyDelair. 46.5 x 34.5 in.

The *Malamp Reliquaries* are meant to engage audiences but are not scientific illustrations nor didactic graphics intended to deliver a single message. As art historian Lucy Lippard has said of the *Malamp Reliquaries*, ‘Any resemblance to “illustration” is avoided by the aesthetic choices made and the consequent power of these embodiments’ (2010: 16). The works are not meant to lecture but to be experienced—so the readings and interpretations are open-ended.

Although *Malamp Reliquaries* are inspired by scientific study, they are works that embody my definition of transdisciplinary art and not meant to be read as science
visualization. Fundamental to my thinking is the belief that the work must be open to interpretation and be aesthetically engaging to move beyond mere illustration of a scientific phenomenon. There is also the aspect of self-expression in the *Malamp Reliquaries*. In my scientific studies I must stay objective and let the results speak for themselves. However, through making art I am able to explore the emotional and psychological complexity of working directly in degraded landscapes with impacted organisms—thus propelling the work beyond the boundaries of a single discipline.

*Figure 7. DFA 186: Hades, 2012. Unique digital-C print on watercolour paper. Cleared and stained Pacific tree frog collected in Aptos, California in scientific collaboration with Stanley K. Sessions. 46 x 34 in.*
In terms of content, the works are informed by actual local ecological studies and act to frame a real-world problem. My hope is to show a level of ecological reality few viewers are aware of. Lippard has described the Malamp Reliquaries as ‘searing images that are dangerously beautiful, both alluring and alarming, testimony to dire changes happening beneath our radar’ (2010: 16). In this way the works reveal the state of amphibians at a local and larger level, a condition to which most of us are oblivious.

5.5. Sculptural Series, Styx

The one-to-one dialogue between specimen and viewer in the Malamp Reliquaries is also emphasized through my sculptural series Styx (1996–present: figures 6, 7, and 8). Here viewers individually look into small glass dishes containing a single illuminated, cleared and stained deformed anuran. The specimen is precisely illuminated underneath to become the ‘light’ and focal point. As the specimens are often tiny, out of our normal human scale for bodily association, viewers must physically approach the glass dishes, forcing an intimate encounter. As Lippard has surmised, ‘There is a cruel intimacy about our viewing of these tiny corpses, with their disturbing, malfunctioning beauty we have helped to create’ (2010: 16).

Figure 8. Styx: Variation XII. 2012. Portal MMC Kibla, Maribor, Slovenia. Mixed media installation with 9 cleared and stained Pacific treefrogs on sculptural light-box.

In our daily lives we are seldom confronted with the impact of environmental degradation upon another organism. Through Styx I attempt such a one-on-one confrontation between viewer and human impact. Viewed up close, these specimens resemble gems or the highly detailed diatoms depicted by Ernst Haeckel. They are beautiful yet horrible, telling the
sad story of ecosystems on the verge of collapse. As art historian Suzaan Boettger has posited of these specimens, ‘[A]ccentuated by the removal of flesh and the addition of crimson and turquoise stain to the bones and cartilage, the amphibians' grotesquely malformed anatomy visually recalls the whimsical linearity in Paul Klee's watercolours but, even more, the twisted forms of crucified martyrs’ (2012: 175).

Figure 9. Styx: Variation I. 2007. Yerba Buena Center for the Arts, San Francisco, California, USA. Mixed media installation with 9 cleared and stained Pacific treefrogs on sculptural light-box.

Intimacy and reverence are important factors with Styx, rather than the creation of a spectacle through the exploitation of the malformed beings. It is more a sculptural expression of the complex sensations derived from finding the abnormal frogs in nature in the first place. As Lippard has stated, ‘There is no Damien Hirst–like opportunistic spectacle involved here, but metaphor plays its part as life is reduced to essentials before our eyes’ (2010: 17). Instead of the specimen exploited as material, the biological entities in Styx are treated as sacred and displayed as in a memorial setting.

To create Styx, tiny specimens are carefully post-fixed, cleared, and stained (as discussed above) and displayed on large, dark structures meant to resemble fallen obelisks. When viewing the specimens, there is something familiar about them: enchanting but terrible and otherworldly. The series was titled after the Greco-Roman mythological river Styx that formed a border between the worlds of the living and the dead. In Styx each specimen is unique, valued, and revered, posing a larger ethical question about the value of life.
My decision to display actual specimens deformed by the ecosystems they develop in is grounded in the ethical frameworks of ideas discussed previously from Charles Darwin, Thoreau, and Leopold. As under Darwin’s value system, the small—even worms and metamorphic frogs—have great ecological importance and need to valued by people. How are contemporary audiences supposed to value amphibians or understand what human environmental decisions may be doing to them if they do not see them in the first place?

Likewise, I have considered Thoreau’s views of nature morality, which was inclusive of greater equality among all ‘neighbors’: all non human species. How are we to form a system of respect for other species without being confronted with the way may be impacting them? *Styx* offers this confrontation, making the small and unseen visible and impossible to deny.

More attuned with the ideas of Leopold, should we not question our ‘immoral’ actions towards the landscape when we see how it has impacted such malformed individuals? Our actions that prevent amphibians from reaching sexual maturity and reproducing are certainly ‘wrong’, as we deny them self-renewal (Leopold 1949: 224–225).

My goal is to tell the story of the global amphibian population collapse visually through the organisms themselves with *Styx*. These malformed beings are ecological reality. The underlying aesthetic was an important means to reach audiences in order to deliver this message of ecological crisis.

The *Styx* installations are intended as transformative tools, placing the viewer in dialogue with another being that is malformed because of the degradation humans have
caused. As Lippard has said, ‘A transformation occurs the moment we viewers are inserted into the equation … our own imaginations merging with the life force of the creature under the microscope, or the lens. And we understand…. Or we do not’ (2010: 10). *Styx* does not offer a concrete solution for such large-scale problems but instead attempts to focus the audience on the issue through a one-on-one connection to these specimens. The hope is that a sense of concern for the fate of amphibians and other organisms will be awakened in the viewer: a feeling that, if experienced on a deep enough level, may catalyse change in that person.207

5.6. Un Requiem pour Flocons de Neige Blessés (Requiem for Injured Snowflakes)

More recently I have been exploring video as a format for presenting the complex impressions associated with the amphibian malformation phenomenon. In 2009, in association with Quebec studies of amphibian deformities, my research team and I began documenting young anurans found at one of the study’s malformation hotspots (reflecting a malformed population greater than the natural level of less than 5%). At this heavily agricultural location, hundreds of severely abnormal metamorphic toadlets were discovered. Dozens were found dead and many lay dying as we attempted to gather data on deformation rates.

In response to this tragic finding, the resulting video work consisted of a series of twenty-one individual portraits of these tiny, short-lived beings. Each was born into a hostile universe of predators, parasites, and ecological degradation. Like all beings, these young creatures represented a particular moment in history and carry the environmental marks of their birthplace. In the case of these individuals, trauma during development resulted in terminal abnormalities. As they emerged to begin life on land, severe deformations fated them to early death.

In Photoshop I created unique backgrounds for each individual toad from high-resolution scans of laboratory-grade cotton, which visually recalled the storm clouds depicted in paintings by Joseph Mallord William Turner (figure 9). With the help of video editors Philip Henken and Gillian Wilson, the video ran as a slide show, morphing one portrait into the next. I asked sound artists Ariel Benjamin and Andrew Andi Diluvian to respond to the images through sound, and they created an original musical score to accompany the piece (please see appendix materials).

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207 The effectiveness of these works is analyzed through qualitative surveys discussed below.
208 Photographic team members included Marissa Nolan (McGill undergraduate biology student) and Frédérique Paquin (designer and later student of environmental science at Concordia University).
209 Canadian studies research findings discussed in later chapter; see Ballengée and Green 2010a; Ballengée and Green 2011.
The final video work was made available free of charge online for download under the condition that once it was begun, the video should be projected so the toadlet is approximately the size of a human toddler, and should be played for infinity—until the extinction of our species or until someone chooses to turn it off—at which point the file was to be deleted. This finite/infinite artwork was meant to be a memorial to these small creatures and in honour of the countless number of beings coming into this world and passing without our notice.

In an attempt to make this work broadly available to audiences, the decision was made to allow the work to be downloaded free of charge and viewable online. As lithographs by Audubon and Haeckel have reached hundreds of thousands of people through the mass
production, my hope was disseminate the tragic story of these toads to as wide a viewership as possible.

5.7. Qualitative Analysis of Organizer Responses to These Works (2007–2013)

My primary research question asked, ‘How can transdisciplinary art and participatory biology successfully increase popular understanding of ecological phenomena?’ To answer this question I found it important to gauge the thoughts of professional arts organizers (none of whom were amphibian specialists) who exhibited varied bodies of work from Malamp: The Occurrence of Deformities in Amphibians. As Malamp has appeared in eight solo exhibitions (2006–2013) and 23 group exhibitions (2006–2013), staged in galleries, museums, and other venues in the United States, Canada, the United Kingdom, and seven other countries, these malformed amphibian artworks have been viewed by thousands of people since the project began. However, have these transdisciplinary artworks been successful in increasing public understanding of ecological phenomena? To ascertain the effectiveness of the Malamp artworks towards heightened popular understanding, questionnaires were given to 43 arts professionals who organized exhibitions of the Malamp works. Thirty-eight (88.4%) organizers responded to the questions.

To ascertain the effectiveness of the Malamp works in increasing popular understanding of ecological phenomena, I found it important to ask the organizers firstly, which body of works they exhibited. This may shed light on specific exhibition strategies that may be more effective than others in reaching audiences with an environmental message. The Malamp Reliquaries, at 84.2%, were by far the most often chosen body of Malamp works exhibited by organizers, followed by one of the Styx installations, chosen by 50% of the respondents, although 47.4% of organizers chose to exhibit more than one body of the Malamp works (see figure 10; full accounts can be found in appendix). These results demonstrated that the Malamp Reliquaries were the most popular selection among organizers for exhibitions, perhaps suggesting that traditional two-dimensional works were more popular than sculpture installation and video. However this could also be due to pragmatic reasoning (shipping, logistics, costs) instead of actual curatorial choice, as it is much less problematic to install a framed print than to install specimens into a large light-box or to have a constant projection.
As the *Malamp* artworks focus on the ecological phenomena of amphibian deformities and the organisms’ decline, it is important to gauge firstly if these works reached individuals by increasing their understanding of frogs, toad, newts, and salamanders. This question was posed to individual organizers to ascertain if exhibiting the *Malamp* works increased their understanding of amphibians. The majority of participants (71.1%) answered in the affirmative—the works did increase their understanding of amphibians. Five percent answered that the works increased their understanding somewhat; however 10.6% answered in the negative, saying that the works did not increase understanding. One respondent did not answer, and 7.9% did not give clear answers (see figure 11; full accounts can be found in appendix). These data suggest that the Malamp artworks did increase participant understanding of amphibians, and several organizers share their specific stories below, illustrating this increased ‘understanding’.

![Figure 12. Winter 2013 Questionnaire for curators, gallerists, and organizers who have exhibited amphibian themed artworks, Question #2: ‘Which amphibian artworks were exhibited as part of our exhibition together?’](image12.png)

![Figure 13. Winter 2013 Questionnaire for curators, gallerists, and organizers who have exhibited amphibian themed artworks, Question #3: ‘Did this artwork increase your understanding of amphibians?’](image13.png)
Director of the Amelie A. Wallace Gallery, SUNY College at Old Westbury (USA) Dr. Hyewon Yi stated, ‘Yes, the artwork by Brandon Ballengée displayed for the exhibition, *Biotech Art: Signs of Existence*, dramatically increased my understanding of amphibians. I learned that the amphibian specimen is used as a “bio-indicator” that measures the health of ecological systems. Learning about the causes of deformity of amphibians was a revelation to me’ (Yi 2013). Yi’s response suggested the *Malamp* artworks did effectively increase her understanding of amphibians in ecological terms.

Yi’s opinions were echoed by former Curator of Art at Z33 (Hasselt, Belgium) Claire Warnier. She shared Yi’s opinion about the *Malamp* works’ ability to increase understanding about amphibian as ecological monitors. Warnier stated, ‘It did increase my understanding of amphibians, because I never thought of them being so important as environmental indictors’ (Warnier 2013). This is important because it suggests that art may be an effective tool to increase understanding of specific groups of animals as indicators of ecological system health, which could have important ramifications for conservation efforts.

Basic understanding of amphibian anatomy could be achieved through the *Malamp* artworks, according to Anne-Marie Belley, independent curator and PhD candidate in art history (Montréal, Canada). Belley stated, ‘By showing specimens in their actual size and by staining them to increase the contrasts of their forms … I have been able to observe their physical specificities and details’ (Belley 2013). This opinion was repeated by former Director of Verbeke Gallery (Antwerp, Belgium) Simon Delobel, who stated, ‘Through Brandon Ballengée’s work, I learned about his way to collect deformed frogs and […] learned more about the reproduction of those. It completed the basic knowledge I got when studying biology when I was 15–16 years old in France. By answering visitors’ questions in the gallery, I was forced to look always more in detail at the anatomy of the frog revealed by Brandon Ballengée’s visualization techniques. I read on the Internet one article about vertebrates in order to compare human anatomy to the frog’s anatomy’. This suggested that the *Malamp* artworks became a novel form of and catalyst for science education, for both the organizer and audience.

Likewise, even some participants with no prior interest in amphibians found a point of connection to this group of animals through the *Malamp* works. As Director Anush Zeynalyan of the Central House of Artists (Moscow) stated, ‘To be honest, I’m kind of a squeamish person and I’d never been interested in amphibians. Still, this video work has shown me the beauty of [these] creatures, but this beauty […] it’s stealing beauty. Nowadays due to lots of anthropogenic activities, amphibians are experiencing changes that do no good for them’ (Zeynalyan 2014). If art can help people to appreciate species they never previously considered, this may be an effective tool for conservation efforts.

The overall results from participants suggested that the *Malamp* works did, at least in the case of most organizers, increase understanding of amphibians. Still, 10.6% stated it did not, and this may suggest that organizers who curate such works may already have a good degree of knowledge about amphibians. As Dr. Tim Joye, Art Director of the department of Communications Service for Nature, Environment, and Energy (Vlaamse Overheid, Belgium) stated, ‘The work did not increase my understanding of this particular species. The work did
generate more complex contents’ (Joye 2013). This important insight by Joye suggests that even if the works did not directly increase understanding of amphibians, it may have supplemented pre-existing knowledge about these creatures.

As amphibian deformities and declines are an increasing global phenomenon, it is important to understand whether artworks about such issues may alter popular attitudes. The next question sought to learn if exposure to the Malamp artworks changed the organizers’ attitudes towards amphibians. The majority, 60.6%, said yes, exposure to these works changed their attitudes about amphibians, while 12.8% stated that their attitudes were changed somewhat (see figure 12; full accounts can be found in appendix). As Senior Curator of Yorkshire Sculpture Park (Yorkshire, UK) Dr. Helen Pheby stated, ‘It changed my attitude in that I had never really taken the time to think about them, and now every time I walk past our formal pond I am reminded of the important lessons learned through Brandon’s project, and it’s one I share on site and through talks and presentations about the work of YSP’ (Pheby 2013). This is important because it suggests that visual art may be helpful to alter attitudes toward non-human animals by fostering awareness of the fundamental aspect of conservation efforts, as discussed previously in the thoughts of Aldo Leopold.

**Figure 14.** Winter 2013 Questionnaire for curators, gallerists, and organizers who have exhibited amphibian themed artworks, Question #4: ‘Did exposure to this artwork change your attitude towards amphibians?’

As curator Dr. Lidija Pačnik Awais, KIBLA (Maribor, Slovenia) stated, ‘Yes it did, in a very positive way …With Brandon’s work, I realized how alarming[ly] [these species’] population has declined in the past years’ (Awais 2013). If the works helped people to notice amphibians in the first place, that is an important step towards changes in attitude about such species and the fact they are in decline.

However, the results of the questionnaires also show that 13.2% of participants’ attitudes about amphibians were not affected by viewing such works, and 13.2% did not respond or their answers were unclear (figure 13). As director of Les Territoires Marie-Josée Parent (Montréal, Canada) stated, ‘No. It reinforced my attitude towards them. They are key in our ecological equilibrium’. This statement suggests that the artwork did not change the respondent’s attitude but may still have been a beneficial reminder to Parent of the species’
importance to ecosystems. Nevertheless, it is discouraging that 26.3% of participants were not clearly impacted by the exposure to these Malamp works, suggesting that further research is needed to understand how or if visual art strategies may truly change viewer attitudes towards non-human organisms.

As amphibians are amid a population crisis, with upwards of 41% of known species in decline, I found it paramount to ask if the Malamp artworks increased awareness of this dire phenomenon among participants (Stuart et al. 2004; Wake and Vredenburg 2008; Collins and Crump 2009; Hoffman et al. 2010). In response, the overwhelming majority, 81.6%, of respondents, answered yes, the artworks did increase their awareness of declining amphibians, while one person said it did somewhat (see figure 13; full accounts can be found in appendix). Projects Manager of the Coalition pour l'art et le Développement Durable/COAL (Paris, France) Maëva Blandin stated, ‘Definitely yes. I did not know a lot about the problem before meeting Brandon Ballengée’s work. As a consequence, it totally increased my awareness of declining amphibian populations, and my will to make exhibitions, which raise ecological knowledge through cultural perspectives, and allow every citizen to change their behaviour towards the planet’. Blandin’s comments suggest that the works not only raised her awareness but also inspired her to create future exhibitions about amphibians to further a message of conservation.

The aesthetic of the Malamp works appeared to be an important point of entry for delivering ecological awareness for some participants. Guest Curator at Yerba Buena Center for the Arts (San Francisco) Phillip Ross stated, ‘…The images of Malamp are beautiful and provocative, their colour, framing, and aesthetics drawing in a viewer by their otherworldly and grotesque nature. To understand the desire and aversion these images evoke there is a hunger for greater understanding of what has been the mover of this unsettling aesthetic encounter. I was able to imagine and receive information that I might otherwise not find remarkable as a result of lacking specific visual references or context’ (Ross 2013). The
observation made by Ross was important, as it suggested that visually captivating artworks may disseminate information about ecology in novel ways that data alone cannot.

Empathy and emotional response from viewing the Malamp artworks was another point of entry, according to some participants. Art Curator of Deutsche Bank (New York) Liz Christensen said, ‘Yes, I am not only more sympathetic to their plight, but also see their decline as a warning or “canary in the coal mine” for humans and other species’ (Christensen 2013). Founder of Ronald Feldman Fine Arts (New York) Ronald Feldman stated that viewing such works ‘… not only increased my awareness of declining amphibian populations, but made me angry. How could we possibly let them disappear? The almost silent disregard for the amazing species raises the question of how important is this anyway? Portraying the amphibians in such a beautiful manner makes our connection to them all the more important and our actions in their defence all the more necessary and human’ (Feldman 2013). This reaffirms ideas discussed earlier about the works of John James Audubon and others, showing that emotive connection to non-human animals through visual art may still be a very relevant way of engaging audiences.

Some participants noted that the Malamp works brought the story of amphibian decline home, literally to their specific region. As Director of Residencies and Creation at SAT (Society for Arts and Technology, Montréal, Canada) Joseph Lefèvre noted, ‘Yes this project increased our awareness of declining amphibian populations and also how this takes place in Quebec in our own areas’ (Lefèvre 2013). This information is helpful as it suggests that such visual artworks could disseminate knowledge to local communities about localized ecological phenomena.

Going beyond the singular idea of amphibian decline, some participants suggested that the works brought out larger ideas of climate change and even evolutionary limitations of species for adapting to ecosystem compromise. As Cofounder and Chairperson of Coalition pour l’art et le Développement Durable//COAL (Paris, France) Alice Audouin stated, ‘Yes, a lot. Now I consider that they are very important. And I see them as a symbol of the diversity collapse … We have to change. They do not have to adapt? They can’t adapt. They die. Human beings are the ones who must change. For themselves, for the frogs, and [for] the nature and the climate, which is the same since nature and climates are our conditions of life’ (Audouin 2013). Such a response to viewing Malamp works confirms that visual art may not only be an effective strategy for increasing understanding of singular ecological phenomena but may simultaneously address larger scale environmental issues, such as climate change.

However, not all participants agreed. In fact, 13.2% said the artworks did not increase their knowledge of amphibian declines. Yet, as Dr. Andrew Yang (Biologist and Curator) stated, ‘No, I was aware of the issue already’ (Yang 2013). This suggests that others may have known about the issue beforehand, including Managing Director of BAASICS (Bay Area Art and Science Interdisciplinary Collaborative Sessions, San Francisco) Christopher Reiger, who posited, ‘No, it did not increase my awareness, but I am not as important or relevant a measure as the exhibition visitors who are not herpophiles (like myself). Indeed, I had conversations with a number of viewers of Brandon’s artworks who had no idea amphibian populations were declining, and certainly not at the staggering rate that we are witness to. In all cases, Brandon’s artwork increased their awareness of the present plight of
amphibians’. In light of this statement by Reiger, even if the work did not have an impact on him personally, it may well have increased visitor understanding of the declining amphibian issue.

These findings are very important, suggesting that visual art may be an effective tool for communicating information about species loss to a larger, non-science specialist audience. This may be very helpful to the cause of amphibian conservation, since the public is largely unaware of the population crisis among frogs, toads, newts, and salamanders (Wake and Vredenburg 2008; Collins and Crump 2009; Kriger 2010).

The final question sought to shed light on whether transdisciplinary art could successfully increase popular understanding of ecological phenomena through the context of the Malamp works. For this question participants were asked to comment on their observations of how the public may have perceived the Malamp artworks. Thirty-seven participants offered their thoughts, and a wide range of opinions were shared (full accounts can be found in appendix). A majority of respondent comments (65.8%) suggested that the Malamp exhibitions did increase viewer understanding of ecological phenomena, in this case the occurrence of deformities and declines in amphibians (figure 14). More detailed analysis of responses is provided below.

Many suggested that the exhibitions of Malamp works were effective at increasing audience interest about amphibian issues through inquisitiveness. For example, Anne-Marie Belley stated that from her observations, ‘I have experienced public reactions and can confirm that the artwork did play a major mediation role in their curiosity of knowing and understanding the amphibians’ (Belley 2013). Dr. Mike Weilbacher, Executive Director of the Schuylkill Center for Environmental Education (Philadelphia) characterized his observations thus: ‘I frequently saw people in the gallery counting appendages, trying to guess what was wrong with the creatures, reading the text’ (Weilbacher 2013). These comments suggest that through novel display strategies, such as exhibiting actual specimens and using highly
detailed prints, the *Malamp* works helped generate overall interest in amphibians and their afflictions.

Guest Curator of Nowhere Gallery (Milan, Italy) Francesco Monico furthered these ideas when he stated that the *Malamp* works were ‘very important because it makes aware the generalistic public of the silent dead of millions of amphibians, and put this secret world on a totally new light that force[d] the viewers on a direction of understanding on how amphibians are a fragile part of our ecosystem’ (Monico 2013). Curator Claudio Cravero of Parco Arte Vivente, Centro d’Arte Contemporanea (Torino, Italy) offered a similar suggestion when he stated, ‘The visitors perceived the artwork as an important mirror of what happens in our planet on an ecological level’ (Cravera 2013). Revealing to the public the reality of what is happening to amphibian inhabitants because of ecological degradation is a cornerstone of the *Malamp* works, and the statements by Monico and Cravero have suggested a degree of effectiveness.

At a larger environmental level, Dr. Marc Wellmann, Former Director of Exhibitions of the Georg-Kolbe-Museum (Berlin, Germany) stated that the works influenced the public at an interpersonal level, as they ‘…became more aware of their ecologic footprint’ (Wellman 2013). These thoughts are attuned with those shared by Ronald Feldman, who stated that from viewing the *Malamp* works, ‘The best of human nature emerged in the genuine question—what can we do to turn this around?’ (Feldman 2013). Claire Warnier furthered this line of thought by suggesting that the works invoked a sense of stewardship in the audience: ‘The images of the deformed frogs were very strong and made you realize at once the importance of water and the fact that we have to take care of it’ (Warnier 2013). These statements all suggested that audiences viewing the *Malamp* works not only achieved an increase of ecological understanding, but more importantly may have become inspired towards more sustainable behaviours through self-reflection.

Many of the participants described the works being attractive to audiences at a complex aesthetic level, acting as a mechanism for captivation and emotional response. Guest Curator of Z33 (Hasselt, Belgium) Jane Withers had this to say: ‘Many people have a strong visceral response to the images and ask about them, intrigued to understand what they represent and the processes involved’ (Withers 2013). This visual captivation described by Withers was echoed by Anush Zeynalyan, who stated, ‘Lots of people felt pity [or were] sad, others were just curious, but they never left unaffected’. Christa Donnar, Guest Curator of Gallery 400 at the University of Illinois at Chicago stated, ‘Visitors to the exhibition gained an awareness of declining amphibian populations as well as an empathy for these (and other) animals. The clearing-staining process highlighted both the biological processes under discussion and the beauty of the organisms themselves. The presence of the physical specimens provides a more intimate and perhaps emotional experience of this visual information’. These comments reaffirm the idea that aesthetically captivating art may, as discussed previously in the works of John James Audubon and Cornelia Hesse-Honegger, still be an effective tool for emotionally engaging audiences in order to deliver a conservation message.

The conceptual merging of visual art and research science within transdisciplinary art may also be an affective tool for arousing public interest in ecological issues. As Dr. Filip
Colson, Exhibition Organizer and Scientist in the department of Environment, Nature and Energy, Flemish Government, (Vlaamse Overheid, Belgium) stated of the Malamp works, “… this combination of sound science and clear and very appealing visualization of human environmental influence makes for strong works of art that linger on in people's minds” (Colson 2013). This combining of art and science maybe useful to generate further contemplation in viewers, according to Dr. Semen Erohin, Art Historian and Curator of the Lomonosov Moscow State University: ‘Our experience of exhibiting of this artwork … showed that the work is perceived rather philosophically’ (Erohin 2013).

Such contemplation may open new discourses about projects that fuse art and science integration as suggested by Dr. Andrew Yang, who stated of the Malamp artwork that it ‘provides an additional avenue for interpreting the work as art, art-science, and science in a way that I think is productive towards interdisciplinary dialogue’ (Yang 2013). This combination of science with art may even surprise viewers, as Art Historian and Freelance Curator Edward Lucie-Smith (London, UK) suggested, saying that the Malamp works ‘provoked questions from people who may have expected to find something quite different in a London art show’ (Lucie-Smith 2013).

However, issues of semantics may arise with such transdisciplinary artworks, as Claudio Cravera pointed out. The ‘art’ side of the art-science merger may become ambiguous to some who may have ‘Asked him/herself if [they] were looking at an artwork or a biological display’ (Cravera 2013). Additionally, many viewers may lack the time or patience to actually interface with works, as Simon Delobel pointed out: ‘Visitors of a gallery or a museum mostly don't really spend a lot of time in front of an artwork. Most of them didn't even notice the abnormal number of legs’ (Delobel 2013). As lack of time spent by viewers looking at works of art is not a problem unique to transdisciplinary artworks, it may reflect larger social attitudes towards art that are outside the scope of this dissertation. Regardless of limitations, the vast majority of data collected through these questionnaires does suggest that transdisciplinary art, such as the Malamp project, can be an effective strategy towards increased understanding of ecological phenomena for a larger, non–science specialist audience.

5.8. Conclusion

In this chapter, I have examined the research question, ‘How can transdisciplinary art and participatory biology successfully increase popular understanding of ecological phenomena?’ through the analytical lens of my artworks based on my studies of malformed amphibians. By displaying these works, my aim was to arouse public interest in the topic of malformed and declining amphibians as well as to disseminate suggested causative factors for the ecological phenomena to a larger populace.

Analysis of qualitative data collected from questionnaires suggested that exhibitions of these amphibian-themed transdisciplinary artworks was a successful strategy for increasing popular awareness of ecological phenomena, in this case amphibian declines and deformities. This is important because it suggested that compelling visual art with depictions of non-human animals may still be an affective tool for reaching audiences with a conservation
message. As Sir David Attenborough has stated, ‘People are not going to care about animal conservation unless they think that animals are worthwhile’ (Attenborough, quoted in Jonathan and Pisano 2011: 160). Perhaps visually engaging transdisciplinary artworks may be helpful in letting the public know that such animals are indeed worthwhile, serving a function in overall conservation efforts.

Additionally, the questionnaire data suggested that art-science projects like Malamp, through novel visual displays, are able to generate audience interest and emotional responses to organisms like amphibians. As Aldo Leopold once stated, ‘What conservation education must build is an ethical underpinning for land economics and a universal curiosity to understand the land mechanism’ (1966: 157). It is precisely through the aesthetic impact of the Malamp works that this curiosity, as well as empathy, is invoked in viewers. As such, visual artworks like Malamp may offer innovative and successful visualization strategies for science communication and environmental outreach.

Over time Malamp: The Occurrence of Deformities in Amphibians has become an ongoing and open-ended project. Beyond merely provoking public knowledge or interest, however, I hope that the results of my own scientific research can be utilized to develop tools for amphibian conservation and be met with a populace that cares about these amazing, ancient creatures. Toward that end, I have developed as part of my practice a series of works that incorporate performative, collaborative elements involving public participation in scientific research; these efforts will be discussed in the following chapter.

On a personal level, the afflictions currently facing amphibians and other wildlife are a strong motivation for this work. We are living amidst the Holocene extinction, with organisms disappearing at upwards of a thousand times above the natural level. Through art, science, and environmental education programs, I hope to inspire change in as many people as possible, even if the environmental problems species face seem insurmountable. As Aldo Leopold once wrote in a letter to fellow ecologist Bill Vogt, ‘That the situation is hopeless should not prevent us from doing our best’ (Leopold 1946, quoted in Meine 1988: 478). In this way, Malamp: The Occurrence of Deformities in Amphibians treats the frog as an omen, as their decline heralds a grave danger that threatens not just them, but our own longevity as a species.
Chapter 6. Case Study II: Participatory Biology to Study Deformities in Amphibians

6.1. Introduction

In this chapter, I will further address the question of how transdisciplinary art and participatory biology may disseminate knowledge of ecology to non-specialists. Further I will demonstrate how such combinatory art-science practices may contribute new and important knowledge to the field of primary research biology. To explore these questions, I will first discuss the ways in which citizen science may contribute to the study of amphibians, and why public participation may be important for overall conservation efforts. Through qualitative analysis of questionnaires provided by scientists working in the field of amphibian studies with citizen scientists, the pros and cons of such publically involved programs will be examined.

This will be followed by a detailed account of my own public art-science collaborative works, Eco-Actions and Public Bio-Art Laboratories, with special emphasis on the contributions of citizen scientists in these efforts or, more specifically, what I refer to as participatory biology.

As discussed previously, my term ‘participatory biology’ is defined as primary research biological studies in which students, volunteers, or members of the general public are involved directly in all aspects of field and laboratory investigation. In the case of the Eco-Actions and Public Bio-Art Laboratories these included: problem identification, observations and data collection in field and laboratory settings, aiding in the establishment and monitoring of experiments, as well as post-research reflective, creative activities, all of which verge on a potential merging of art and science, as discussed below.

Additionally data from participant questionnaires and video interviews from my own participatory biology programs will discussed to examine whether these citizen scientist contributors achieved increased understanding of current challenges amphibians face, the ecological phenomena of population declines, and developmental malformations. Likewise I will shed light on the question of whether such participatory biology programs are successful in contributing new scientific knowledge to the field of amphibian science: specifically, the identification of underlying mechanisms responsible for malformations and the relation between such etiologies and ecological system health. Finally, the relationship between transdisciplinary art and participatory biology will be discussed, with emphasis given to the possible positive contribution to larger conservation efforts.

6.2. Impetus for Participatory Biology Programs in Amphibian Conservation

Frogs, toads, newts, and salamanders are an ancient group of animals that have survived several mass-extinction events. However, today they are disappearing at alarming rates. Of the known amphibian species, over 40% of them are in decline or have become extinct since 1979 (Hoffman et al. 2010; Kriger 2010). Considered an important bio-indicator group, they often are called the environmental canary in our global coalmine (Collins and Crump 2009). Loss and modification of habitats, emerging diseases, pollutants, climate change, and other factors are all considered causes for mass amphibian declines (Collins and
Humans are responsible, directly or indirectly, for many of the causes, and unless we remedy these threats, amphibians and other species will continue to disappear (Gascon et al. 2006). Environments that cannot support their non-human populations may also fail to serve the requirements for continued human life. To solve these complex, dire problems, a collective social effort will be required: one in which artists, scientists, students, and the public must all contribute. As Mendelson et al. (2006: 48) stated, to save amphibians, ‘Support from individuals, governments, foundations, and the wider conservation community is essential’.

Although amphibian extinctions may be considered among the most urgent environmental issues of this century, there are relatively few organizations or scientists fully focused on their conservation. Globally there are just over 2,000 full-time amphibian biologists, and only a tiny percentage of these are focused on conserving these species (Kriger 2010). In addition, international efforts for amphibian conservation have struggled to fund initiatives and remain largely underfunded (Bishop et al. 2012; Stuart 2012). Likewise, to date there are less than half a dozen international organizations210 focused entirely on amphibian conservation, and the human populace is largely unaware of the issue in the first place (Kriger 2010).

The need to reach the public was an important component of the first-ever transnational effort to limit global amphibian declines. The International Union for Conservation of Nature (IUCN) published the Amphibian Conservation Action Plan (ACAP) by Gascon et al. (2007). Within ACAP were a set of priorities that included public awareness-raising as paramount to success for long-term amphibian conservation (Gascon et al. 2007: 8, 29, 31, 61). Implementation of such efforts should include outreach in the form of exhibits and participation of international citizens involved in research, as the authors stated: ‘The road to success must include a broad set of stakeholders’ (Gascon et al. 2007: 48).

However, one must ask: How do a small set of amphibian biologists reach seven billion people? As a strategy ACAP suggested regional moderate-scale efforts with local participants under a unified plan of global amphibian conservation (Gascon et al. 2007; Bishop et al. 2012).

Since 2007, Amphibian Survival Alliance (ASA) has worked to implement several such moderate-scale initiatives. Since their formation ASA have placed public outreach and community participation as an integral part of their mission of saving amphibians. Such programs include regional working groups to collect data on local populations; these groups often involve citizen scientists and students. Such a recent educational campaign on the island of Sulawesi, Indonesia, taught local children and communities about biodiversity and helped to establish a 10,000-hectare forest preserve (Bishop et al. 2012).

Another organization, the Amphibian Ark (AArk) has also focused on public outreach and involvement of citizens in amphibian conservation. In their first large publicity campaign, the ‘2008 Year of the Frog’, AArk partnered with well over a hundred public institutions that

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210 Amphibian Specialist Group (ASG), Amphibian Survival Alliance (ASA), Amphibian Ark (AArk), Declining Amphibian The Populations Task Force (DAPTF), and Save the Frogs are the most prominent.
included museums, universities, schools, zoos, aquariums, and others to spread the message of amphibian decline and to raise funding for conservation with a focus on captive breeding programs (Pavajeau et al. 2008; Zippel et al. 2011). While hugely successful as a public relations campaign, the effort was not able to reach the monetary levels needed to save hundreds of amphibian species (Gascon et al. 2007; Zippel et al. 2011). In addition some authors have pointed out that though the very focused campaign was successful at raising popular awareness and some funding, when the campaign ended, the public largely assumed the problem of amphibian decline was solved (Bishop et al. 2012).

The only organization focused entirely on anuran conservation, Save the Frogs (STF), has taken the ACAP initiative from a grass roots level to a widely successful international education program. Since 2008, founder Dr. Kerry Kriger alone has given 274 talks to an audience of greater than 14,000 attendants (Kriger 2014). Additionally, STF has organized over 1,300 events in 59 countries and annually coordinates international “Save the Frogs” Day, with over 20,000 participants annually (Kriger 2014). In addition to educational talks and citizen programs, STF also has offered peer-to-peer biologist training including amphibian disease diagnosis and treatment, strategies for involving citizens in science, and public outreach preparation. STF also integrates visual art into their programming and annually holds a Save the Frogs art contest. More than 9,000 students from 66 different countries have participated since 2009 (Save the Frogs 2014). It should be noted, however, that such public relations and citizen science campaigns are not without their limitations, as discussed below.

Internationally several groups have implemented amphibian calling surveys to involve citizens in amphibian research, including Froglife (UK), North American Amphibian Monitoring Program (USA), RAVON (Netherlands), La Société Herpétologique (France), Associazione Erpetologica (Italy), and many others. Such calling surveys generally involve training participants on proper identification of species and data collection for analysis of regional populations (Nelson and Graves 2004; Dickinson et al. 2010; Wiggins et al. 2011). Some of the issues that have arisen from such programs include misidentification of species and over-reporting others (Weir et al. 2005; Galloway 2006; Dickinson et al. 2010). To further shed light on such public participatory calling programs, responses to questionnaires from individual biologists will be discussed below.

In addition to acoustic surveys, visual surveys and road monitoring of amphibians have already demonstrated relative degrees of success. One example is vernal pool monitoring programs with citizen scientists in Maine, where volunteers aided in the identification of such temporary wetlands and collected viable data on aquatic species (Oscarson and Calhoun 2007). In addition such citizen experiences influenced regional land planning and regulatory processes (Oscarson and Calhoun 2007). This could be a very important strategy, especially at large scales (involving more programs), towards habitat conservation, as 90% of amphibian populations in decline are believed to be due to habitat loss (Bishop et al. 2012).

In the years since ACAP was initiated, many successful efforts have been made to unify and popularize amphibian conservation. Notwithstanding, at least seven more frog species have become extinct, and overall there has been great disappointment among the
amphibian research community at the lagging pace at which legislation and finances have been allotted towards conservation (Stuart 2012; IUCN 2014). Likewise, efforts to reach the public have been limited, and as Bishop et al. have stated, to conserve amphibians, ‘It is essential that we engage more with communities beyond the amphibian research and conservation community’ (2012: 106). For us to save the frogs—and many other species—a broad effort beyond science alone will be required: one where the public plays a significant role.

6.3. Qualitative Analysis of Prior Citizen Science Programs in Amphibian Conservation

To investigate how transdisciplinary art and participatory biology might successfully increase popular understanding of ecological phenomena and contribute new and important knowledge to the field of primary research biology, and to evaluate how the results of such efforts might be disseminated, I found it important to ascertain effectiveness of amphibian monitoring efforts that involved citizen scientists. My primary means of gathering data on these questions involved querying biologists who had ran such programs. Such questionnaires sought to shed light on whether the benefits of such programs (data gathering, increased awareness of amphibian issues) outweigh problematic issues such as unreliable data? I was also interested in the scale of such programs, the level of public involvement, and overall outcomes.

Of ten questionnaires sent to such researchers in 2011, six responded (Completed responses may be found in the appendix). Firstly I found it important to ask basic information about the programs and their underlying goals. This is important in order to understand strategies currently used for amphibian citizen science programs and why they are done in the first place. This also shed light onto whether such methodologies are effective for increasing popular awareness and generating viable knowledge for primary research (table 3).
<table>
<thead>
<tr>
<th>Contributor/ Title:</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. Franco Andreone (FA)/ Curator Of Zoology, Museo Regionale Di Scienze Naturali, Torin, Italy</td>
<td>“Yes, I did survey work with volunteers from 2004 to 2009 for studying the breeding migration and estimate the population size of the Italian spadefoot toad, <em>pelobates fuscus insubricus</em>, at two sites, next to Torino, and next to Asti. The study was coordinated by me, but there was the participation of volunteers every night for around 3 months a year (from February to May), to check pitfall traps placed along a drift fence around the breeding pools. The volunteers helped to check the traps, to measure the individuals, and to photograph them.”</td>
</tr>
<tr>
<td>Dr. David M. Green (DMG)/ Professor, Redpath Museum, McGill University, Montréal, Canada</td>
<td>“No. I have student volunteers in field research but I have not enlisted the assistance of the general public in amphibian research.”</td>
</tr>
<tr>
<td>Dr. Kerry Kriger (KK)/ Executive Director Save the Frogs, Berkley, USA</td>
<td>“During my Ph.D. research in Australia I regularly took volunteers into the field to help me catch and sample amphibians. 2003-2007 (80 volunteers). With SAVE THE FROGS! I use volunteers to help in the office, and with our campaigns. About 150 volunteers have helped out in this manner. Another 150 have helped with our habitat restoration project at Antonelli Pond in Santa Cruz. On Save The Frogs Day 2009, 2010 and 2011 we had 40, 104 and 142 events respectively; each of these was coordinated by volunteer(s).”</td>
</tr>
<tr>
<td>Pierre Raymond Warny (PRW)/ Associate Researcher the New York State Museum, Albany, USA</td>
<td>“Yes, swabbing frogs for chytrid fungus assay on Long Island, New York. April 2010 to present”</td>
</tr>
<tr>
<td>Dr. Linda Weir (LW)/ Wildlife Biologist/ United States U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, USA</td>
<td>“The North American Amphibian Monitoring Program (NAAMP, website: <a href="http://www.pwrc.usgs.gov/naamp">www.pwrc.usgs.gov/naamp</a>) is a collaborative effort between USGS and numerous State Partners that manage the program locally. State Partners recruit and train observers, assign survey routes, and help manage the data using online resources provided by USGS. The USGS Patuxent Wildlife Research Center provides central coordination for the survey effort. Over 20 states are currently participating. Survey effort under a common survey protocol began in 2001, with some earlier data collection in a few states. Start date varies by state. NAAMP uses trained volunteer observers, who must pass an online frog call quiz, to conduct frog call surveys on assigned roadside routes. The project’s underlying goal is tracking population trends for calling amphibians at the state and larger geographic scales.”</td>
</tr>
</tbody>
</table>
All researchers answered that citizen scientists, even if they were student volunteers, were involved in the collection of field data through auditory surveys, visual observations, or physical handling of live animals for disease testing (figure 3). Interestingly, four researchers utilized volunteers for amphibian population studies in the field, a very time consuming and often expensive task. This suggested that such participatory programs with volunteers may be helpful when funding for paid staff is limited.

Additionally two respondents stated they utilized volunteers to aid in disease testing on wild amphibians. This is very important because it firstly means that more information about infections was generated from their research, but also that volunteers must have gained a degree of understanding about amphibian diseases, which increased their knowledge of ecological phenomena.

The following question attempted to ascertain the professional opinions of utilizing such participants in scientific amphibian monitoring efforts. This was asked to gauge the level of effectiveness of non-scientists in such programs and also to surface any benefits that may arise that would be beyond standard primary research practices in which the public was not involved (table 4).
Contributor: FA  
Response: “In some cases it is useful, but tasks must be kept at a very minimal size. Moreover, it is important a moment of formation, and there must always been a control and coordination by people experienced and competent. There is the risk that, if the work is left totally at the charge of the volunteers, that they perceive this kind of activity as non-professional, and they even may think to drive the research activity and the conservation activities on other “roads”. I stress the fact that any volunteer activity must be strongly coordinated.”

Contributor: DMG  
Response: “The major projects I know of that have involved public participation are the various amphibian monitoring studies such as the NAAMP, the Marsh Monitoring Program and the Backporch amphibian surveys. All have problems in maintaining the involvement of volunteers, ensuring data quality and amassing analyzable data sets. However, they have been very valuable in determining the presence of species in many places that would not otherwise be surveyed.”

Contributor: KK  
Response: “So long as they are well-supervised, volunteers are very important. Without proper supervision, their productivity would be questionable. Always though, it is good for making them like amphibians, which is important for amphibian conservation.”

Contributor: PRW  
Response: “It is good for educational and public relation purposes”

Contributor: LW  
Response: “Public participation allows long-term, geographically large programs like NAAMP to be feasible. It would be too expensive to have paid technicians to conduct the same tasks over the same geographic area.”

Contributor: JKW  
Response: “Essential in order to have enough scope to get meaningful results, consistency and maintaining interest can be difficult.”

**Table 4.** Responses to Question 3: ‘What is your opinion on public participation (e.g. citizen science or volunteers) in amphibian research?’

Four out of six respondents discussed the benefit of increased geographic range of studies through the use of volunteers. In fact, two responded with the suggestion that their large-scale programs would not be feasible without such volunteers, either because of scale or monetary limitations. This data demonstrated a clear benefit towards overall amphibian conservation, as without citizen involvement the research could not have been conducted in the first place.

Additionally, respondents mentioned that volunteer involvement contributed to increased size of data sets and finding locations of new populations, which suggested that the use of citizen scientists in such practices was effective towards the contribution of important knowledge to the field of primary research biology. These responses speak directly to one of my primary questions.

Improved public appreciation and understanding of amphibians was also posited as a contribution of such programs. This directly provided evidence that participatory biology does successfully increase popular understanding of ecological phenomena, another of my primary questions. As discussed earlier reaching the public with the message of the amphibian crisis will be paramount for their long-term conservation.
The next question (table 5) asked respondents to identify specific benefits and challenges for amphibian citizen science programs. This is important, as it helped to ascertain if such public participatory programs are worth the effort in the first place. This also helped to identify reasoning as to why such programs may be important, firstly for increasing participant understanding, and secondly for pragmatic means toward primary research.

<table>
<thead>
<tr>
<th>Contributor</th>
<th>Upside:</th>
<th>Downside:</th>
</tr>
</thead>
<tbody>
<tr>
<td>FA</td>
<td>1. “There is a general awareness increase; 2. People perceive research activity as something worth and interesting; 3. There is a lowering of costs; 4. There is a general participation of local communities.”</td>
<td>1. “A strong coordination is needed; 2. Researchers must maintain the control of the scientific activities; 3. Sometimes volunteers are not so responsible, and then there might be a heterogeneity in competences and motivations; 4. After an initial period of enthusiasm, the interest rapidly lowers, and at the end of the study period (when animals are less active), there is a general request of stopping the data collecting, with problems with the data themselves that are practically no more collected.”</td>
</tr>
<tr>
<td>DMG</td>
<td>1. “Public awareness and appreciation for amphibians. 2. Discovery of sites worth investigating more thoroughly.”</td>
<td>1. “Cost in time and effort to set up a workable study protocol and police the volunteer helpers. 2. Unreliable data. 3. Difficulty in ensuring longterm commitment to a project.”</td>
</tr>
<tr>
<td>KK</td>
<td>1. “Free assistance for amphibian researchers. 2. Gets citizens interested and educated about frogs.”</td>
<td>1. “Requires time to supervise and instruct. 2. Results not always as good as that of a paid employee.”</td>
</tr>
<tr>
<td>PRW</td>
<td>“Educational and public awareness to ecological and environmental issues. It is currently a newsworthy issue”</td>
<td>“Involving the general public cuts down efficiency, ie it takes longer to accomplish a task because of all the time consuming questions the public ask, questioning EVERYTHING. I can work much faster alone.”</td>
</tr>
<tr>
<td>LW</td>
<td>1. “Lower cost 2. Increase public awareness of science and conservation.”</td>
<td>“Recruitment and retention can be challenge, but same is true for a paid workforce.”</td>
</tr>
<tr>
<td>JKW</td>
<td>“Essential in order to have enough scope to get meaningful results.”</td>
<td>“Consistency and maintaining interest can be difficult.”</td>
</tr>
</tbody>
</table>

Table 5. Responses to Question 4: “What is the upside/downside of public involvement in amphibian research projects?”

All researchers responded to this question and provided important insights into the
pros and cons involved in their programs. One of the largest challenges to programs appeared to be time resources devoted to volunteers and levels of their commitment. Five respondents mentioned as a challenge the amount of time required for such tasks as recruitment, coordination, training, and management of volunteers. Four respondents identified retention or long-term commitment to the research on the part of volunteers as an issue. This is an important observation, as it suggested that professional researchers may devote important time resources to preparing volunteers for field work only to have them abandon the project. A secondary question that remains to asked is how to keep commitment levels high throughout the duration of the study. One of my strategies for keeping volunteers engaged in such programs is reflective art practices following field work, as discussed below.

Additionally, two respondents mentioned the unreliability of data collected by volunteers as a potential problem. This is why careful coordination and supervision is very key to viable data collection on the part of volunteers. My own strategies for ensuring viable data collection from volunteers will be discussed below.

However, such programs also demonstrated strong benefits, especially for volunteers. Five out of six respondents identified such programs as effective for increasing participant understanding of amphibians. Additionally three respondents mentioned the monetary benefit of working with a volunteer labour force, as this lowered the overall cost of research programs. These are very important observations, as they firstly suggested that such participatory programs did increase popular understanding of ecological phenomena and secondly allowed for research to be conducted despite of the lack international financial support for amphibian conservation as mentioned above by Stuart (2012).

Additionally two respondents mentioned the data benefit of working with the public in research, both in terms of scale as well as identification of localities not previously examined. This is important, offering two concrete examples of how participatory practices contributed new and important knowledge to the field of primary research biology.

The following questions sought to understand what role the public served in such programs as well as how many participants were involved. This is important to gauge what types of tasks the public were expected to perform and the overall outreach of such programs (table 6).

<table>
<thead>
<tr>
<th>Contributor</th>
<th>Role of Public</th>
<th>Numbers of Public involved</th>
</tr>
</thead>
<tbody>
<tr>
<td>FA</td>
<td>Data collection</td>
<td>Greater than 30</td>
</tr>
<tr>
<td>DMG</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>KK</td>
<td>1. Data collection 2. Public outreach</td>
<td>Approx. 80</td>
</tr>
<tr>
<td>PRW</td>
<td>Data collection</td>
<td>Approx. 30</td>
</tr>
<tr>
<td>LW</td>
<td>Data collection</td>
<td>Approx. 500</td>
</tr>
<tr>
<td>JKW</td>
<td>Data collection</td>
<td>Greater than 1000</td>
</tr>
</tbody>
</table>

Table 6. Results of Question 5: ‘What role(s) did the public have in the project?’ and Question 6: ‘How many members of the public were involved?’
Five out of six researchers responded that the primary job of participants was “data collection” (please see appendix for full responses). A wide range of tasks was performed by volunteers while collecting such data: auditory surveys and online data entry; physically collecting, measuring, and documenting animals; collecting and epidermal sampling; and assistance with public outreach campaigns. These are important data, as they demonstrate the broad range of skills utilized by volunteers. This has larger ramifications for the public’s successful involvement in many different aspects of research programs aiding in many aspects of amphibian conservation. Similarly, diverse tasks were performed by my volunteer teams in England and Canada, which are later in this chapter.

These data are also important for the information provided on the scale of such programs. Just among these five professionals and their programs, over 1,600 volunteers were involved. These groups ranged in size from 30 to greater than 1,000 members of the public participating in such programs, which suggested that such studies may be conducted with large numbers of people, potentially increasing good amounts of ecological understanding for a wider populace.

The last question asked about concrete outcomes of such public programs. This was asked to gain a better understanding of whether goals were fulfilled through public involvement in research. Also it is important to ascertain if new scientific insights could be achieved through such participatory biology programming.

<table>
<thead>
<tr>
<th>Contributor:</th>
<th>Outcomes:</th>
</tr>
</thead>
</table>
| FA           | 1. Increased awareness of amphibians for overall community  
2. Insight into local declining amphibian population  
3. Scientific publications |
| DMG          | n/a       |
| KK           | 1. Scientific publications  
2. Increased awareness for community  
3. Stopped school amphibian dissections  
4. Stopped sell of frog legs  
5. Legal changes |
| PRW          | 1. Increased awareness for community  
2. Data collected on amphibian disease |
| LW           | 1. Scientific publications  
2. Generated future studies |
| JKW          | 1. Scientific publications |

Table 7. Results of Question 7: ‘What was the final outcome of the project?’

The results of these questions demonstrated that several scientific publications resulted from these citizen science amphibian studies (table 7; please see appendix for full responses). This is important, as it showed that at least some of the data collected through volunteer efforts was viable and thorough enough for the peer review process and even led to future studies. This is strong evidence that such participatory programs contributed important knowledge to the field of primary research biology, knowledge that was then disseminated to
the larger scientific community.

Additionally, these insights show the positive benefit of increased awareness of local amphibian populations. This is strong evidence that, at least in the opinions of these professionals, participatory biology programs successfully increased popular understanding of ecological phenomena, in this case changes in amphibian populations.

Overall, these observations were very important, as they suggested such programs may achieve both scientific and conservation benefits through public participation in research. However, from my own experiences leading such participatory amphibian programs, I believe other strategies may be utilized to further public engagement with the message of amphibian conservation.

For example, in the large surveys conducted by Dr. Linda Weir (NAAMP) involving more than 500 participants each year, public handling of animals is not included as part of the methodology, so hands-on experience with living animals does not occur (Weir 2011). Although the participants listened for calling amphibians, their tactile experience of animals and ecological systems was not facilitated.

Learning field collection techniques may add yet another dimension to a program as well as vitally assisting the primary researcher. In an interview, Pierre Raymond Warny, (New York State Museum), suggested that citizen science is ‘good for educational and public relations purposes’ (Warny 2011). In April 2010, Warny conducted a project where citizen scientists swabbed wild collected frogs for chytrid fungus assays in natural amphibian populations on Long Island (New York). But because he did not teach his thirty participants how to capture anurans, he ended up doing most of the time-consuming field collection himself, stating, ‘I did most of the field work, since [non-scientist participants] were so inept at trying to catch frogs; [the specimens] all hopped away’ (Warny 2011). However, if Warny had taught students to safely catch anurans from the beginning in addition to teaching them swabbing techniques, he could have saved himself time and effort while greatly enhancing the participants’ experience.

Teaching the public and even school children how to collect frogs was an important component of the citizen science programs lead by Dr. Franco Andreone from 2004 to 2009. Such participants monitored drift fence traps, measured individual frogs, and photographed them. (Andreone 2011). Such tactile experiences impacted the participants’ awareness of amphibians. As Andreone stated, as the result of the programs, ‘Local populations are aware of the importance of the frogs there, and local schools have included this biodiversity aspect and item within their scholastic programs’ (Andreone 2011). Andreone suggested, on the other hand, that there is a labour-intensive side to keeping data and volunteers in check: ‘there must always been a control and coordination by people experienced and competent … any volunteer activity must be strongly coordinated’ (Andreone 2011). Perhaps then an answer may be to keep groups small and to maintain constant control of quality. This is the strategy that I have employed in my *Eco-Actions*, which will be discussed later in this chapter.

In the midst of the current great amphibian extinction event, Dr. Kerry Kriger, biologist and founder of Save the Frogs, advances the idea that the research community needs to make the message of conservation more pronounced and to involve the public in its efforts (Kriger 2010). Involving citizens in monitoring programs can be an effective strategy for
increasing awareness about the complexity of amphibian declines,²¹ it has yet to be perfected (Kriger 2011). As Kriger has suggested, training the public can be a major hurdle, as it takes a lot of time and the results generated from volunteers are ‘not always as good as that of a paid employee’ (Kriger 2011).

Nevertheless, some volunteers have made their mark. During his doctoral research, Kriger worked with over 80 volunteers, successfully generating more than ten peer-reviewed scientific papers. Kriger also suggests that in his environmental organization, he has continued to work with volunteers in educational programs and at an administrative level, resulting in ‘many thousands of people worldwide being educated about amphibian extinctions and ways they can help, as well as tangible results including ten schools stopping frog dissections and two restaurants and 76 supermarkets ceasing frog leg sales’ (Kriger 2011).

Dr. David M. Green, amphibian specialist at McGill University, agreed with some of the citizen-science hurdles put forward by Kriger. It takes time to teach volunteers, and not all of them will necessarily commit to the development of long-term research projects (Green 2011). Additionally, Green suggested that data collected by the public may not be as reliable as information collected by a trained biologist. However, Green agreed that including citizens in public research programs can increase ‘awareness and appreciation for amphibians’ and help biologists find wetland ‘sites worth investigating more thoroughly’ (Green 2011). As funding for pilot amphibian surveys is often limited, having the local public’s insight into sourcing viable study sites saves time and money for the researchers.

Dr. Jean Wilkinson, research and monitoring officer of the UK’s Amphibian and Reptile Conservation Trust (ARC), even suggests that public involvement in large-scale studies of amphibians is vital and that having large numbers of participants generate information over a geographically widespread area is ‘essential in order to have enough scope to get meaningful results’ (Wilkinson 2011). Wilkinson’s work with ARC has involved over a thousand members of the public, who participated in amphibian calling surveys between the years 2007 and 2011 (Wilkinson 2011). This enormous project spanned the whole of the United Kingdom, with reports submitted in England, Ireland, Scotland, and Wales and results collected from the 524 surveys conducted (Wilkinson and Arnell 2011). This information provided important insights into the state of amphibian populations in the UK, including the discovery of previously unknown populations, changes (losses) of previous breeding habitats, and others (Wilkinson and Arnell 2011).

The evidence provided in these questionnaires demonstrates that public participation in field studies can and does provide new knowledge to the larger field of primary research biology. Of equal importance, the studies also provide important evidence that such programs did increase ecological understanding for participants, a finding that could have important ramifications for the larger amphibian conservation movement.

### 6.4. Eco-Actions: Public Participatory Biology Field Surveys

²¹ Kriger surmises that the loss of amphibians cannot be attributed to a single cause but instead suggests a host of possible culprits that include habitat loss and alteration; introduced native and nonnative species that compete with or consume native species; emerging infectious diseases (including bacteria, parasites, and fungus); pollution; climate change; over-collection from the pet and food trade, and others (2010).
Eco-Actions are participatory biology inquiries into ecological phenomena conducted through public field surveys. Working in hands-on aquatic and terrestrial biological field sampling, members of the community participate directly in scientific investigations. Likewise, participants are encouraged to reflect upon their experiences through creative art practices (such as drawing, painting, poetry, sound, and video), utilizing encountered species as subjects and field-collected material as media. In this way the Eco-Actions become a link between transdisciplinary art practices and scientific research. Fundamentally they are attempts to bridge communities to local ecosystems, disseminating to participants increased understanding of the biodiversity—and often the lack of biodiversity—at these sites.

These Eco-Actions give form to my concept of ‘participatory biology’, which empowers students, volunteers, or members of the general public to be directly involved in varied tiers of the scientific research process: problem identification; testing hypotheses through both preliminary and primary field and laboratory studies; reflective art activities; analysis and understanding of results; and dissemination of these results to a larger audience.

Diverging from other citizen science programs, Eco-Actions feature art as an important component. As stated earlier, Joseph Beuys’s work Eine Aktion im Moor was an early inspiration for my work, because he directed public attention toward bog loss and its environmental ramifications. Also, like Beuys, I grew up with a keen interest in nature and maintained a working laboratory since my youth while also making artworks of animals. These early, autodidactic experiences of learning by direct interaction with animals and ecosystems have contributed directly to my concept of ‘participatory biology’ and the way art may play an important, reflective role in research.

Perhaps because my own professional background is untraditional and has involved collaboration with a number of other biologists, artists, and members of the public, the methods I employ in Eco-Actions are novel in citizen science, involving tactile immersion of participants in place (wetlands) and with subjects (amphibians); collective discussions for hypothesis testing; participatory field and laboratory studies leading to group and individual observations; post-research experience with creation of participant artworks; collective analysis of research results; and dissemination of these results to not only the scientific community but also to a larger, non-science audience through creative means. (table 8).

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212 According to art historian Robert Mattison, ‘Brandon Ballengée is one of the most interesting young artists to present a true fusion between art and science ... Ballengée was brought up in the farm country of Ohio in constant contact with nature. By age twelve, he had built a small laboratory in his basement where he bred fish from the Amazon Basin that were exhibited in local science fairs’ (Mattison, forthcoming, please see appendix).

213 Please see appendix for 2009 interview in Antennae.
Table 8. Comparisons and contrasts of standard citizen science amphibian programs (as discerned from examples discussed in previous section) with my Eco-Actions.

<table>
<thead>
<tr>
<th>Methodology:</th>
<th>Standard Citizen Science Amphibian Programs:</th>
<th>Eco-Actions:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identification of problem:</td>
<td>Public not normally a part of this process</td>
<td>Public to some degree a part of this process.</td>
</tr>
<tr>
<td>Testing hypotheses through field and laboratory studies:</td>
<td>Public participation in field work, often auditory sampling minimal tactile interactions with wetlands nor actual amphibians. No public involvement in laboratory work.</td>
<td>Public participants involved in finding and choosing field sites. Full emersion in field work with tactile experiences with animals and wetlands. Public participate in laboratory studies, such experiments are conducted in open laboratory settings.</td>
</tr>
<tr>
<td>Post-research experience reflection through creative means:</td>
<td>Not conducted</td>
<td>Participants often create creative writings, visual or auditory art works.</td>
</tr>
<tr>
<td>Analysis and understanding of results:</td>
<td>Limited to no participant involvement in analysis of data sets</td>
<td>Participants are asked to interpret the results of findings and are part of the analytical process.</td>
</tr>
<tr>
<td>Dissemination of results:</td>
<td>Peer reviewed science articles. Participants not involved in scientific publishing, limited outreach to a larger public</td>
<td>Peer reviewed science articles. Larger public dissemination of results through art, online platform, social media, others.</td>
</tr>
</tbody>
</table>

These novel approaches of the Eco-Actions diverged from other biologists’ citizen science programs in many ways. For example, in contrast to programs discussed by Warny, my participants underwent preliminary training for collecting and safely handling aquatic organisms. This saved me collection time (which can be very physically involved and take countless hours) as well as allowing for more robust sample sizes. Importantly, it also enriched the experiences of participants, as they had to work towards refined auditory and visual searching skills for collecting such wild amphibians (Ballengee and Green 2011). The participants also aided in the preliminary physical examination and documentation of collected amphibians, which added a further tactile experience and one-on-one interaction between human/s and non-human animals. (see figure 11).

This multi-sensory experiential model in my Eco-Actions differed from programs discussed by Weir and Wilkinson in that the tactile experience of being in the wetland and handling the animals increased participant ecological consciousness, a method attuned to the philosophy of Richard Louv, environmental educator and writer. Louv stated that in recent years youth and the general public in developed countries have increasingly suffered from what can be described as ‘nature-deficit disorder’ (2005: 34). This has culminated in alienation from experiences in nature, resulting in a host of malevolent psychological issues and environmentally non-sustainable practices, including a ‘diminished use of the senses, attention difficulties, and higher rates of physical and emotional illnesses’ (Louv 2005: 34).

Even more acute in cities,²¹⁵ this detachment stems from lack of access to and physical exploration of the outdoors and other natural environments, which, according to Louv, can be associated with increased rates of ‘crime, depression, and other urban maladies’ (2005: 34). Louv surmised that occidental cultures have evolved away from direct, environment-based experiences and have become increasingly reliant on secondary sources for knowledge growth, such as learning about frogs from a smart phone application without actually ever seeing—or even holding—a live amphibian.

This model of knowledge acquisition has removed individuals from active learning

²¹⁵ Special efforts have been made to reach urban populations through my programs. For example, in 2006–2008, a Public Bio-Art Laboratory was founded in the New Haven Business Center (New Haven, CT). The lab was utilized as base of operations for conducting numerous student/public Eco-Actions through partnerships with Artspace, the Peabody Museum at Yale University, and Solar Youth, involving more than 120 urban students and the public. Former Solar Youth student Tatiana Winn stated of the programs, ‘Brandon encouraged youth to lead hikes in the woods and to express their own perspective about the natural elements around them. He also asked the youth to talk to their families and friends about the knowledge they gained during sessions in a tactic he calls “viral knowledge”, hoping to “infect” others with the knowledge to care for the environment’ (Solar Youth 2006: 6; please also see report in appendix materials).
participation and has made them passive learners or consumers: a position that, according to Louv, has depersonalized experiences with nature and even with other humans (2005: 64–65).

In agreement with Louv, I think that learning the science behind ecology through actual, tactile interactions with wetlands and living animals is essential for increased appreciation and understanding of the environment.

Furthermore, as digital technologies have become increasingly mobile and widespread, learning by physically doing has largely been replaced with learning through virtual interfaces. As science philosopher Edward Reed (1996) has suggested, more and more we lack multi-sensory or primary experiences in our everyday lives. This has resulted in what Reed has called an ‘experiential gap’ and the erosion of natural mental resources, and has lead to a further disconnect from one another and the natural environment (1996: 64).

As Reed has suggested, we have lost the understanding of ourselves as living organisms that are part of a larger physical environment in connection with other species. An underlying aim with my Eco-Actions was to offset this experiential gap by physically involving the public in all aspects of the research. Here participants waded into wetlands, searching for and handling amphibians, thus inducing multi-sensory experiences (see figures 11, 12, and 13).

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216 As Reed surmises, ‘There is something wrong with a society that spends so much money, as well as countless hours of human effort, to make the last drags of processed information available to everyone everywhere and yet does little to nothing to help explore the world for ourselves’ (1996: 64).

217 According to Reed, the philosophy of René Descartes suggested that reality is ephemeral and that human beings can only interpret experience through their own individual set of internal sensory inputs—a model that Reed has said is now an underlying cultural construct in the West and has increased rapidly with technology and postmodernism (1996: 64–65).

218 Reed confirmed Louv’s position, namely, that Western cultures have become increasingly reliant on ‘processed’ or ‘secondhand’ information, stating that as a result we have begun to ‘lose the ability to experience our world directly’, adding, ‘What we have come to mean as the term “experience” is impoverished; what we have of experience in daily life is impoverished as well’ (1996: 64–65).

Figure 18. Volunteers during 2009 Quebec Eco-Actions.

Figure 20. Lough Boora, Ireland Eco-Action from 2010 Common frog (Rana temporaria) studies.
A more experiential methodology was needed to help people be more conscious of the environment, and consequently, to find more detailed evidence of phenomena. When participants in the Eco-Actions examined wetlands, they did so using multi-sensory observations: listening, looking for, and physically handling organisms, even smelling and tasting amphibians. In this way the experience of the investigation becomes more personal and more detailed. This method was also more open-ended, as participants were asked to make a broad range of observations and share their opinions. For example, in the 2009 Quebec studies, participants noted that frogs in degraded wetlands had duller colours and lacked an alkaline smell, compared to those collected from more pristine ponds, an observation that suggested environmental quality of habitats may have been a factor for overall amphibian health (further discussed later in thesis).

In addition to multi-sensory experiences, as Kriger and Green surmised, keeping teams of volunteers motivated with a long-term project was difficult. From my experiences with the Eco-Actions, I encouraged participants to make their own observations and reflections beyond just science. Here, participants were encouraged to reflect creatively—through the creation of their own artworks or other forms of expression—on their experiences with the animals, the wetlands, and the research process (examples below). As a result, I believe this direct connection to the animals and an outlet through art kept my volunteer teams motivated to stay in the research program (please see 2009 Quebec research volunteer video interviews in the appendix and further discussion below).

During my Eco-Actions, viable data on wetlands and encountered species was

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219 Olfactory and gustation testing are sometimes utilized in amphibian field studies to monitor palatability to predators and health of individual frogs (Wassersug 1971; Valerie C. Clark 2010)
collected and shared with the greater scientific community. Researchers such as Green and Andreone have questioned the reliability of data from citizen-science observations. However, I have found that by carefully directing group actions and following strict scientific methods, the results of public field investigations did provide important information about localized ecological phenomena (please see later chapters; Ballengée and Sessions 2009; Ballengée and Green 2011).

In fact, throughout my PhD research, the public was directly involved in scientific investigation through the Eco-Actions, resulting in observations of over 15,000 wild amphibians and new insights into mechanisms responsible for amphibian malformations. This is strong evidence that such transdisciplinary art and participatory biology practices contributed new and important knowledge to the field of primary research biology. Likewise, data from participant interviews suggested that the methods employed in these Eco-Actions also successfully increased their understanding of ecological phenomena, in this case the causes for amphibian malformations (presented below and in the appendix).

6.5. Public Bio-Art Labs: Primary Research Laboratories Open to the Public

Further merging together ideas of transdisciplinary art and participatory biology, my series of Public Bio-Art Laboratories (2006–present) embrace a systemic methodology that posits art practice as a means of realizing research science and vice-versa, blended with a form of ‘ecosystem activism’ implemented through involvement of students and the public, all fully integrated into primary research processes.

Pragmatically, the Public Bio-Art Laboratories comprise temporary laboratory installations (as opposed to earlier metaphorical lab installations221) that have been generated for actual biological research. Experiments have been successfully conducted and science happened, yet such spaces also facilitated artistic outcomes in the form of visual artworks, sound-works, videos, and creative writing.

Additionally these Public Bio-Art Laboratories have functioned as important platforms for public interactions, discussions, and participant involvement in laboratory experiments. They have also supported and complemented my Eco-Actions in order to identify and address localized environmental problems. In the spirit of Nicolescu, they have facilitated increased popular ‘understanding of the present world’ (1998: 1) through concrete strategies by which art and science merged to engage local populations.

For the Public Bio-Art Laboratories, I was on hand to directly engage with audiences as they visited and volunteered in scientific research activities (see figures 15 and 16). Here my role was a blending of artist, scientist, educator, and manager of participants. I sought to inform rather than simply provoke, but more importantly to question locals about their views of proximate ecosystems and amphibians. This was very important, as it permitted people to share their knowledge of local ecology, a strategy very much attuned with the ideas, discussed earlier, of Cornell University Ecologist Caren Cooper, who states that such opportunities are effective at ‘empowering people to contribute to the formation of knowledge’ and increasing

220 Please see post-research reflections made by my 2009 Quebec volunteers in video interviews in the appendix.

221 During the 1990s I made several metaphorical laboratory installations such as Doc Frankensteins at Exit Art 1999 (please see Lilly 2010 in the appendix).
a sense of stake-holding (Cooper 2012b: 3).

Additionally such public access to research laboratories is novel in science. The Public Bio-Art Laboratories were open during select times and installed at art venues
This was done to encourage non-science specialists to see first-hand the process of ecological research and also for them to question their definitions of art (responses below). This in part demystified the research process, even if a functional arrangement of tanks, samples, notes, and microscopes was present.

In addition, through their placement in art centres, the Public Bio-Art Laboratories allowed for increased levels of exchange with large numbers of visitors, in an attempt to spread a message of local ecology to a wider audience. As commented upon by curator Claire Lilley at Yorkshire Sculpture Park, ‘Over 800 people visited the lab and participated in these eco-actions’ (Lilley 2010: 52). In this way, I hoped to offer a strategy for reaching new audiences in the amphibian conservation community, an aspect that has been very problematic, as discussed early in this chapter by Mendelson et al. (2006), Bishop et al. (2012) and Stuart (2012). Data presented below suggested the Public Bio-Art Laboratories did increase audience awareness of amphibian issues and in this way was successful.

Within the Public Bio-Art Laboratories programs there have been two primary types of participants: Firstly those who visited the working laboratory for a short period of time, often only coming only once; and secondly those who visited the laboratory and volunteered for extended periods of time (a few days up to six months). In this way a small group of locals could contribute to the research for extended periods of time, an approach attuned with ideas discussed earlier by Michael Gibbons et al. (1994) by which such programs need be ‘locally driven and locally constituted … in response to problem-formulations that occur in highly specific and local contexts’ (1994: 30).

Embedded volunteers participated in all aspects of primary research. These included aid in experiment observations, input into experimental designs, aid in the care of animals, documentation, discussions with short-term visitors, and other responsibilities. Attuned with pragmatic ideas of Mittelstraß discussed earlier, high-level scientific work was performed without being generalized down to the non-expert level. As rigorous scientific methods and standards were utilized throughout laboratory experiments, the findings were reported in several peer-reviewed and governmental scientific publications (Ballengée and Sessions 2009; Sessions and Ballengée 2010b; Ballengée and Green 2010, 2011).

Though scientific research was successfully conducted, throughout the process I encouraged participants to reflect on their experiences of the process, local environments, the animal research subjects, and other elements they found inspirational. In this way the Public Bio-Art Laboratories moved beyond ‘activated spectatorship’ as described by art historian Clare Bishop (2004: 78), to facilitate actual creative participant outputs. These have included sculpture, new media works, creative writings, installations, photographs, and others (figures 17, 18, and 19; more in appendix). Such post-reflective art practices were important for allowing individuals to express themselves, to stay committed to the research programs, and also to further spread the message of amphibian conservation to a larger populace through exhibitions, social media, and others means, such as the volunteer frog blog hosted by Société Des Arts Technologiques, Canada.222

Figure 24. *Planète* by Nolwenn Gouezel, 2009. Digital-C photograph on acrylic resin. 57x72 cm.

Figure 25. *Untitled* by Zoé Brunelli, 2009, urethane casts of preserved deformed frog and vellum banner. 1.5 m x 3 m x 1.5 m
This merging of art and science, though reminiscent of approaches to some principles of citizen science and transdisciplinarity, has often been at odds with the mainstream art world and, as art historian Lucy Lippard has stated, ‘It is often argued that art is “useless”, whereas science can achieve more definable goals’ (Lippard 2010: 13). Yet the model employed in the Public Bio-Art Laboratories is much more aligned with ideas discussed earlier by Art historian Sue Spaid, who deemed ‘art-making as a mechanism of discovery, totally on par with that of science’ (2007: 1). Thus, art is an active form of investigation, parallel with the underlying goal of conducting scientific research in the first place. Critics might charge that the Public Bio-Art Laboratories installations are science or activism and not art, but they are exactly my vision of transdisciplinary art merged with participatory biology.

6.6: Qualitative Analysis of Volunteer Responses to These Programs

To ascertain if transdisciplinary art and participatory biology programs could successfully increase popular understanding of ecological phenomena, I utilized my own British and Canadian Eco-Actions and Public Bio-Art Laboratories as case studies. Questionnaires and interviews were given to participants to gauge if such programs increased their understanding of the challenges amphibians face, the ecological phenomenon of population declines, and developmental malformations in amphibians.

The first questionnaires were given to visitors to the Public Bio-Art Laboratory installed at Yorkshire Sculpture Park in Wakefield (UK) in the summer of 2008. One hundred
thirty-eight visitors answered these questionnaires, of which almost half (45.7%) had either participated in a related amphibian research Eco-Action. Other respondents had visited the research blog (5.1%) or visited the laboratory only (49.2%).

To gauge the effectiveness of these experiences for increased ecological understanding, participants were asked if they learned anything about amphibians by visiting the laboratory. The overwhelming majority (91%) responded ‘yes’, while only four individuals said ‘no’ and eight did not answer (figure 20). These data strongly suggested that such transdisciplinary artworks as the Public Bio-Art Laboratory were able to successfully increase overall visitor understanding of amphibians.

![Figure 27](image)

Figure 27. YSP Public Bio-Art Laboratory Questionnaire (1 June 1–1 August 2008). Question 11: ‘Did you learn anything about amphibians by visiting this open laboratory?’

Other questions sought to shed light on the public understanding of amphibian issues such as malformations and perception of individual environmental impact after visiting the laboratory. The results of the questionnaires demonstrated that the majority (92%) of visitors identified the local and global occurrence of amphibian malformation as a problem (figure in appendix). However only 73.9% of visitors identified themselves as having an impact on the environment (figure in appendix). This suggested that the laboratory experience positively increased their awareness of the deformed amphibian problem, yet may not have been successful at spreading the larger message of the impact of an individual ecological footprint.

The visitors were also polled on their bioethical views on experimentation with living animals as conducted in the laboratory. Results were very mixed, with the majority of those surveyed answering the question of whether the practice was ethical with ‘yes’ (35.5%). However, 25.6% were undecided, 17.7% said such experiments were not ethical, and a large percentage (21.2%) did not answer the question (figure in appendix). Interestingly these numbers reflect the complexity of the bioethical debate, as discussed in previous chapters and as discussed again from my own standpoint on animal research, later in this thesis.
Another question attempted to ascertain public categorization of the transdisciplinary Public Bio-Art Laboratory and related programs. The results demonstrated that the majority of visitors (51%) identified the lab’s activity as ‘science’ when asked, ‘Is this art or science or both?’ and only 30.4% found it both art and science (figure 21). Perhaps reflective of popular opinion, the most tangible products resulting from these programs stayed largely in the scientific community.\(^{223}\) Regardless, as stated above, more than 800 visitors came to or participated in the 2009 programs, and I hope that at least some transfer of ecological appreciation occurred to the public.

![Figure 28. YSP Public Bio-Art Laboratory Questionnaire (1 June–1 August 2008). Question 10: ‘Is this art or science or both?’](image)

A later Public Bio-Art Laboratory was created in the summer of 2009 at the Société des Arts Technologiques (SAT) in Montréal, Canada. This variation differed from the early UK version in that it was open to the public only three times per week and only a small core group (n=10) of public participants were trained and aided in field studies Eco-Actions over the course of twelve weeks. Visitors to the laboratory were asked to fill out post-experience questionnaires, and the core members were interviewed on camera to gauge the effectiveness of programs.

Although far fewer people visited this Public Bio-Art Laboratory and only 56 visitors answered questionnaires, the majority (63.4%) still asserted that visiting the lab increased their understanding of amphibians, with only 3.6% feeling it did not and 33% not answering the question at all (figure 22). Though less positive than the UK results, the data still support the belief that such transdisciplinary artworks were effective at increasing overall visitor understanding of amphibians.

\(^{223}\)Scientific results of these field and lab investigations led to a scientific paper co-authored with Stanley K. Sessions, published in the peer-reviewed Journal of experimental zoology that has been cited often in recent publications (please see appendix materials).
As for the question of the importance of the ecological issue of amphibian malformations, only 63.4% answered ‘yes’ while a large number (36.6%) of visitors remained undecided (figure in appendix). This suggested that the SAT lab variation was less effective than the previous UK model at increasing public understanding of amphibian issues. To speculate, this was perhaps because most visitors had not participated in Eco-Actions before visitation the lab, which limited the extent of their experiences.

In regards to the question of individual environmental impact, the overwhelming majority (98.2%) of visitors identified themselves as having bearing on ecosystems (figure in appendix). The extent to which the experience of the open laboratory influenced this perception is not known, as the data may have suggested pre-existing societal differences between the populations in Quebec compared to those in middle England.

On the question of bio-ethics of laboratory experiments, 49.2% did deem the practices as ethical with 36.9% undecided and only 13.9% saying such experiments were not ethical (figure in appendix). An additional question was added to the Quebec questionnaire to gauge audience perception of the necessity of such experiments. Here the majority (76%) of participants did deem animal experiments conducted in the laboratory as necessary, while only 18.3% remained undecided and one individual (5.7%) was opposed (figure in appendix). These data again reflect the bioethical complexity of the animal use in such experimentation, as discussed in this thesis.

For the question on categorization of the laboratory’s activity, the majority (76%) of participants viewed the project both art and science, with only 16.4% viewing it only as art and 7.6% only as science (figure 30). This was encouraging as it suggested the Quebec audience perceived the underlying art-science fusional intention behind the Public Bio-Art Laboratory.
As mentioned above, during the Quebec amphibian studies, a core group of ten public volunteers were trained and aided in all aspects of the field and laboratory research. The program duration was twelve weeks, and on average volunteers worked 18.3 hours per week towards the project. Of these initial ten members, nine remained for the full duration of the project. As the project was coming to a close, interviews were conducted to ascertain the effectiveness of these experiences towards increasing understanding of ecological phenomena, amphibian population declines, and developmental malformations.

Five out of ten participants answered questions through video interviews, while four wrote their responses and one did not respond (for interviews please see appendix). Of these, all participants stated that working on the project increased their understanding of amphibians and the challenges they face. As team member Francis Pineau (DJ and sound art teacher) explained, ‘It has changed my understanding of amphibians and increased it … also about understanding the problems they face in terms of habitat transformation, predation, and pollution of course … about the whole complexities of the whole issue’ (Pineau 2009). This opinion was furthered by carpenter Jean Martinoli, who stated, ‘Many years ago in school I learned about amphibians and relearned through this project. All the stages of tadpole to frog development, their predators and habitats. I never heard of amphibian deformities or malformations … or how many are dying and we still don’t know fully why, now I understand more’ (Martinoli 2009). In summary, designer Natalie Bouchard stated, ‘All the amphibians are important, we must understand them to save their species’ (Bouchard 2009).

15. None of the participants had a science background and instead most came from the creative sector. Core participants included: Natalie Bouchard (designer); Zoe Brunell (visual artist); Audrey Desjardins (designer); Marie-Chantale Desrosiers (visual artist); Nolwenn Gouezel (journalist and photographer); Marie Larocque (filmmaker and visual artist); Jean Martinoli (carpenter); Frédérique Paquin (visual artist, film industry); Francis Pineau (DJ and sound art teacher); and Marilyn Teuwen (arts major at L’ Université Du Québec à Montréal—UQAM).
Beyond only the issues of amphibian deformities and decline, participation in this project appeared to increase participant understanding of larger environmental issues, as suggested by their responses. Maria Larocque stated she learned from the project that ‘we have to know what is happening to amphibians to know what is happening to the earth, as they show all the changes on the planet’ (Larocque 2009). This position was reaffirmed by art student Marilyn Teuwen, who said, ‘Frogs and bees, we are so used to having them around but they tell us about what is happening in the world … there are all these other factors climate, pollution, predators … it is all very big complicated issues’ (Teuwen 2009).

These responses demonstrated that participant awareness of ecological phenomena was increased, but what of larger questions about the human approaches to the environment? This was remarked upon by journalist and photographer Nolwenn Gouezel, who stated of the entirety of the project, ‘It can show humans that the environment is drastically going down … not only about just pollution or climate change, and the big decline and how this relates to changes in evolution … it is important that we talk about synergy … humans have a big responsibility’ (Gouezel 2009). As Francis Pineau epitomized, ‘We should be aware of what is happening in our surroundings … we are all part of this one great ecosystem it is important to take notice … we don’t live in a bubble’ (Pineau 2009).

These answers all provided evidence that transdisciplinary projects such as the Eco-Actions and Public Bio-Art Laboratory increased participant understanding of ecological and conservation issues. However one concern I had was whether by working directly in animal testing, where tadpoles were injured or even killed by predators, the volunteers may have become desensitized or less empathetic to such organisms. Unanimously, participants answered they did not, even going further as Marilyn Teuwen stated, ‘Contrary to being desensitized, you actually start to see they are like humans; the animals are vulnerable, like humans’ (Teuwen 2009). This increased empathy was not expected, but Maria Larocque noted, ‘The experiments opened my eyes about the life of the frogs, the problems they face with predators and pollution’ (Larocque 2009).

This increased appreciation of amphibians through laboratory observations was very encouraging to hear, and other volunteers said it even changed their overall perception of nature. As stated by Francis Pineau, ‘It is a reality that I did not know and understand … it breaks down the rosy picture of animals I had … opens your eyes to [the reality] that life can be savage … not like the cartoons or comic books’ (Pineau 2009).

For the question of the bioethics of such animal tests we conducted in the lab, all participants agreed unanimously that such experiments were ethical and necessary. As Marilyn Teuwen posited, ‘We are reproducing what is happening in nature … it is quite ethical, really’ (Teuwen 2009). Nolwenn Gouezel answered, ‘We are not supposed to do anything we want, it is ethical because every tadpole with a predator we put together were found together in nature … we just place them in the lab to observe what is happening in nature. We do not kill any specimen for pleasure or art’ (Gouezel 2009). Here it was interesting that Gouezel contextualized the experiments under the umbrella of art.

What function did artistic creativity play in these experiences, beside the obvious outputs by participants, discussed above? One outcome was further environmental outreach: letting people know about extinction and causes. Nolwenn Gouezel stated, ‘This is why this
project is so important, because making art can make people sensitive to all this’ (Gouezel 2009). The team member artworks were even spotlighted in a city-wide exhibition at Montreal’s Journées de la Culture 2009, potentially further spreading a message of amphibian conservation (Ballengée 2012, please see appendix).

All of these responses were quite positive and demonstrated that such participation in transdisciplinary art-science projects did increase volunteers’ ecological understanding. However, as with all projects, there are challenges, and participants were asked what they would have changed about the overall program. Through their answers the volunteers emphasized three areas that could have been improved. Firstly, lack of time: many felt the project should be longer than twelve weeks. Next, the necessity for more personnel was identified. Lastly, participants mentioned the limitations of financial and equipment resources.

As discussed at the beginning of this chapter, such restraints were not limited to our project but instead represent a larger issue prevalent in the overall amphibian conservation effort.

Although it is impossible to gauge whether participating in the 2009 Quebec Eco-Actions and Public Bio-Art Laboratory actually had a long-term impact in elevating environmental stewardship in volunteers, it is my hope that at least in some modest way appreciation of amphibian will stay with them for the rest of their lives. As Jean Martinoli concluded, ‘If we do not take care of them, who is next, what will happen? It is important to me’ (Martinoli 2009).

6.7. Conclusion

In this chapter, I have examined the research questions, ‘how can transdisciplinary art and participatory biology successfully increase popular understanding of ecological phenomena?’ and ‘how can such practices contribute new and important knowledge to the field of primary research biology, and how can the results be disseminated?’ I have discussed my own facilitation of citizen artists-scientists through Eco-Actions and Public Bio-Art Laboratories. My intention was to determine whether involving the public through my participatory art-science projects was effective for their increased awareness of ecological issues, and further, whether such involvement facilitated the gathering of new scientific knowledge and subsequent dissemination of that knowledge. I also sought to shed light on the novelty of these participatory, transdisciplinary methods, which merged art and science, when compared to conventional citizen science programs.

To answer the first question, data was collected from more than 200 participants of my prior art-science programs, either Eco-Actions, Public Bio-Art Laboratories, or both. The results overwhelmingly suggested that such programs did increase participants’ understanding of the ecological phenomena of amphibian declines and deformations. On a larger level, data also suggested that these projects effectively achieved two primary results: the empowerment of locally diverse participants to learn and express themselves through experiential ecosystem studies; and the increased sense of place in ecological terms for participants.

Regardless of age, class, sex, education level, or professional background, participants were equally encouraged to express what they experienced and observed at each site or in laboratory settings. As former participant Orieta Brombin stated, ‘Exchanges of views among the group lead to in-depth discussion … through a performance shared with the
group as a whole … with a goal of producing an echo, a choral movement of taking responsibility for complex environmental problems’ (2010: 29, video documentation in appendix). Precisely through the utilization of their individual senses to make observations, participants were empowered through the effective use of their abilities. Likewise attuned with the ideas discussed earlier regarding democratic research by Nicolescu (1998) and Hartley and Robertson (2006), my participants by shared their findings with peers. As a result, the overall complexity of ideas grew to create a much more holistic view of amphibians, other organisms, and the environments themselves.

This increased awareness of place and its inhabitants was an important aspect of the Eco-Actions and Public Bio-Art Laboratories. As Lippard stated, these projects ‘reveal aspects of place to those who live there, aspects hitherto unseen or unappreciated … framing local ecologies in order to draw attention to them, but doing so in real-time rather than [the] frozen present in paintings or photographs’ (2010:14). Data from questionnaires affirmed Lippard’s suggestion, as it demonstrated that such experiences did increase participant understanding of ecological phenomena and scientific methods and also enhanced appreciation of local species and ecosystems. Aligned with the goals of transdisciplinary and citizen science efforts discussed previously by Funtowicz and Ravetz (2003), Gibbons et al. (1994), Irwin (1995), Moss et al. (2008), Zoellick et al. (2012) and others, my participants became stake-holders not only in the primary research but also in their local environments.

For the larger question of whether such art-science practices could contribute new knowledge to the field of primary research biology, the answer, without doubt, was yes. Amphibian research findings were reported in several peer-reviewed and governmental scientific publications (Ballengée and Sessions 2009; Sessions and Ballengée 2010b; Ballengée and Green 2010, 2011).

Even though embedded volunteers participated in all aspects of primary research, rigorous scientific methods and standards were utilized throughout field and laboratory studies. As pointed out by Mittelstraß and discussed earlier, science necessarily retained a high level without being generalized down to the non-expert level, even with public participation.

The viability of the data produced in these participatory studies has been further emphasized by the fact that findings contributed to the overall direction of amphibian malformation research and has been generously cited by later researchers internationally (Johnson and Bowerman 2010; Reeves et al. 2010; McAlpine and Smith 2010; Johnson et al. 2011; Peltzer et al. 2011; Ursprung et al. 2011; Todd et al. 2011; Nomura et al. 2011; Bionda et al. 2012; Bacon et al. 2013; Thompson et al. 2014; and others). This alone is strong evidence that transdisciplinary art and participatory biology practices may effectively contribute new and important knowledge to the field of primary research biology.

In larger terms these findings demonstrated that through public field and lab programs, important insights into local populations of amphibians were achieved (please see chapters 8 and 9; scientific publications in appendix). Likewise, participants gained a better understanding of localized ecological phenomena through direct research experiences and reflection through art. Furthermore, through Eco-Actions and Public Bio-Art Laboratories, public participants found themselves in a position of not taking the natural world and species
diversity for granted but instead discovered a means of empowerment towards larger conservation efforts.

In closing, I suggest that the majority of humanity assumes diverse wildlife will continue to exist somehow, someplace, in spite of overwhelming scientific evidence to the contrary. The art/science undertakings of the Eco-Actions and Public Bio-Art Laboratories attempted to offer a platform that might challenge our human capacity for denial and offer a strategy for empowering individuals towards species conservation. As scientists and environmentalists have observed, the relatively sudden, observable decline of species that have existed for thousands or millions of years, such as amphibians, is already a genuine cause for alarm. As noted biologist E. O. Wilson has stated, ‘We should preserve every scrap of biodiversity as priceless ... We should not knowingly allow any species or race to go extinct’ (1992: 351).
Chapter 7. Unravelling the Ecological Mystery of Misshapen Amphibians: An Analysis of Prior Research in the Field

7.1. Introduction

My overall study has sought to clarify by what means transdisciplinary art and participatory biology may increase understanding of ecological phenomena for larger audiences of non-specialists. Firstly, it is important to clarify how such comprehension of organisms and ecosystems on the part of researchers is achieved and likewise how this knowledge can be disseminated to a larger public. In the previous chapters I addressed my own art and participatory science programs that increased audience awareness of the amphibian declines and deformities. Education about these issues was achieved not just through participation in embodied programs or viewing exhibitions, but also through the sharing of relevant subject-related discourses during these practices.

I found it was important firstly to perform a thorough literature review of the majority of previous published studies on amphibian malformations and declines. If I was to inform the public about the issues amphibians currently face, I had to know the prior science in this area. Such literature reviews are an essential component to all research projects, as Tuckman and Harper have stated: ‘It is in fact a significant and necessary part of the research process’ (2012: 41). Likewise, the literature review was an important process for me, as it helped with problem identification, the overall amphibian studies hypothesis, and structuring methods for participatory field and laboratory programs. To some degree it also informed my artistic output.

Additionally, if participants were to gain understanding of the current state of amphibians as well as to participate in primary studies that might provide new ecological insights, acquiring knowledge of previous studies in this area was an essential starting point. As such, reviews of literature aid in the construction of the research question and ensure not repeating previous studies (Schuster and Powers 2005; Supino 2012; Tuckman and Harper 2012). As Tuckman and Harper have stated, ‘It is necessary to survey past work in order to avoid repeating it. More importantly, past work can and should be viewed as a springboard into subsequent work, the later studies building upon and extending early ones’ (2012: 43). Thus, a literature review is a fundamental part of the scientific research process.

From a larger philosophical context, such an analysis of existing knowledge in a specific area of scientific study aligns with both approaches of transdisciplinarity as described by Mittelstraß and Gibbons et al. (2004). As Mittelstraß has stated, it is fundamental that those involved in practical transdisciplinarity and coping with ecological problems, ‘contribute with their specialised knowledge to the solution’ and ‘do not change themselves in their forms of knowledge or methodology’ (Mittelstraß 2011: 336). In my case, as a biologist conducting primary research into the problem of amphibian malformations and also an educator attempting through participatory public programs, to disseminate knowledge of this ecological phenomenon to a larger audience of non-specialists, such a perspective forms an important starting point.

From the participatory science standpoint, it is fundamental that research conducted during such programs follow rigorous methods and be objective and thorough. As Miller-
Rushing et al. (2012: 285) have affirmed, it need be ‘genuine scientific research’. Cooper further asserted that such methods and the knowledge derived from such participatory research need be ‘reliable, repeatable, and indisputable’ (2012b: 3). Notwithstanding public involvement in the primary research process, the methods still need to follow scientific standards, which alone justifies the necessity of he following literature review.

This literature review was performed over several years, firstly as my own independent investigation (2005–2007) and then furthered with the assistance of participants at the Public Bio-Art Laboratories (discussed in a previous chapter) during the summers of 2008/2009 and finalized in 2013. To begin this chapter I will discuss relevant existing scientific thoughts on amphibian declines and deformations. This will be followed by an in-depth analysis of recent suggested causes for amphibian deformities, which include agrochemical pollutants, parasitic (trematode) infection, predator-induced injuries, and potential synergies among these and other factors. In conclusion, I will discuss the necessity for a more ecosystem-focussed approach (rather than focussed solely on the anurans themselves) in future studies, mention key unknowns, and outline the impetus for the field and laboratory studies conducted during my participatory biology Eco-Actions and Public Bio Art Laboratories (presented in later Chapters 8 and 9).

7.2. Introduction to Discourse: The Occurrence of Deformities in Amphibians

The global decline of amphibian populations has been considered one of the most pressing environmental issues of recent times and has become emblematic of ecosystem demise (Gascon et al. 2006; Kriger 2010). As early as the 1970s the development and overall health of frogs, toads, and their larvae have been suggested as indicators of wetland ecological quality (Cooke 1970, 1972, 1977, 1981; Birge et al. 1975). More recently, amphibians have been popularized as environmental ‘canaries’ in our global ‘coal mine’ (Collins and Crump 2009).

However, neither the labels ‘bio-indicator’ nor ‘canary in the coal mine’ may appropriately describe amphibian physiology, their natural history, nor their recent declines (Green 2001; Collins and Crump 2009). On the contrary, amphibians are a sentinel group of survivors, not fragile indicators, nor delicate ‘canaries’ (Green 1997; Collins and Crump 2009; Kriger 2010; Kerby et al. 2010). A potential danger of these inaccurate labels may come from spreading a popular misconception that poor amphibian health will act as an ‘early’ warning of environmental demise (Collins and Crump 2009).

In actuality, amphibian declines may represent a much longer-term, larger-scale, and heavier degree of overall change to and loss of amphibian habitats (Wake and Vredenburg 2008; Collins and Crump 2009). Likewise, these declines may not only relate to ecosystem compromise or loss, but instead reflect numerous other causes such as invasive species introductions, emerging diseases, pollutants, over-exploitation (for food and the pet trade), increased ultraviolet radiation, climatic change, and others (Linder et al. 2001; Gascon et al. 2006; Collins and Crump 2009).

Please note that the review presented here is an abbreviated version because of limitations of space. For the complete, final version, please see the appendix.
What is established is that of the greater than 7,000 known amphibian species, over one-third of them have become threatened, critically endangered, or extinct in the past century (Stuart et al. 2004; Gascon et al. 2006; Wake and Vredenburg 2008; Collins and Crump 2009). Hoffman et al. (2010) estimated as many as 41% of known amphibian species are in decline, compared with 12% of birds and 22% of mammals, and boosting their extinction rate to 200 times the expected background rate of natural extinction (Roelants et al. 2007; McCallum 2007). As Amphibians are experiencing such unprecedented declines, finding out specific information about localized phenomena may be paramount towards achieving larger-scale conservation efforts (Stuart et al. 2004; Gascon et al. 2006; Wake and Vredenburg 2008; Sodhi et al. 2008). Clearly, amphibians are a group of special concern.

Hind limb deformities (sometimes called ‘malformations’) among wild amphibians have been suggested as a factor in the decline of some populations (Johnson et al. 1999; Schotthoefer et al. 2003; Rohr et al. 2008; Lannoo 2008; Blaustein et al. 2011). As there is little evidence to suggest severely deformed post-metamorphic anurans survive to breeding age, it has been assumed there must be some degree of population impact, particularly among groups with high frequencies of abnormalities (Schotthoefer et al. 2003; Rohr et al. 2008; Lannoo 2008).

Low levels of developmental abnormalities occur naturally in all vertebrates. In anurans, the current accepted normal background incidence for abnormalities is thought to be less than 5% of the overall population (Van Valen 1974; Dubois 1979; Tyler 1994; Ouellet 2000; Lannoo 2008). Evidence from recent studies suggests that the majority of abnormalities found are among peri-metamorphic and metamorphic age–class frogs and toads (Lannoo 2008). The author, with Sessions (2009; 2010b) has therefore suggested that these young anurans should be a target age-class for future deformity studies, as their survival may be directly related to the extent of deformation. Abnormalities in this stage have been reported on six continents and appear to be increasing among some regional populations (Ouellet 2000; Johnson et al. 2003; Lannoo 2008; Ballengée and Sessions 2009; 2010b).

7.3. Historic Studies

The earliest scientific records of deformed amphibians come from Europe (Ouellet 2000; Piha et al. 2006; Ballengée and Sessions 2010b). Most of these reports are limited to anecdotal accounts and often describe single abnormal frogs found sporadically or accidentally during other studies (Ouellet 2000, Piha et al. 2006). In comparison to North America, very few contemporary European studies have been conducted on the frequency of morphological abnormalities among wild populations, and deformity levels remain unknown throughout most of Europe (Puky 2006; Piha et al. 2006).

These early European reports mostly described single frogs with supernumerary or sometimes full missing limbs (Vallisneri 1706, 1733; DeSuperville 1740). Such ‘curiosities’ were recorded in France, Germany, Italy, England, and elsewhere (Saint-Hilaire E 1825, 1828, 1833; Saint-Hilaire, I 1836; Dumeril 1865; Bonnet and Rey 1935; Chalaux 1952; Dely 1960; Rostand 1955, 1958; Van Valen 1974; Borkin and Pikulik 1986; Ouellet 2000). Although visually spectacular, anurans with extra limbs or limb segments—‘monsters’—
appeared to be very uncommon and were often believed to be caused by genetic factors such as mutation or embryonic damage (DeSuperville 1740; Saint-Hilaire I 1836; Rostand 1958; Van Valen 1974). These accounts mostly described unusual specimens anecdotally instead of providing a modern analysis, making it difficult to ascertain abnormality frequencies among historic amphibian populations (Piha et al. 2006; Henle et al. 2012).

Jean Rostand provided the first long-term studies of anuran deformities, resulting in numerous publications and the first book dedicated to the understanding of abnormalities among frogs and toads (Rostand 1947a, b, c, 1949a, b, 1950a, b, 1951a, b, 1952a, b, 1955a, b, c, 1956a, b, 1958, 1959, 1971; Rostand and Darré 1967, 1969; Rostand et al. 1967). Rostand studied abnormalities in populations of anurans in Europe (mostly France), spanning more than three decades and as many as 100,000 frogs and toads (Life 1956; Rostand 1958; Rostand 1971). Among these thousands of sampled animals, Rostand described numerous types of deformities: ‘missing limb’ and ‘extra limb’, including a subset grouping referred to as ‘anomalie P’.

Rostand (1971) postulated that varied limb deformities were attributed to causes that were often population- and species-specific, as well as seasonally variable. Among some populations of European common toads (Bufo), Rostand (1947a, c, 1950b, 1951b) credited congenital defects to a recessive gene, which resulted in supernumerary digits. However, in other B. bufo populations, he concluded that a dominant gene was inherited that caused supernumerary digits, shortened limbs, and other minor limb abnormalities (Rostand 1949a, 1951b; Dubois 1979; Rothschild et al. 2012). Rostand also suggested that inherited defects contributed to at least some cases of reduced limb segments and supernumerary digits in various populations of the anurans such as the European green frog (Pelophylax kl. esculentus) and the European brown frog (Rana temporaria) but was unable to induce limb deformities in breeding experiments from frogs of these populations (Rostand 1950a, c, 1951b, c, 1952a, b, c; Dubois 1979).

Rostand noted a variety of supernumerary limb abnormalities that varied in severity among a population of P. x kl. esculentus in Trévignon (Brittany, France); he titled this finding ‘anomalie P’ (1952d). Among this population, late-stage tadpoles and metamorphic frogs had severe forms of hind limb abnormalities, such as truncated supernumerary limbs, which he suggested were terminal, while those with less acute malformations survived but often had extra digits (Rostand 1952d, f). Frequency of ‘anomalie P’ varied by season but was sometimes as high as 80% in tadpoles and 14.5% in adults (Dubois 1979).

Rostand generated various experiments to ascertain the origin of ‘anomalie P’ among the Trévignon frogs but was unable to induce these abnormalities with various potential stressors, including teratogens, salinity and temperature extremes, ultra-violet radiation, and others (Rostand 1950c, d, e, 1955b, 1958a, 1971; Dubois 1979; Rothschild et al. 2012). In addition, amputations of abnormal limbs in the developing Trévignon tadpoles resulted in the regeneration of normal limbs, suggesting that an external factor rather than inherited defects was a likely cause (Rostand 1952e; Dubois 1979). These findings and numerous unsuccessful experiments led the author to believe that ‘anomalie P’ was not caused by genetic, chemical, or extreme environments, but instead by an unknown infectious microbial agent: a virus (Dubois 1979).
These findings were further affirmed by later experiments in which Rostand and Darré (1969) induced ‘anomalie P’ in developing *P. x kl. esculentus* tadpoles by feeding them the dried gut contents of Tench and eels collected from the Trévignon site. Later Rostand (1970) suggested that this fish-borne virus might be carried by a wide species range of fishes, potentially impacting other non-Trévignon populations of anurans. In the subsequent decades, little to no research has been conducted on the virus described by Rostand.

### 7.4. Recent Studies

Amphibian deformities first became a highly publicized environmental issue in North America in the middle 1990s, when a group of Minnesota school children found several misshapen frogs at a local wetland (Souder 2000, 2002; Ballengée and Sessions 2010b; Helgen 2012). National media coverage of the Minnesota case strongly implied that the deformities were caused by chemical pollution, most likely pesticides (Souder 2000, 2002; Helgen 2012). Soon thereafter, North American citizens were asked to report such frogs to the United States Geological Survey’s NARCAM (North American Reporting Center for Amphibian Malformations). Within two years, hundreds of reports were published online; the deformities appeared to be a widespread phenomenon in North America (Souder 2002; Ballengée and Sessions 2010; Helgen 2012).

These Minnesota frogs, with missing and supernumerary limbs, visually recalled malformed human children: victims of Agent Orange, thalidomide, or the radioactive aftermath of Chernobyl (Souder 2000, 2002; Ballengée and Sessions 2010; Helgen 2012). Under unprecedented public and governmental (congressional) pressure, researchers attempted to rapidly ascertain a cause for these ‘malformed frogs’ (Souder 2002, Helgen 2012). Nearly a decade earlier, Sessions and Ruth (1990) had already posited substantial evidence demonstrating that a trematode parasite could explain amphibians with extra and missing limbs. Regardless, research by the Minnesota Environmental Protection Agency and other regional efforts largely focused on the direct role that teratological chemicals (e.g. pesticides) may have in the induction of such deformities (Souder 2002; for detailed overview see below; Sessions and Ballengée 2010b).

Wetlands where amphibian populations exhibit a greater than 5% level of deformed individuals have been referred to as ‘hotspots’ and are considered to have epidemic levels of abnormalities (Lannoo 2008). Some researchers have suggested that these hotspots may be increasing in some regions and may impact already declining species (Johnson et al. 2003; Johnson and Chase 2004; Lannoo 2008; Rohr et al. 2008; Anderson and Hoppe 2010; Lunde and Johnson 2012). Lannoo has suggested that high frequency of anuran malformation may correlate with overall wetland degradation and the decline in the health of wild amphibians (2008).

More than a decade after the finding of the Minnesota malformed frogs, the causes for amphibian deformation has remained scientifically controversial (Souder 2002). The potential causes most currently investigated include chemical pollution (mostly industrial, urban, and agricultural effluents), parasitic (trematode) infection, predator-induced injuries, and potential synergies among these and other factors, which are discussed below (Blaustein...
and Johnson 2003; Ankley et al. 2004; Ballengée and Sessions 2009; Lunde and Johnson 2012).

7.5. The Agro-Pollution Hypotheses

The majority of recent deformed amphibian studies have involved a broad range of chemical pollutants attributed to agricultural practice (e.g. pesticides, herbicides, fungicides, fertilizers, etc.). Agriculture, historic and recent, is one of the most pronounced factors of anthropogenic change, and has been widely shown to be a contributor to the decline of amphibian populations due to breeding habitat alterations (for review see Bishop and Pettit 1992; Wells 2007; Collins and Crump 2009) as well as agrochemical effluents (for review see Linder et al. 2001; Mann et al. 2009). Numerous studies have reported increased levels of hind limb deformities in proximity to agricultural practices, and several chemicals associated with farming have been nominated as potential causes, as discussed below.

In midwestern North America Burkhart et al. (1998) utilized pond water, sediment, and sediment extracts from several agricultural sites in Minnesota to perform a FETAX assay (frog embryo teratogens assay – *Xenopus*). Test media (pond water and sediments) were collected from ‘hotspot’ field sites found to have high frequencies of deformed frogs (mostly Northern Leopard frogs, *Lithobates pipiens*) as well as from control sites with lower numbers of deformities (Burkhart et al. 1998). Supplementary chemical analyses were performed to gauge for substantial differences between affected sites and control sites (sites with below 5% anuran deformation rate). Early-stage African clawed toad (*Xenopus laevis*) tadpoles were reared in varied pond test solutions for 96 hours. The results demonstrated that pond water samples from affected sites increased mortality rates in embryonic *X. laevis* as well as generating higher frequencies of embryo abnormalities compared to tests using materials from control sites. Supplemental chemical analyses did not suggest significant differences in metals, pH, or other tested chemicals between affected sites and reference sites. The authors did however find ion variation between sites and suggested this as a causative factor for deformations.

In related studies, Fort et al. (1999 a, b) exposed *X. laevis* tadpoles to water and sediments from affected Minnesota and Vermont study sites (‘hotspots’) for varied time durations. The results demonstrated an increased mortality of *X. laevis* larvae reared in media from ‘hotspots’, as well as varied degrees of abnormalities; in a single 30-day treatment using water from one site, abnormal limbs were reported be induced in *X. laevis*. This was the only treatment from these studies that was reported to have induced limb abnormalities, which are the predominant deformities observed at the sample sites. Unfortunately, the morphologies of the experimentally induced limb abnormalities were not presented in the publication, and their similarity to the deformities found in nature was not discussed (Fort et al. 1999b). Although these studies suggested the presence of teratogens at Minnesota and Vermont ‘hotspots’, they did not rule out low levels of ion concentrations as a potential cause for abnormalities in their laboratory simulations. In later related studies by Garber et al. (2002), mineral supplementation added to ‘hotspot’ waters increased ions and alleviated abnormalities in *X. laevis*.

In one of the largest North American deformed amphibian surveys to date, Levey et
al. (2003) reported findings on more than 10,000 frogs in Vermont. Here the researchers examined metamorphic and larval \textit{L. pipiens} for obvious deformities at up to nine selected sites, all with varied degrees of agricultural exposure (all within nature reserves in close proximity to Lake Champlain) over a five-year period (1997–2001). The results of consecutive years of field sampling showed that metamorphic \textit{L. pipiens} frogs at all five study sites had an overall deformity ratio of 6% out of 5,661 total examined (Levey et al. 2003). Of these abnormalities, the vast majority (79%) occurred in the hind limbs and included reduced segments, full missing limbs, and varied limb truncations. A single individual was found with a full mirror duplication extra limb, and abnormalities also included the forelimbs (15%) and eyes (5%). However the field data did not demonstrate significantly higher levels of abnormalities at sites exposed to agriculture compared to those with limited exposure. On the contrary, one location (Alburg Dune) with limited to no exposure to agrochemicals, had a deformity frequency of 3.3 to 7.3\% between years, while at another study site directly exposed to agriculture (Mud Creek), deformity ratios ranged between 0.0 to 4.7\% between years. The highest deformity ratio (35.1\% of 188 examined in 1997) was reported from a site (Ward Marsh) that was not directly exposed to agriculture but subjected to influences in water quality from seasonal flooding of the Poultney River. However in later surveys at this same site, frequency of abnormalities dropped to a range of 0.0 to 3.4\% in subsequent years (1998–2001). Tadpole surveys (1,254 larval \textit{L. pipiens} examined between Gosner stages 24 through 46; Gosner 1960) demonstrated a stronger link between agriculture and frequency of deformity, as the highest percentage was found at a site directly exposed to agricultural activity (Mud Creek) with 10.2\% of 254 examined displaying obvious abnormalities. However at sites with little to no exposure to agriculture, deformities were still found in tadpoles, which ranged between 3.3\% (of 577 examined at Alburg Dune) and 1.9\% (of 162 examined at North Hero). Chemical analysis of water and sediments for agro-chemicals showed detectable levels of Atrazine and the metabolite desethyl at four out of five tested wetlands. Metolachlor along with the metabolites ethanesulfonic and oxanilic acid were detected at all sites. No heavy metals were detected among water samples, but sediment samples did demonstrate elevated levels of copper, nickel, chromium, and iron at some field sites. Nitrogen levels at one field site appeared to be high at North Hero (a site with limited to no exposure to agriculture) but with small percentages of deformed frogs (less than 2.1\% overall over 5 years). As with the case of mentioned pesticides and metals, no correlation between these findings and the reported deformities were established in Levey et al. (2003).

In a related study of Vermont wetlands, Taylor et al. (2005) utilized an epidemiologic approach to ascertain if probability for frog malformation increased with extent of agricultural and residential land use. Data from field-sampled, deformed frogs, developmental stages of these anurans, water quality testing, and GIS (geographic information system) with field observations on land use/land cover data from 42 total wetlands was analyzed using bivariate and multi-variant techniques. In total 5,264 metamorphic anurans (representing six different species: Grey treefrogs (\textit{H. versicolor}); Spring peepers (\textit{Pseudacris crucifer}), \textit{L. catesbeianus}, \textit{L. clamitans}, \textit{L. sylvaticus}, \textit{L. pipiens}, and \textit{L. clamitans}) were examined, with an overall 1.6\% deformity rate reported, which ranged between 0\% and 10\% by sampling location. From GIS data on sampled sites, greater than 40.5\% of wetlands were identified as being in proximity to
agriculture, while less than 35.7% could be described as suburban with lawns and/or septic systems nearby and 23.8% deemed more pristine. Results of multivariate data strongly suggested a more than double risk of malformation to frogs found in proximity to agriculture (also found to have the poorest water quality) compared to those in more pristine habitats (OR = 2.26; 95% CI, 1.42–3.58; p < 0.001). Risk was also increased for frogs found in suburban habitats (potentially exposed to lawn and septic run-off) but was less acute than those in farm ponds. Secondly, their results suggested that as post–Gosner stage 26 tadpoles developed, their risk of malformation increased 18% per stage (Gosner 1960). These findings were important, as they provided evidence that decline in habitat quality positively affected frequency of anuran deformities.

Numerous specific agricultural pesticides have been shown to increase mortality, impact behaviour and have teratological effects on developing anurans (for review see Bishop 1992; Cowman and Mazanti 2000; Lannoo 2008; Mann et al. 2009). Yet reports linking limb malformation to exposures to specific pesticide or pesticide combinations in laboratory settings are infrequent. A selection of recent studies are discussed below.

The insecticide S-methoprene was nominated as a likely cause for high levels of deformed frogs in the midwestern United States during the 1990s (Helgen 1996; Helgen et al. 1998) In response, La Clair et al. (1998) investigated how S-methoprene, when exposed to UV-radiation from sunlight, induced malformation and increased mortality in X. laevis during FETAX assay. The authors suggested that as S-methoprene photo-degraded to release retinoid-mimicking molecules, it thereby inhibited normal development in experimental X. laevis. In addition to short-term (90 hour) exposure assays, a portion of the treated individuals were allowed to develop into post-metamorphic toads so that deformities could be further characterized. Results of long-term duration studies found no effect by S-methoprene on limb development. Furthermore, neither S-methoprene nor its photoproducts were shown to exist at teratogenic levels in wetlands reported to have high frequencies of amphibian deformities (La Clair et al. 1998).

That same year, the potential role of S-methoprene for the induction of abnormal anuran limbs similar to those encountered in the field was addressed by Ankley et al. (1998). The authors exposed L. pipiens to varied degrees of S-methoprene and UV radiation from early egg fertilization through complete metamorphosis. L. pipiens were chosen as an anuran model because they were one of the species with highest frequencies of deformities at ‘affected’ study sites discussed by Burkhart et al. (1998) and Fort et al. (1999a, b). At high concentrations, the insecticide produced 100% mortality in developing L. pipiens. In lesser concentrations, which more closely resembled field conditions for durations of up to three months, S-methoprene did not produce additional mortality or deformities of any type, including in the hind limbs (Ankley et al. 1998). In conclusion, the authors and others suggested S-methoprene was not a likely mediator for the abnormal hind limbs in wild populations of anuran amphibians as reported in prior Minnesota or Vermont studies (Ankley et al. 1998; Henrick et al. 2002; Ankley et al. 2004).

S-methoprene or other pesticide-related unknown teratogens were not ruled out by Gardiner and Hoppe (1999), who suggested exogenous retinoids (retinoic acids: RA) as the probable cause of the reported deformities at Minnesota study sites. Here the authors
examined a small number (n=27) of deformed Mink frogs (*Lithobates septentrionalis*) from one of the affected Minnesota study sites and based their hypothesis solely on interpretation of abnormal morphologies. They reported that supernumerary hind limbs and bent tibiafibula (bony triangles) found in these *L. septentrionalis* specimens were particularly significant and indicative of retinoid exposure. Though retinoids are the only chemical known to produce bony triangles, other studies demonstrate they can also be produced through mechanical perturbation of developing anuran limbs (Sessions et al. 1999; Hecker and Sessions 2001; Stopper et al. 2002; Sessions and Ballengée 2010b). Several reports have demonstrated retinoids as an inhibitor to hind limb development in anuran amphibians, actually reducing limbs and limb segments (Scadding and Maden 1986; Stocum 2000). However, numerous studies have also shown that injured and regenerating tadpoles can produce supernumerary limbs and structures when exposed to retinoids (Maden 1983; Mohanty-Hejmadi et al. 1992; Maden 1993; Maden and Corcoran 1996; Sessions et al. 1999).

In later experiments Degitz et al. (2003) conducted varied life-cycle studies with *X. laevis* exposed continuously to RA. Test *X. laevis* were at varied developmental stages (early embryos through complete metamorphosis toads) and with varied exposures to RA. As with Degitz et al. (2000), they reported that RA exposures greatly increased mortality at early developmental stages of *X. laevis* but had less impact at later stages of development. No limb malformations in surviving tadpoles were induced through the varied experimental simulations. The authors concluded that RA has far more of an impact on survivorship than limb development and is not consistent with the interpretations of Gardiner and Hoppe (1999).

Various agricultural pesticides were suggested as the cause for high frequencies of deformed frogs reported by Ouellet et al. (1997) in southern Quebec. The authors sampled 1,124 young anurans at 26 field sites (14 ‘pesticide-exposed’ and 12 ‘pesticide-free’ sites) during the field seasons of 1992/and 1993. Field sampling demonstrated that deformity levels (mostly in *L. clamitans*) at sites subjected to pesticides were higher (12%) compared to those found at pesticide-free sites (0.7%). The authors listed a variety of agrochemicals used by regional farmers, including Atrazine, Carbofuran, Glyphosate, and others. However no testing was conducted to confirm the existence of such chemicals in the study wetlands themselves. Additionally, Ouellet et al. (1997) reported that the increased level of deformities at agricultural sites compared to control sites was not statistically significant, in part due to the fact the team collected almost three times the number of frogs from farm ponds (n=853) compared to ‘pesticide-free’ wetlands (n=253), making analytical comparison difficult.

In a related study, Bonin et al. (1997) monitored potential health impacts of agrochemicals on *L. clamitans* frogs in Quebec wetlands. Metamorphic and adult *L. clamitans* were sampled from three control sites (limited exposure to pesticides) and five wetlands in proximity to agriculture (2 near potato fields applied with the pesticides Azinphosmethyl, Cypermethrin, Oxamyl, Mancozeb, Chlorothalonil, and 3 near sweet corn fields applied with the pesticide Carbofuran, according to the authors) and water was analyzed for the presence of toxins. Collected frogs were examined alive for developmental deformities and post-mortem for hematological analysis, hemoparasite presence, diseases, and genomic micronucleus frequencies. This resulted in an overall finding of a 5.4% (n=22) deformity
ratio among *L. clamitans* of the 410 sampled, which was higher at agricultural habitats (6% of 348 examined) than at control sites (1.6% of 62 examined). Post-mortem examinations also showed a significant increase in ratios of disease among anurans from farm ponds, with 8.1% found diseased (thought to be infection by *Bacillus hydrophilus fuscus*, or ‘red leg’) compared to only 1.6% of those sampled at more pristine sites. DNA content analysis demonstrated increased intra-individual genome size variation (CVs) among frogs collected at farm ponds in comparison to controls. In addition, water testing demonstrated an elevated level of genotoxins from unspecified agrochemicals at farm ponds compared with control sites, with the highest toxicity levels reported among potato field habitats, which also had the highest incidence of *L. clamitans* deformations (6.9% of 288 examined) and disease (data not reported). Increased CVs among deformed anurans is not well studied, nor the mechanism by which genotoxins from agrochemicals could alter normal development in frogs.

Harris et al. (1998a, b) examined the potential impacts on developing anurans from varied pesticide use in commercial apple orchards. Early-stage *L. clamitans* and *L. pipiens* were cage-reared in seven wetland sites, four in proximity to orchards and three in conservation areas to act as controls, for two to three weeks. Complementary laboratory simulations exposed early-stage *L. clamitans* to pesticides commonly utilized in orchards (Guthion 50WP, Imidant 50WP, Thiodant 50WP, Dithanet DG, Novat 40W, Basudint 500EC, and technical grade Diazinon) to gauge toxicity and potential teratological effects. The results demonstrated no significant variations in mortality, growth rates, or deformities among caged anurans at the orchard or reference sites. However under laboratory conditions, pesticide-treated *L. clamitans* demonstrated high levels of mortality, and those exposed to Basudin 500EC, Diazinon, Dithane DG, and Thiodan 50WP developed varied malformations. Diazinon and Basudin induced edemas to head and abdomen, blistering, curved or kinked tails, stunted tails, and abnormalities of the gills (underdevelopment) in larval *L. clamitans*. Dithane caused curved or kinked tails and some abdominal edema. Thiodan caused skeletal abnormalities (overall curvature of the spine) as well as changes in avoidance and overall swimming behaviours.

As with many of the types of pollution previously discussed, a substantial connection between suggested factors (e.g. chemicals) and abnormal anuran limb development has not been well established experimentally. However, Harris et al. (2000) reported a joint deviation of the forelimb in one metamorphic American toad (*A. americanus*) induced by chronic exposure to the organochlorine insecticide Endosulfa within laboratory settings. Jayawardena et al. (2010) subjected larval Common hourglass tree frogs (*Polypedates cruciger*) to chronic exposures of four common agricultural pesticides (Chlorpyrifos, Dimethoate, Glyphosate, and Propanil). This test resulted in no malformed limbs, but it did cause severe axial abnormalities and edema, which might have affected limb mobility, had the larvae survived. Alvarez et al. (1995) reported exposure to ZZ-Aphox® and Folidol® induced limb malformations (twisting of the epiphyses between short and long bones, thought to be caused by muscle constriction) in developing Perez's Frog (*Pelophylax perezi*). The size of hind limbs was reported by Raj et al. (1988) to have been influenced by exposure to varied degrees of Baygon® (propoxur) in developing Sri Lankan green pond frogs (*Euphlyctis hexadactylus*). Riley and Weil (1986) reported heavy exposure to the pesticide additive Thiosemicarbazide caused curvature of the
digits and abnormal articulation of limbs in developing *L. sylvaticus*. Endosulfan was reported by Brunelli et al. (2009) to induce axial malformation and other abnormalities following chronic exposure, but showed no effect on limbs in developing *B. bufo*. Of the above types of limb malformations, none are reported frequently among wild populations. Nevertheless, the fact that any of these pesticides or their metabolites induced anuran limb or other developmental abnormalities indicates the need for further research attention.

7.6. The Parasite Hypotheses

Trematode infection has been the most thoroughly explored potential cause of anuran limb abnormalities, with more than fifty reports published in the last few decades (Sessions and Ruth 1990; Szuroczki and Richardson 2009; Sessions and Ballengée 2010b; Blaustein et al. 2012). Sessions and Ruth (1990) provided the earliest evidence linking trematode infections to deformed amphibians. The authors reported high frequencies (greater than 70%) of limb abnormalities among wild populations of Pacific treefrogs (*Pseudacris regilla*) and Long-toed salamanders (*Ambystoma macrodactylum*) in California. Water testing for pollutants (heavy metals, chlorinated hydrocarbons, and petroleum hydrocarbons) at study sites yielded negative results. Post-mortem analysis of collected deformed specimens revealed varied quantities of trematode cysts often in proximity to abnormal limb appendages. Supplemental experiments involved implanting resin beads (of approximate trematode cyst size) into the developing limb buds of laboratory bred larval *X. laevis* and *Ambystoma mexicanum*, which then developed limb deformities similar to their wild counterparts (*P. regilla* and *A. macrodactylum*). Deformities included supernumerary hind limbs, suggesting that mechanical disruption of limb development by trematode cysts was the proximate cause for deformities among the wild amphibians they examined.

Johnson et al. (1999) established the link between trematode cysts and hind limb deformities. Pacific treefrog tadpoles (Gosner stages 23–26) were exposed four times to varied ratios of free-swimming cercariae of (either or both) trematode species, *Alaria mustelae* and *Ribeiroia* species, within experimental enclosures. Infected tadpoles were allowed to develop through metamorphosis, resulting in no limb deformities for those exposed to *Alaria*, and a limb abnormality frequency of 85% among those exposed to *Ribeiroia*. Effects of *Ribeiroia* were dose responsive, showing increased tadpole mortality (60%), and 100% deformity ratio among those that survived the heaviest concentration of cercariae exposure. All of the experimentally induced deformities occurred in the hind limbs and ranged in severity from bilateral missing limbs to multiple limb duplications and abnormal structures, including bony triangles. In supplemental field investigations of wetlands contaminated with *Ribeiroia*, the authors reported the same broad range of limb abnormalities among wild Pacific treefrogs and confirmed varied levels of *Ribeiroia* cysts in their tissues.

In a later study, Johnson et al. (2001) identified the species of trematode as *Ribeiroia ondatrae* and demonstrated that infection could induce malformations in other anuran species besides Pacific treefrogs. Utilizing both field and laboratory methods similar to those
employed in Johnson et al. (1999), Western toad larvae (*Anaxyrus boreas*) tadpoles were exposed to different numbers of *R. ondatrae* cercariae in experimental simulations and compared to wild counterparts. As with prior Pacific treefrog studies, toad survival and levels of limb deformities were dose-dependent on the level of cercariae infection. Limb malformations were reported at up to 86% in toads receiving the heaviest levels of infection. Likewise toad survivorship dropped to lower than 45% among groups that received the heaviest level of infection. Induced malformations in toads varied from those previously reported in treefrogs (Johnson et al. 1999), with the most prevalent toad deformity being cutaneous fusions (abnormal unions or webbings of the skin), followed by a broad range of deformities in both the hind and forelimbs, including supernumerary limbs and segments as well as varied limb reductions. Bony triangles of varied frequencies (8.7% to 17.8%) were reported among all study groups exposed to *R. ondatrae*.

The next year, Stopper et al. (2002) experimentally demonstrated the specific developmental mechanism by which *R. ondatrae* cercarial infection mechanically disrupts normal developmental limb patterns to induce leg malformations, especially supernumerary limbs, in frogs (figure 31). Supernumerary limbs were induced by 180° surgical rotations of developing tadpole limb buds (Gosner 30–31) around their anterior-posterior axis in two species of *Rana, L. pipiens* and *L. sylvaticus*, (figure 32). Likewise, same-stage tadpoles were infected with *R. ondatrae* for comparison and histological analysis. Limb bud rotations resulted in cellular intercalation, producing a range of leg abnormalities including two or more mirrored limbs from a single limb bud. Cellular interaction occurs when cells of different positional values are forced to interact, producing daughter cells (via mitosis) with intermediate positional values and thereby re-establishing limb pattern continuity (e.g. compensating to fill gaps between cells with incongruent positional information: for review see Hecker and Sessions 2001; Sessions and Ballengée 2010b). Histological studies showed that trematodes caused massive tissue perturbation through encysting, which altered the positional relationship between cells, often resulting in intercalation and thus generating supernumerary limbs or associated structures. Trematodes also caused acute tissue damage, which resulted in truncated, missing limbs and missing limb segments.
Figure 31. ‘Phase contrast photomicrograph of a *Ribeiroia* metacercaria removed from a deformed frog. The ruptured cyst capsule is shown at the top. Esophageal diverticulae (arrow) are diagnostic of trematodes of the genus *Ribeiroia* (Schell 1885)’. Image and text from Stopper et al. (2002).

Figure 32. ‘Microsurgical 180° limb bud rotations to create positional confrontations among cells in tadpole limb buds (Hecker and Sessions 2001). Amputation level in a stage 51–52 hind limb bud and the final orientation of rotated limb bud axes (pigmentation patterns used for orientation) are shown on the left. Circular diagram on the right shows the resulting confrontations in cellular positional values around the circumference of the limb bud after 180° rotation of the distal portion (inner circle) relative to the stump (outer circle). Circumferential positional values (1–12) are indicated by the conventional “clockface” of the Polar Coordinate Model (French et al. 1976; Bryant et al. 1981). A: anterior; P: posterior; D: dorsal; V: ventral’. Image and text from Stopper et al. 2002.

While, Johnson et al. (2003) reported *R. ondatrae* as an emerging parasitic disease
among North American amphibians that has increased in recent decades. Several studies mentioned above and others confirmed *R. ondatrae* as the proximate cause for recent high frequencies (epidemic levels) of limb malformations among wild frogs in western North America (Sessions and Ruth 1990; Johnson et al. 2001a, b; Johnson et al. 2003; Bowerman and Johnson 2003; Johnson and Sutherland 2003). Though numerous historic reports of mass incidence of amphibian deformities in North America appear in the scientific literature, the presence of *Ribeiroia* genus trematodes was not known (Ouellet 2000; Johnson et al. 2003). Johnson et al. (2003) analysed historic specimens for presence of trematode cysts, collected during mass deformity events (ranging from 1946 to 1988) at nine North American study sites and then resampled amphibians at these sites during the 1999–2002 field seasons for comparison. This confirmed the presence of *Ribeiroia* genus trematode cysts in historic specimens from eight out of nine sites dating as far back as 1946. Resampling surveys of historic sites found that of six that still supported amphibian populations, three continued to have high frequencies of limb malformations (7% to 50% in one or more species) among wild amphibians, and recent animals sampled tested positive for *Ribeiroia* species(s) infection. Two of these three study sites had higher levels of malformation in recent studies than in historic accounts, suggesting *Ribeiroia*’s infection has increased over time. Since *Ribeiroia*’s infection is confirmed to affect several frog, toad, and salamander species and has been demonstrated to be increasing at least in some study sites and populations, Johnson et al. (2003) concluded that it is an emerging disease among amphibians.

Further evidence that *R. ondatrae* is an increasing disease among wild amphibian populations was provided by Johnson and Chase (2004), who suggested that other environmental factors such as eutrophication from agriculture may favour trematode populations. Hereby, Johnson and Chase (2004) hypothesized that anthropogenic changes to wetlands lead to excess nutrient loading (e.g., phosphorus), resulting in preternatural occurrence of eutrophication. This chemical imbalance can alter aquatic food chains favouring snails (*planorbea* species) by increasing food sources (e.g. algae), and by making changes in how multiple snail species interact with predators (Chase 2003a, b). *Planorbea* species molluscs had been confirmed as a vector for *R. ondatrae* in prior studies, and increased snails may equate to increased parasitic infection among frogs inhabiting such wetlands (Johnson et al. 2001, 2002). Johnson and Chase (2004) provided evidence for this phenomenon utilizing a meta-analysis of wetlands along a large regional range (*n=43*, in California, Oregon, Washington, Michigan, Minnesota, and Wisconsin), which were found to have an increased density of planorbid snail biomass at sites with heightened levels of phosphorus. Such sites were also reported to have increased frequencies of deformed frogs among several species (*P. regilla*, *A. americanus*, *Rana luteiventris*, *Rana pretiosa*, *L. catesbeianus*, *Rana cascadae*, *Rana aurora*, *L. pipiens*, *L. clamitans*, *L. septentrionalis*, and *L. sylvaticus*). This suggests that although *R. ondatrae* infection resulting in malformed frogs is a natural phenomenon, elevated frequency of deformities may be attributed to anthropogenic alteration of wetland habitats, a position that has been further elucidated by several recent studies (Koprivnikar et al. 2006; Johnson et al. 2007; Rohr et al. 2008a; Johnson and Carpenter 2008; Johnson et al. 2010; Hartson et al. 2011; Koprivnikar et al. 2012).
Continued studies have helped to piece together a description of the complex multi-host life cycle of *R. ondatrae*. Three hosts are required for *R. ondatrae* to complete development. It starts with planorbid snails, then larval amphibians or fish, and finally birds or mammals (figure 3; Johnson et al. 2004; Szuroczki and Richardson 2009). In nature, the life cycle begins through the self-fertilization of *R. ondatrae* within infected avian or mammal hosts. These hosts then defecate into wetlands, releasing trematode eggs that develop under optimal climate conditions (20–25° C), usually in two to three weeks (Johnson et al. 2004). Newly hatched, ciliated miracidia freely swim to infect planorbid snails (figure 3). Within their snail host, miracidia shed cilia to become sporocysts, which colonize the veins in proximity to the mollusk’s kidneys. The sporocysts slowly develop into mother rediae, which migrate into and feed on reproductive tissues, castrating their snail hosts (Johnson et al. 2004). These mother rediae mature to again asexually reproduce, creating first-generation daughter rediae. These rediae then give birth to free-swimming cercariae, usually in about 4 to 6 weeks following initial snail infection (figure 3; Szuroczki and Richardson 2009). Cercariae leave the snail host in search of a second intermediate host such as other molluscs, fish, or tadpoles (Szuroczki and Richardson 2009). If they successfully locate tadpoles or fish, they utilize two oral suckers to move themselves around the host epidermis, seeking openings such as the mouth or cloaca. Once on the surface of the host skin, often the developing limb buds in tadpoles or in fish the lateral line of under scales of the head, body, and gills, cercariae shed their tails (Johnson et al. 2004). Cercariae then encyst, whereby they encapsulate themselves within cyst walls, becoming metacercariae as they are absorbed into host tissues. Metacercariae stay in semi-dormant state until their secondary host is consumed. When and if the secondary host, be it tadpole or fish, is fed upon by a warm-blooded bird or mammal (primary or definitive host), metacercariae presumably hatch from conditions in the digestive system of their host such as alkaline pH, digestive enzymes like trypsinbile, salts, and temperatures of 34–43° C inside warm-blooded vertebrates (Szuroczki and Richardson 2009). Once freed from cysts, metacercariae migrate up the small intestine and attach to the mucus layers of the ileum or other areas within the digestive tract (Johnson et al. 2004; Szuroczki and Richardson 2009). Here, they stay to reach maturity, at which they fertilize themselves or others, releasing eggs that are carried by host waste, beginning the cycle over again. This complex life cycle of *R. ondatrae* suggests long-term evolutionary adaption to multiple hosts and environments (external and inter-body), which is still not well understood but is likely, as handicapped, malformed frogs would be much more easily caught and consumed by predatory birds and mammals, increasing the likelihood of trematodes reaching reproductive maturity within primary hosts (Sessions 1998, 2003; Szuroczki and Richardson 2009; Sessions and Ballengée 2010b).
Figure 33. ‘Generalized life cycle of *Ribeiroia ondatrae*. Clockwise from the top (outer circle), is the definitive host (avian or semi-aquatic mammal), followed by the first intermediate host (aquatic snail) and finally the second intermediate host (Ranid tadpoles), where *Echinostoma trivolvis* preferentially encysts in the developing kidney system, and *R. ondatrae* in the developing limb bud system. Note that *E. trivolvis* can reinfect snails and use them as second intermediate hosts whereas *R. ondatrae* cannot. The inner circle depicts the various life stages of the parasite as it is transferred from host to host. This figure is courtesy of B. Ballengée, and was modified in collaboration with D. Szuroczki’. Image and text from Szuroczki and Richardson 2009.

7.7. The Predation Hypothesis

Injury by small predators has been nominated as a potential cause for anurans with missing limbs or limb segment deformities. Numerous aquatic amphibian larval predators, such as aquatic invertebrates (annelids and arthropods) and some species of fish have been shown to practice partial consumption or selective predation of tadpole prey (Formanowics 1984; Johnson 1975, Brodie et al. 1978; Glandt 1983, 1984; Manteifel and Reshetnikov 2002). These predators have mouthparts that are too small to consume whole tadpoles and instead can only eat portions of anuran prey (Ballengée and Sessions 2009; Bowerman et al. 2010). Such partial consumption or ‘selective predation’ may be an optimal foraging strategy employed by certain predators that cannot eat their entire prey, but instead consume bodily areas with high nutritional value or that are easily removed (Sih 1980). Formanowics (1984) observed this behaviour in the aquatic predaceous diving beetle (*Discus verticalis*) feeding on portions of tadpoles. The author suggested that different areas of the tadpole body contained
varied degrees of food quality, and some portions of the tadpole were relatively easily removed, maximizing the cost-benefit ratio by increasing the quality of extracted food relative to handling time of the prey (Formanowics 1984).

Selective predation may be an important predatory adaptation (Cook et al. 1978). Peckarsky (1982) described a result of long-term coevolution of strategies employed by predators in response to defences by prey. Insect predators may be at risk of predation when consuming larger prey such as late-stage tadpoles, so removing of tissues quickly and easily would increase likelihood of survival (Brodie and Formanowics 1983). Caldwell (1980) demonstrated that the ability of naiad predators to handle and hold tadpoles decreases as tadpoles become larger, suggesting age-class (size) of both predator and prey may be important factors regulating lethal and non-lethal injuries. Likewise, Travis et al. (1985) demonstrated that increasing body size among Crawfish frog (Lithobates areolatus) larvae caused a decrease in overall numbers of tadpoles predated by nymphs of Black Saddlebag dragonflies (Tramea lacerate). Formanowics (1986) suggested that prey size relative to predator size affects handling time, and some aquatic insect predators (D. verticalis) may even have a foraging tadpole size ‘preference’.

Peckarsky (1982, 1984) theorized that aquatic insect predators have a wide variety of specialized consumption mechanisms in response to physical, chemical, and behavioural defences of prey. Anuran tadpoles of varied species have been shown to be unpalatable to aquatic insect predators because they produce a variety of chemical defences (Formanowics and Brodie 1982; Crump 1984; Brodie and Formanowics 1978, 1987; Crossland 1998). In addition to insects, certain crustaceans and other invertebrate predators, especially leeches, are known to attack anuran limbs, causing loss or damage (Licht 1974; Duellman and Trueb 1986; Johnson et al. 2001a). Licht (1974) reported hind limb removal by invertebrate predators in two species of anuran larval prey, Northern red-legged frog (Rana aurora), and Oregon spotted frog (Rana pretiosa). Martof (1956) attributed missing limbs among field-collected metamorphic Green frogs (L. clamitans) to predator attacks by aquatic arthropods, fish, and other animals. Wisniewiski (1958) and Van Gelder and Strijbosch (1995), in studies in the United Kingdom and Netherlands, both suggested that Common toads (B. bufo) with varied degrees of reduced hind limbs were caused by predatory attacks. Dubois (1979) attributed missing digits among edible frog species (Pelophax esculentus complex) to injuries from small aquatic invertebrates (freshwater clams) in France. Duellman and Trueb (1994) observed numerous attacks to the Central American dendrobatid (Colostethus inguinalis) by terrestrial invertebrates (crabs), resulting in the removal of limbs and limb segments. More recently, Gray et al. (2002) found amputated limbs and digits, which the authors associated with predation attempts by terrestrial arthropods in two species of neotropical frogs (Dendrobates auratus and Engystomops pustulosus).

Some studies have identified specific predators that induce permanent limb deformities in tadpoles. In Germany, Bohl et al. (1996) and Bohl (1997) concluded that injuries to developing wild Common toad (B. bufo) tadpoles by aquatic predators, specifically the leech (Erpobdella octoculata) were a cause for permanent limb deformities. Field surveys of wild populations of young toads reported frequencies of missing limb abnormalities as high as 20% in the Aufsess (Upper Franconia). Initially, the team suspected toad genetics or
environmental contaminates as the proximate cause for high-levels of abnormalities (Bohl et al. 1996). However, experimental enclosures at study sites, which allowed water to pass through but excluded predators, eliminated abnormalities in developing toads. Likewise, reductions to *E. octoculata* populations at one study site greatly reduced abnormalities in developing toads (Bohl 1997).

Investigating similar missing limb deformities among wild Common toads found at a quarry wetland in Remagen-Oedingen (Rhineland-Palatinate, Germany), Viertel and Veith (1992) utilized predator-prey laboratory simulations, genetic analysis, and water chemistry to identify proximate cause(s). The researchers carefully observed varied stages of developing *Bufo* tadpoles grown in aquariums with predators found at field sites, either the leech (*E. octoculata*), the fish, Sunbleak (*Leucaspius delineates*), or Alpine newt larvae (*Ichthyosaura alperstris*). Predation density was varied per experiment with four age-classes of *Bufo* tadpoles (Gosner 22–23; 25–26; 28; 35). Fish did not cause limb injuries in toad tadpoles, whereas two peri-metamorphic *Bufo* toads (Gosner stage 43) were reported to have had one fully amputated limb, and another a missing foot, resulting from exposure to newt larvae. Leeches consistently were recorded attacking and damaging tails and hind limbs (in older age-classes) of tadpoles, anchoring themselves to aquarium walls then removing tissues (feeding) on tadpoles with their opposite oral sucker. Struggling, captured tadpoles appeared to attract other leeches. Injuries to anuran larvae often led to death, and extent of damage appeared to be contingent on tadpole’s ability to escape. Mortality and extent of injury was dose-responsive to the number of leeches; enclosures with the greatest tadpole mortality were those with the highest concretions of *E. octoculata* (*n=15*). Some tadpoles that survived leech attacks healed and regenerated limb structures, depending on the degree of tissue loss and developmental stage (Veith and Viertel 1993). The resulting range of regenerated limb structures led to a wide array of permanent limb abnormalities (e.g. those with reduced limb segments), closely resembling those of young toads observed at Remagen-Oedingen field site. Although Viertel and Veith (1992) did not publish results of toad genetic studies nor water chemistry analysis, field observations of high–leech density study sites along with laboratory evidence was sufficient to provide a proximate cause for limb abnormalities in toads at their Remagen-Oedingen wetland (Viertel and Vieth 2012).

In a sequential paper, Veith and Viertel (1993) suggested natural regenerative response as the underlying mechanism by which leech damage to tadpoles induces permanent limb abnormalities in metamorphic toads. The authors compiled a detailed report on types of injuries found in the Remagen-Oedingen wetland on young toads and at least one Ranid species (*R. dalmatina* or *R. temporaria*, not reported). Histological analysis of abnormal toad limbs showed regenerative markers of prior trauma in both bone and muscular tissues. Characteristics of prior injuries in anuran limbs included increased calcified presence at bones that healed after amputation and cartilaginous outgrowths (e.g. ‘spikes’). Supplemental outdoor enclosure studies further elucidated predators as the cause of injury and related limb abnormalities among wild anurans. Tadpoles reared at the Remagen-Oedingen wetland (potentially exposed to waterborne teratogens) in cages that allowed water to pass through but mostly eliminated leeches and other predators lacked injuries and abnormal limbs, whereas with cages in which predators penetrated enclosures an 8.8% injury rate to tadpoles was
reported. The authors also stated that chemical analysis of water and genetic study results were null, suggesting predatory injury was the most probable cause for young, deformed toads found at the study site. Further field observations nominated *E. octoculata* as the proximate cause of limb abnormalities among anurans, as leeches were reported in high densities and their preferred food of other invertebrates was limited, forcing them to seek out new food sources (Vieth and Viertel 2012).

Laboratory and field studies by Ballengée and Sessions (2009; see chapter 8 and appendix) demonstrated that attacks by predatory dragonfly nymphs caused a wide array of hind limb reduction deformities to anurans in Yorkshire, England. In total, 3,134 wild toads were examined over three seasons, with abnormality frequencies ranging between an average of 1.2% to 9.8% between field sites. During field surveys, high population densities of predatory larval Darter dragonflies (*Sympetrum* species) were recorded at sites with the highest numbers of deformed toads. Experimental simulations were conducted to test impact and extent of predatory injury by dragonfly nymphs on toad tadpoles. In experiments, many of the tadpoles survived the dragonfly-induced injuries and healed with complete, partial, or no regeneration of hind limbs, which by metamorphosis manifested itself as various kinds of reduced limb deformities including missing limbs and limb segments, resembling field-sampled, deformed *Bufo*.

In a later predation study, Bowerman et al. (2010) reported limb abnormalities in two species of anurans caused by Odonate nymphs, salamander larvae, and fish in a long-term study of wetlands in Oregon (USA). Metamorphic wild Cascades frogs (*R. cascadae*) were found to exhibit an average of 12.4% hind limb deformities among 945 examined 2003–2004 at one study site (Bowerman et al. 2012). Young Boreal toads (*A. boreas*) from another study site averaged hind limb deformities of between 1.0% to 34.2% (varied each season) for 13,443 examined over a total of 11 field seasons (Bowerman et al. 2010). Observations of potential tadpole predators and predatory attacks to anuran larvae at study sites compelled authors to monitor fish, salamander larvae, and dragonfly nymph densities, supplemented by outdoor and laboratory experimental simulations. Odonate nymphs were reported to have been seen removing limbs from tadpoles during 2003 to 2004 at the Cascade frog study site. The authors placed 10 uninjured *R. cascadae* tadpoles (Gosner stages 35–40) in outdoor experimental enclosures with either 5 White-ringed Emerald dragonfly nymphs (*Somatochlora albicincta*) or 5 larval Long-toed salamanders (*Ambystoma macrodactylum*) in multiple sets, as well as controls with no predators. Within 48 hours, two tadpoles with salamander larvae and one control tadpole exhibited hind limb abnormalities (percentage data and total number of tadpoles not reported), while 17.6% (n=37) of 210 tadpoles placed with nymphs suffered complete or partial amputation of one or both hind limbs. Long-term observations at the Boreal toad study site showed high seasonal variation in the population level of Three-spined stickleback fish (*G. aculeatus*), which positively correlated with levels of limb deformities seen among wild metamorphic toads; the highest levels of abnormalities were reported in the years with the heaviest stickleback densities. The authors utilized both laboratory aquaria and outdoor enclosures to confirm fish impact on developing toads. In laboratory conditions where 5 toad tadpoles (Gosner stages 35–38) were placed with 4 adult *G. aculeatus* for 24 hours, fish were observed injuring tails (53%) and hind limbs (7.5%)
among 40 exposed tadpoles. In outdoor studies, 1000 tadpoles were monitored periodically for injuries from Gosner stage 26 until metamorphosis within cages protecting them from fish and later compared with wild-caught toad larvae from the same study site. The results demonstrated that in protective cages tadpoles had far fewer tail injuries and no limb abnormalities compared to wild toad larvae collected at the same wetland, further confirming stickleback as a mediator of injury and limb abnormalities in toads.

Laboratory and field studies presented by Ballengée and Green (2010, 2011; and see chapter 9 and in appendix) identified several species of predators that induced anuran limb deformities in southern Quebec. During the two field seasons (2009 and 2010) 9,974 anurans were observed, exhibiting an average abnormality rate of 4.6%, of which deformity ratios at pristine wetland sites were significantly lower (1.9% compared to 7.2% of frogs from degraded sites). Tadpole predator population densities were far lower (as were tadpole injury rates) at pristine sites compared to wetlands deemed as degraded. Laboratory experiments identified several predators that non-lethally injured tadpoles, inducing limb deformities, including three dragonfly species \( (Aeschna umbrosa, Anax junios, \text{ and } Sympetrum costiferum) \) and one species of fish \( (C. inconstans) \).

There is a growing body of evidence to suggest predatory injury as a plausible explanation for missing limb deformities reported among wild anuran populations (Viertel and Veith 1992; Veith and Viertel 1993; Sessions 2003; Eaton et al. 2004; Piha et al. 2006; Ballengée and Sessions 2009; Sessions and Ballengée 2010a, b; Bowerman et al. 2010; Johnson and Bowerman 2010; Ballengée and Green 2010, 2011; Reeves et al. 2010, 2011; Novarini and Boldrin 2011; Bionda et al. 2012; Roberts and Dickinson 2012). Likewise there is a growing list of invertebrate and vertebrate predators confirmed in laboratory simulations to selectively predate or non-lethally injure tadpoles, resulting in reduced limb deformities in metamorphic anurans (Viertel and Veith 1992; Veith and Viertel 1993; Ballengée and Sessions 2009; Ballengée and Green 2010, 2011; Bowerman et al. 2010; Reeves et al. 2010). However, there are numerous questions that still need to be addressed, including: the possible impact of introduced predators in predation induced deformities; the potential synergistic effect that ecological quality may have in anuran larvae predator-to-prey relationships; the impact predator-induced deformities may be having on already declining amphibian populations; and numerous others. There is still much work left to do to better understand the deformed amphibian phenomenon in relation to the ecology and evolution of anurans and their predators.

7.8. Conclusion: The Synergy Hypotheses

Although several proximate causes (e.g. underlying mechanism and origin) for anuran limb deformities have been identified, other environmental factors may be working in synergy with parasites and predators to create anuran limb deformities. These factors may include changes to ecological systems, such as preternatural levels of wetland eutrophication, ultraviolet radiation, and climate change, which may mediate increases in populations of some tadpole predators or parasites. Several recent studies suggest that eutrophication from agricultural runoff appears to benefit \( R. ondatrae \) populations, thus increasing levels of
infected amphibians (discussed above). Likewise, elevated temperatures resulting from climate change may benefit \textit{R. ondatrae} populations (Johnson and Mckenzie 2008; Paull and Johnson 2011). Such changes to climate, UV radiation, and overall wetland ecological quality decline have all been confirmed as amphibian stressors and may impact tadpole hosts, making them more susceptible to diseases such as \textit{R. ondatrae} infection (Tevini 1993; Rohr and Raffel 2010; Johnson et al. 2010; Rohr et al. 2011). In addition to parasites, aquatic predators discovered to induce limb deformities in anuran amphibians were more abundant in degraded wetlands than at more pristine sites in southern Quebec (Ballengée and Green 2011).

Other stressors such as anthropogenic chemicals (e.g. pesticides, herbicides, and fertilizers) may alter tadpole behaviour, immunology, and development, making them more susceptible to predation and parasitic infection. Kiesecker (2002) found a decrease in immune response, higher percentage of severe abnormalities, and higher rate of infection among \textit{L. sylvaticus} exposed to \textit{R. ondatrae} and agricultural runoff, compared to those exposed exclusively to \textit{R. ondatrae}. Northern leopard frogs exposed to the agro-chemicals Atrazine and phosphate exhibited immunosuppression, which resulted in increased levels of \textit{R. ondatrae} (Rohr et al. 2008a). However, increased tadpole susceptibility to \textit{R. ondatrae} infection by agrochemicals may be a species- and/or chemical-specific phenomenon, as Budischak et al. (2009) found no significant difference between infected Pickerel frog (\textit{L. palustris}) tadpoles exposed to the pesticide Malathion. Numerous studies demonstrate that varied agricultural and industrial chemicals can alter anti-predatory behaviour in tadpoles, yet the link between this and amphibian deformities remains mostly unexplored.

Predation was the most likely cause for limb and skeletal abnormalities among \textit{L. sylvaticus} found in Alaska, according to Reeves et al. (2008). However such deformities were shown to be more prevalent in wetlands near roads, suggesting that potential chemical or other anthropocentric factors may have influenced predation impacts. In a sequential study, Reeves et al. (2010) found that population levels of dragonfly nymphs (\textit{Aeshna s}, \textit{Leuchorrinia s}, and \textit{Libellula s}) along with a degree of contamination (from organic and inorganic chemicals) at field sites directly correlated with frequencies of limb deformities among wild-collected \textit{L. sylvaticus}, suggesting a synergetic relationship. To further understand underlying mechanisms responsible for increased tadpole susceptibility to injury from dragonfly nymphs, Reeves et al. (2011) tested the potential impact that copper (Cu) had on tadpole detection and avoidance behaviour with respect to larval Zigzag darners (\textit{Aeshna sitchensis}). The authors discovered that tadpole ability to detect nymphs appeared not to be inhibited by Cu exposure, yet \textit{L. sylvaticus} behaviour when exposed to both chemicals and predators exhibited a great reduction in movement, implying a decrease in foraging, which might impact survival and slow development, making them more likely to be injured by Odonate nymphs (Reeves et al. 2011).

Introduced tadpole predators have been established as a proximate cause for deformities among some populations of native amphibians. Bowerman et al. (2010, discussed above) demonstrated a consistent seasonal correlation between levels of deformities in Boreal toads and populations of the introduced non-native Three-spined stickleback. Preston et al. (2012) reported non-lethal injuries to the tails and developing limbs among Pacific treefrogs, Boreal toads, and California newts (\textit{Taricha torosa}) exposed to the non-native Western
mosquito fish (*G. affinis*) raised in mesocosm experiments. Furthermore, Green darner (*A. junci*) nymphs are sold online in North America as a ‘green solution’ to mosquito control, and the effect of such artificial introductions on amphibian populations is not known (personal observation). Further research is needed to understand how all these factors work directly or indirectly in combination to influence frequency of amphibian deformities in nature. Likewise, the need for more detailed analyses of specific regional (e.g. endemic) phenomena at an ecosystem level are importantly needed to better under the international occurrence of abnormalities in amphibians.

### 7.9. Unanswered Questions from Prior Studies: Why I Conducted My Amphibian Deformity Research

A number of key unknowns arose from this analysis of prior investigations, giving impetus for my own primary studies (presented in chapters 8 and 9). Firstly, although numerous historical studies (e.g. Rostand) were conducted, there have been relatively few recent studies in Europe, compared to North America. Is this because the ecological issue of anuran deformities has occurred less there in recent years? Or is it that European researchers have just not addressed this issue as frequently as those in the Americas? Secondly, the majority of recently reported studies (except those attributed to infection by *R. ondatrae*) found high prevalence of anurans with missing limb deformities; however, the identification for an underlying cause for these malformations is not yet clear. Could pollution, genetic factors, different parasites, or predators be proximate causes? My research conducted in middle England (presented in chapter 8) addressed these questions and others.

Southern Quebec, has been considered a regional ‘hotspot’ for amphibian deformities in North America since the middle 1990s. Although Ouellet et al. (1997) and Bonin et al. (1997) demonstrated an increased frequency of amphibian deformities in agricultural wetlands, no specific chemical pollutant or other environmental factor was discovered to be the cause. Could pesticides induce the types of deformities they reported, or could predators and other natural factors be a potential cause? Likewise, how much do we really know about the interrelationships between anuran larvae prey, their predators, and parasites within complex natural wetland ecosystems? What impact may agricultural practices and other anthropogenic agents play in changing such interconnected food webs involving anuran larvae? Likewise, should we expect to see significant differences between ratios of tadpole injuries among those sampled at wetlands sites deemed ecologically ‘compromised’ compared to those deemed ‘pristine’ or changes in frequencies among young frogs? My studies conducted in southern Quebec (presented in chapter 9) addressed these questions and others.

In addition, these English and Canadian studies asked a larger question about the validity of data collected in participatory biology programs. As both of these primary biological research studies were conducted with the aid of volunteer ‘citizen scientists’ (discussed in chapter 6), was the data we collected useful to the larger scientific field of study? Did we find important insights, and what were these? How were these results shared with the larger scientific community? These and other questions are addressed in chapters 8, 9, and the conclusion of this dissertation.
Chapter 8. Case Study III: The Occurrence and Causes of Amphibian Deformities at Selected Localities in Yorkshire, England

8.1. Introduction

This chapter, presented as a case study, will address the question of how transdisciplinary art and participatory biology practices may contribute new and important knowledge to the field of primary research science. Specifically I attempt to demonstrate by what means scientific findings were achieved from primary research conducted during my hybrid art-science programs, Eco-Actions and Public Bio-Art Laboratories. It is important to clarify that these studies, though primary research science, were participatory biology programs and involved the aid of public volunteers whom I trained. Secondly this science investigation was also contextualized as transdisciplinary art, as it took place at a cultural venue and was commissioned by both artistic and scientific organizations.

However, to insure that data collected during these studies was viable and could be useful to the larger amphibian research community, methods and analyses were thorough, rigorous, and repeatable (cornerstones of scientific analysis as discussed previously by Mittelstraß, Irwin, Miller-Rushing et al. 2012, and others). Likewise as amphibian declines are both a global phenomenon and have been reported in England, it was important to involve local residents in these studies. As Gibbons et al. stated, such transdisciplinary science programs need to be ‘locally driven and locally constituted … in response to problem-formulations that occur in highly specific and local contexts’ (1994: 30).

Yorkshire (England) was chosen as study region because of its historic and continued heavy farming activities. As discussed in the previous chapter, agricultural areas have been found to contain higher frequencies of deformed amphibians, and this phenomenon had not previously been investigated in England. Additionally, during a pilot study of a wetland in Havercroft Village (Yorkshire) conducted in 2006, numerous severely deformed young Common toads (B. bufo) were discovered, which gave impetus for further study at this site and in the region.

My role in these studies was that of a primary investigator conducting a biological study, secondly as an environmental educator who trained volunteers not only in field and laboratory techniques but also in the natural history, physiology, and ecological plight of amphibians. The objectivity utilized through the lens of science to understand material phenomena and the communicative role of a teacher inspired my personal artistic responses, as discussed in chapter 5.

8.2. Background To Study

Historically numerous deformed anurans have been reported in Europe, and long-term studies have been conducted previously (e.g. Rostand; chapter 7). However, as discussed

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227 This research was funded by the Arts Catalyst, Yorkshire Sculpture Park (YSP) and the Biology Department at Hartwick College. YSP in Wakefield (England) became an important home base during these studies, with several wetlands within the park investigated and laboratory experiments conducted at the Public Bio-Art Laboratory established at YSP (see chapter 6).
in the previous chapter, there have been relatively few recent efforts to analyse the frequency of malformed European amphibians, and potential causes have remained elusive. In response, during three field seasons (2006–2008) the incidence and proximate cause for morphological deformities among natural populations of anuran amphibians at selected wetlands in Yorkshire, England, were investigated through my participatory biology programs (discussed in chapter 6).

Visual examinations were performed on site with all age classes of frogs and toads collected, using a novel technique I created entitled VAFID (Visual Analysis for Frog Injuries and Deformities). Wild-sampled amphibians were examined in situ at the wetlands immediately following collection, and the vast majority (often greater than 99%) were released. VAFID was performed to limit study impacts on wild populations, and volunteers were trained in this technique to aid in Eco-Action field studies. If severely deformed frogs and toads were found, they were taken for laboratory analysis, which included parasitic assays along with post-fixing clearing and staining (technique discussed in chapter 5; Ballengée and Green 2010b, and see in appendix).

Laboratory experiments complemented field inquiries in an attempt to better ascertain proximate causes for found wild deformed anurans. To begin, tadpoles (from wetlands where abnormal anurans were found) were collected and reared in captivity to test for potential genetic defects among populations. Next the potential role that agricultural and residential runoff may have had in anuran abnormalities was tested through several controlled experiments. Additionally the possible role that snail-borne parasites may have played in frog and toad deformities was also tested in laboratory simulations. Lastly the prospective role predatory larval Odonates and other predators played in causing anuran deformities and injuries was investigated through experimental simulations between tadpoles and selected aquatic predators found in field sites.

8.3. Roles of Volunteers in This Research

For three consecutive field seasons (2006–2009), greater than 800 members of the YSP public visited or volunteered in the Public Bio-Art Laboratory or participated in an Eco-Action as discussed in chapter 6. This involved, to varied degrees, aiding with overall problem identification (where deformed frogs were found and at what frequency), training in amphibian observation techniques, helping with data collection in field and laboratory settings, sharing prior knowledge of local wetlands and amphibian populations, documentation, and aiding in the establishment and monitoring of laboratory experiments.

8.4. Materials and Methods

This study involved both field observations and laboratory experiments focused primarily on European Common toads (B. bufo) and Common frogs (R. temporaria). Field studies primarily were conducted as Eco-Actions and involved public volunteers (please see chapter 6). A portion of this investigation, along with additional research (not discussed here) was reported by the author and my Ph.D. advisor Stanley K. Sessions in the peer-reviewed Journal of Experimental Zoology in 2009 (please see appendix).

Conducted in the Public Bio-Art Laboratory established at YSP with the aid of volunteers (please see chapter 6).
observations were complemented by numerous experimental simulations with anuran larvae that included testing for genetic defects, chemical contaminants, parasites, and aquatic predators under laboratory conditions. Post-mortem laboratory analyses were also performed, primarily to test for *R. ondatrae* among field-collected, deformed frogs.

**8.5. Laboratory Studies**

During the 2007–2008 field season, anuran amphibians (representing all age classes) were sampled from five pre-selected wetlands in Yorkshire to determine the occurrence of deformities in populations of free-living, native English amphibians. These sites included both permanent and temporal (vernal) wetlands and were chosen based on pilot studies conducted in 2006. All sites represented a geographic range of less than 100 square km. Each site was visited three times (within 6 weeks over the course of 16 total weeks) per season to monitor for ontogenetic changes in frequencies of anuran abnormalities. Field sampling was conducted through dip-netting techniques and timed in 15-minute intervals, averaging two human-hours per visit per site. Common toads were monitored as a ‘model’ anuran species, since they were found at all field sites and accounted for the majority of amphibians sampled. These field investigations, contextualized as *Eco-Actions*, were largely open to the public, groups of students, and YSP staff. Volunteers underwent preliminary training, as most had little to no prior experience in amphibian research, then participated in at least one field survey event.

**8.5.1. Experimental Simulations**

Numerous experiments were conducted to examine for the proximate cause(s) of deformities observed in wild anuran populations. These included simulations examining natural genetic mutation, chemical pollutants in site water, parasitic infection, and predatory injury. We utilized two anuran species, *R. temporaria* and *B. bufo*, as these were the only native species found at collection sites. Tadpoles at different developmental stages and in varied group sizes were reared to metamorphosis and exposed to various environmental factors in experiments. Odonate nymphs and other predators soon became a focus because of early positive results. These experiments were conducted completely open to the public on the grounds of the Yorkshire Sculpture Park or within the *Public Bio-Art Laboratory* I established there in 2008. Additionally, visitors, students, and YSP staff were encouraged to volunteer to aid in these studies. The vast majority of these participants had no special prior training in science.

**8.5.2. Hereditary Defects//Intrinsic Malformation Experiment**

A series of preliminary studies were conducted to explore hereditary defects, or

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230 Primary sites were selected after 2006 pilot studies based on viable populations of anuran amphibians and the occurrence of one or more deformed individuals. Of selected primary study sites, some had multiple collection areas such as Yorkshire Sculpture Park (some wetlands had more than one collection location and differing inflow origins of water as observed prior in our 2006 pilot studies).
intrinsic malformation, (under the suggestion of Ph.D. advisor A. Hillbeck) in the toad population at the Havercroft site. Common toad tadpoles representing a range of developmental stages were collected from Havercroft Village Green Pond. These tadpoles were examined for obvious injuries or deformities, sorted using Gosner staging (1960; figure 18 in appendix), and grouped according to developmental stage. Three groups were made representing Gosner stages 28–30, 31–33, and 34–36. Tadpoles with injuries or other abnormalities were rejected, along with tadpoles not in stages 28–36. The selected tadpoles were subdivided into groups of 10 individuals (representing the same stage). Each set of 10 was placed in individual containers with 5 l aged water kept at ambient room temperatures with a natural daylight/night cycle, and a small amount of the pond plant *E. candensisos* (3 total 10 inch sprigs) for partial habitat creation and oxygenation of water (figure 19 in appendix). Experimental tadpoles were fed fish food flakes daily to minimize any potential competitive injuring effects such as auto-predation. Removal of faeces and 10% water changes occurred daily prior to feeding. Each set of 10 was replicated five times (50 total per stage) and five control tanks were established with tadpoles from similar stages collected from Hoyland Bank Pond (where no deformities were observed). Periodic examination of tadpoles ensued for any developing deformities (figure 20 in appendix). The experimental tadpoles remained in their enclosures for eight weeks or until toad metamorphosis, at which point they were examined for deformities. Those with developmental deformities were then described, photographed, euthanized, and fixed for record, and those that developed normally were released.

### 8.5.3. Havercroft Water Contaminant Experiment

A series of preliminary studies were conducted to explore whether the Havercroft site water (e.g. water-borne chemical contaminants) could induce developmental defects in otherwise healthy toad tadpoles. The Havercroft Village Green pond was exposed directly to inflows of agricultural and residential run-off. Common toad tadpoles representing a range of early to mid-developmental stages were collected from Hoyland Bank Pond (a site free from direct agricultural or residential run-off). The tadpoles were sorted and grouped according to Gosner staging (1960). Any tadpoles with injuries or other abnormalities were rejected, along with tadpoles at stage 28 or earlier or stage 34 or later. Three hundred Gosner stage 28–34 tadpoles were hereby divided into grouping for two experimental simulations.

Group 1 consisted of 150 tadpoles. These were kept in an outdoor tub with mesh screen in 60 l of water collected within 48 hours from the start of the experiment at the Havercroft Village Green Pond site (figure 21 in appendix). Small amounts of the pond plant *Elodia candensisos* (3 total 10-inch sprigs) were added for partial habitat creation and oxygenation of water. The tub was placed under the overhang of a roof to minimize precipitation and direct sunlight. Tadpoles were fed fish food flakes daily to minimize any potential competitive injuring effects such as auto-predation. Removal of faeces occurred

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231 Water was collected within one meter of the surface of the wetland using 5-gallon buckets. Before entering experimental tub, water was run through a less than 1 mm. mesh net in an attempt to remove juvenile aquatic predators, small molluscs, and other unintentionally collected species.

232 *Elodia* was collected at Havercroft, rinsed, and examined for snail egg cases and other organisms before being placed in experimental enclosure.
daily, and 20% water changes and filling to compensate for evaporation occurred weekly. The experimental tadpoles remained in the tub for eight weeks, or until toad metamorphosis, at which point they were examined for deformities. Those with developmental deformities were to be then described, photographed, euthanized, and fixed for record, and those that developed normally were released.

Group 2 consisted of the remaining 100 tadpoles. These were subdivided into groups of 10. Five sets of 10 tadpoles were placed in individual containers with 3 l of water collected within 48 hours from the start of the experiment at the Havercroft Village Green Pond site and 5 sets of 10 tadpoles were raised in aged water to act as controls (figure 22 in appendix). These 10 tanks were kept at ambient room temperatures with a natural daylight/night cycle. Small amounts of the pond plant *E. candensisos* (3 total 10 inch sprigs) were added for partial habitat creation and oxygenation of water. Tadpoles were fed fish food flakes daily to minimize any potential competitive injuring effects such as auto-predation. Removal of faeces occurred daily. Twenty percent water changes and filling to compensate for evaporation occurred weekly. The experimental tadpoles remained for the duration of eight weeks, or until toad metamorphosis, at which point they were examined for deformities. Those with developmental deformities were to be then described, photographed, euthanized, and fixed for record, and those that developed normally were released.

8.5.4. Snail-borne Parasite (Bufo bufo/Lymnaea stagnalis) Experiment

Preliminary studies were conducted to ascertain the potential involvement of snail-borne aquatic parasites as an etiology for the deformities observed at field sites. Common toad tadpoles representing a range of early to mid-developmental stages were collected from Hoyland Bank Pond. The tadpoles were sorted and grouped according to Gosner staging (1960). Any tadpoles with injuries or abnormalities were rejected, along with tadpoles at stage 27 or earlier or stage 31 or later. Three hundred Gosner stage 28–30 tadpoles were selected because of pre-toe differentiation in limb buds. These were divided into two groups and reared in outdoor enclosures with varied concentrations of adult Great Pond snails, *Lymnaea stagnalis*, collected from the Havercroft site (figures 23 and 24 in appendix). Since this was a preliminary investigation, no control groups were utilized.

Group 1 consisted of 100 early limb stage (Gosner stages 28–30) toad tadpoles with 100 adult *L. stagnalis* (1:1 ratio). These were kept in an outdoor tub with mesh screen in 50 l of aged water. Ample amounts of the pond plant *E. candensisos* (5 total 10 inch sprigs) were added for partial habitat creation and oxygenation of water. The tub was placed under the overhang of a roof to minimize precipitation and direct sunlight. Tadpoles and snails maintained a daily diet of fish-food flakes. Ten percent water changes and filling to compensate for evaporation occurred weekly, so as to disturb specimens and natural parasitic infection rates as little as possible. The experimental tadpoles remained for the duration of eight weeks, or until toad metamorphosis, at which point they were examined for deformities.

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233 With water collected freshly from the Havercroft site using the above method.
234 Three species of amphibians were found with hind limb deformities at the Havercroft Village Green Pond, Wakefield, West Yorkshire. Of the 37 animals collected, all except two were peri-metamorphic *Bufo bufo* (Common toad). Based on this high percentage, *B. Bufo* became a focal species in consequent studies.
Those with developmental deformities were then described, photographed, euthanized, and fixed for record, and those that developed normally were released.

Group 2 consisted of 25 early limb stage (Gosner stages 28–30) toad tadpoles with 125 adult L. stagnalis (1:1 ratio). These were subdivided into 5 groups of 5 tadpoles per 25 snails and housed in acrylic tanks with 3 liter aged water. Ample amounts of the pond plant E. candensisos (6 total 10 inch sprigs) were added to each tank for partial habitat creation and oxygenation of water. Experimental tanks were kept at ambient room temperatures with a natural daylight/night cycle, and periodic observations for free-swimming parasitic cercariae were performed. Tadpoles and snails maintained a daily diet of fish-food flakes with removal of faeces occurring daily. Ten percent water changes and filling to compensate for evaporation occurred weekly, so as to disturb specimens and natural parasitic infection rates as little as possible. The experimental tadpoles remained for eight weeks, or until toad metamorphosis, at which point they were examined for deformities. Those with developmental deformities were then described, photographed, euthanized, and fixed for record, and those that developed normally were released.

### 8.5.5. Aquatic Predator//Tadpole Prey Experiments

During the summer of 2008, numerous preliminary experiments were conducted to examine the role that potential aquatic predators and tadpole crowding (cannibalism) played in injury induction of anuran larvae resulting in deformities. These experiments exposed two anuran species, R. temporaria and B. bufo, at different developmental stages and in varied group sizes, to several species of aquatic predators found at field sites (table 10). Preliminary experiments identified larval dragonflies (especially Sympetrum sp.) and a fish (Gasterosteus aculeatus) as likely vectors for limb injury among tadpoles, which led to larger-scale primary experiments.
<table>
<thead>
<tr>
<th>Predator</th>
<th>Anuran sp./Gosner stage</th>
<th>Exp. Con.</th>
<th>lethal</th>
<th>Non-lethal</th>
<th>NLI to tails</th>
<th>NLI to hind limbs/buds</th>
<th>Resulting in hind limb deformity</th>
</tr>
</thead>
<tbody>
<tr>
<td>larval R. temporaria (32–38)</td>
<td>50 total, 1 set</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>larval B. bufo (30–38)</td>
<td>10 total, 5 sets</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>adult L. helveticus R. temporaria (32–38)</td>
<td>1/10, 1 set</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>adult L. helveticus B. bufo (30–38)</td>
<td>1/10, 5 sets</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>adult L. vulgaris R. temporaria (32–36)</td>
<td>1/10, 1 set</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td></td>
<td></td>
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<tr>
<td>adult L. vulgaris B. bufo (30–38)</td>
<td>1/10, 5 sets</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
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<tr>
<td>adult G. aculeatus R. temporaria (32–38)</td>
<td>1/5, 2 sets</td>
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<td>Y</td>
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<td>Y</td>
<td>Y</td>
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<tr>
<td>adult G. aculeatus B. bufo (30–38)</td>
<td>1/10, 5 sets</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>adult D. marginalis R. temporaria (32–38)</td>
<td>1/10, 1 set</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>adult D. marginalis B. bufo (30–38)</td>
<td>1/5, 5 sets, 1/5, 5 sets</td>
<td>Y</td>
<td>N</td>
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<tr>
<td>larval D. marginalis B. bufo (30–38)</td>
<td>1/5, 3 sets,</td>
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<td>Adult N. cinerea B. bufo (30–38)</td>
<td>1/5, 5 sets</td>
<td>Y</td>
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<tr>
<td>larval A. mixta R. temporaria (32–38)</td>
<td>1/5, 2 sets</td>
<td>Y</td>
<td>Y</td>
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<td>larval A. mixta B. bufo (30–38)</td>
<td>1/5, 5 sets</td>
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<tr>
<td>larval L. depressa R. temporaria (32–38)</td>
<td>1/5, 2 sets</td>
<td>Y</td>
<td>Y</td>
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<td>larval L. depressa B. bufo (30–38)</td>
<td>1/5, 5 sets</td>
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<tr>
<td>larval Sympetrum sp. R. temporaria (32–38)</td>
<td>1/5, 2 sets</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
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<tr>
<td>larval Sympetrum sp. B. bufo (32–34)</td>
<td>1/10², 10 sets</td>
<td>Y</td>
<td>Y</td>
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<td>Y</td>
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<tr>
<td>larval Sympetrum sp. B. bufo (35–37)</td>
<td>1/10², 10 sets</td>
<td>Y</td>
<td>Y</td>
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Table 10. Tadpole predators demonstrated in our experiments as capable of inducing both lethal and non-lethal injuries among varied anurans in preliminary and primary experiments. Species (in bold) were demonstrated to induce limb bud and limb injuries to tadpoles, resulting in permanent deformities among metamorphic anurans (Ballengée Transfer paper 2009; Ballengée and Sessions 2009; Sessions and Ballengée 2010b, in appendix). 1. A single toad tadpole survived a limb attack by an adult.
Smooth newt, which resulted in a missing foot at the time of metamorphosis. 2. Several limbs in Common frog tadpoles were injured by sticklebacks, all of which initially survived but died before complete metamorphosis. 3. Odonate nymphs were observed partially consuming both frog and toad tadpole limbs/limb regions; several tadpoles survived these initial attacks but died before complete metamorphosis. Three species of dragonfly nymphs, Aeshna mixta, Libellula depressa and especially Sympetrum sp., were observed partially eating both frog and toad tadpoles (even removing one or both hind-limbs) then releasing the injured prey. 4. Injured and killed tadpoles were replaced to keep the constant prey level at 10 to 1 predator throughout the experiment. The only predators identified in experimental simulations to consistently non-lethally injure tadpoles resulting in permanent limb deformities in metamorphic toads were Sympetrum sp. dragonfly nymphs.

8.5.6. Selective Predation Experiment 1 (Bufo bufo/Gasterosteus aculeatus)

Common toad tadpoles representing a range of developmental stages were collected from Hoyland Bank Pond. Tadpoles were kept for observation in an outdoor tub with 100 l of aged water for 14 days and were fed fish-food flakes daily to minimize any potential competitive injuring effects such as auto-predation. Removal of faeces and 10% water changes occurred daily prior to feeding. After initial observations and acclimation, tadpoles were sorted and grouped according to varied Gosner stages. Any tadpoles with injuries or other abnormalities were rejected along with tadpoles at stage 31 or earlier or stage 35 or later. Three hundred non-injured tadpoles (Gosner stages 32–34) were selected for experiments and housed in acrylic tanks with 20 l aged water for 48 hours prior to experiments.

Three-spined stickleback (G. aculeatus) of varied age groups where collected from the man-made College Pond at Yorkshire Sculpture Park. This site was selected because of the large population of stickleback (1 to 5 total per dip-net) and because a deformed newly metamorphic Common frog was collected at the site in the field-season of 2006. Stickleback were sorted and grouped according to estimated age based on size and signs of sexual maturity. Of these fish, 190 were selected for the experimental groups, and 50 were reserved as controls and potential replacements of dead experimental fish. The 190 individual fish were grouped in varied concentrations into 5 l tanks with aged water at 1 per tank, 2 per tank, 5 per tank, 10 per tank, 20 per tank, and replicated 5 times per concentration totalling 25 total tanks. Tanks were kept at ambient room temperature with a natural daylight/night cycle with E. canadensis (3 total 10 inch sprigs) for partial habitat creation and oxygenation at varied concentrations replicated by 5 tanks per concentration. Fish were maintained for one week of observation and were fed Tetramin fish flakes every other day. Removal of faeces and 10% water changes occurred daily prior to feeding. Prior to introduction of toad tadpoles the stickleback were deprived of food for 48 hours to insure hunger.

Ten Bufo tadpoles were then added to each tank containing the varied concentrations of fish at the following ratios; 10 tadpoles: 1 stickleback, 10:2, 10:5, 10:10, and 10:20. Experimental sets were replicated 5 times with 5 tanks containing no stickleback to act as controls. Immediately after introduction, Stickleback nibbling of tadpoles was observed and filmed (figure 25). Injured tadpoles remained in the tanks and were photographed and described daily. Dead tadpoles were removed from tanks, described, photographed, and fixed in 10% buffered formalin. The experiments ran until tadpoles died from injuries or until they reached peri-metamorphic stage (tail absorption), at which point they were released.
8.5.7. Selective Predation Experiment 2 (Bufo bufo/Sympetrum species)

Tadpoles representing a range of developmental stages were collected from Bank Pond. Tadpoles were kept for observation in an outdoor tub with 100 l of aged water for 14 days and were fed fish-food flakes daily to minimize any potential competitive injuring effects such as auto-predation. Removal of faeces and 10% water changes occurred daily prior to feeding. After initial observations and acclimation, tadpoles were sorted and grouped according to Gosner stages. Any tadpoles with injuries or other abnormalities were rejected along with tadpoles at stage 31 or earlier or stage 38 or later. Remaining tadpoles (stages 32–37) were sub-divided into two sets according to developmental stage: set number 1 (stages 32–34) and set number 2 (stages 35–37). The two sets of tadpoles were kept at ambient room temperatures with a natural daylight/night cycle in acrylic tubs with 20 l aged water for 48 hours prior to experiments. Feeding and cleaning methods continued daily.

Dragonfly nymphs (Sympetrum sp.) were collected from a permanent fish-free wetland in the Upton Colliery Eastern Pond. This site was selected because of the large population of Sympetrum dragonfly nymphs (1 to 3 per dip-net) and because deformed and newly injured tadpoles and newly metamorphic toadlets had been found at the site on a prior visit. Dragonfly nymphs were grouped according to estimated developmental instar (based on size and wing development). Thirty-seven individuals from the same stage were selected and kept in individual containers (to prevent cannibalism) with 1-1 aged water kept at ambient room temperature with a natural daylight/night cycle and E. Canadensis (1 total 10 inch sprigs) for partial habitat creation and oxygenation of water. Twenty of the nymphs were selected for the experimental groups and 17 reserved as controls and potential replacements of dead experimental nymphs. Nymphs were maintained by feeding them one Common frog tadpole every 48 hours.

The 20 experimental nymphs were given individual 5 l tanks and kept at ambient room temperature with a natural daylight/night cycle and E. Canadensis (3 total 10 inch sprigs). Experimental nymphs were deprived of food for 72 hours prior to introduction of toad
tadpoles to insure hunger. Ten experimental nymphs were selected to feed on the younger *Bufo* tadpoles (Set 1, stages 32–34) and 10 were selected to feed on the older *Bufo* tadpoles (Set 2, stages 35–37). Ten *Bufo* tadpoles were then added to each tank containing a single hungry nymph. Injured or dead tadpoles were replaced with same stage tadpoles every 24 hours for 11 days, allowing nymphs to gorge themselves on *Bufo* larvae (figure 26 in appendix). Dead tadpoles and remains from all tanks were described, photographed, and fixed in 10% buffered formalin. Injured tadpoles with visible trauma to the limb(s), abdomen, cranium, or tail (if severe enough that less than 50% of tail remained), were removed, euthanized in MS222, photographed, and fixed in 10% buffered formalin to record non-lethal injuries. The remaining live injured tadpoles from 5 out of 10 tanks per set were removed, described, photographed, and placed in isolated tanks containing 500 ml aged water, fed and cleaned daily to allow tadpoles to continue to develop post-injury. Post-injury tadpoles were grouped into tanks by injury date and type of injury and allowed to develop until tail absorption, at which point they were described, euthanized in MS222, photographed, and fixed in 10% buffered formalin.

8.5.8. *Post-mortem Analysis of Field-collected, Deformed Anurans*

During pilot field studies in 2006 several deformed amphibians were discovered at a residential pond in Havercroft Village in Yorkshire. Here, 35 peri-metamorphic Common toads were found with deformities (the majority exhibiting abnormalities in the hind limbs and three with normal hind limbs but single missing eyes) and a single metamorphosed Common frog (*R. temporaria*) with an abnormal hind limb collected from our Havercroft study site. These animals were euthanized using a solution of MS222 and fixed in 10% buffered formalin, rinsed in water, and post-fixed in 90% ethanol within 24 hours of collection. Specimens were then cleared and stained, which enabled further analysis of abnormal morphologies (bone and cartilage) and by which the presence of sub-epidermal parasitic cysts could be easily identified. Visual analysis of specimens by the author was performed using two processes: firstly, a standard visual examination utilizing a stereomicroscope with a 10:1 optical magnification; secondly, specimens were imaged using high-resolution digital scanning.

8.6. *Results of Field and Laboratory Studies*

8.6.1. *Field Observations*

The 2006 pilot study revealed a wide range of missing, partial, and misshapen hind

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235 This pilot study was conducted with the aid of naturalist Richard Sunter. Sunter has previously studied amphibian populations at the site but never examined for or noticed metamorphic anurans with developmental deformities.

236 An adult Smooth newt (*L. vulgaris*) was found to have missing digits on a forelimb. The animal was photographed and released, as the pilot study was focusing on anuran species.

237 Experimental digital scanning of biological specimens was conducted as the focus of a 2008 research residency at La Société des arts technologiques [SAT] in Montréal, Canada. Facilitated by SAT, various imaging scanners were employed at Hexagram Imaging Laboratory, Concordia University, and Oboro, both in Montreal. Additional scanning was conducted at the LAMIC Centre, Université Laval, Québec, Canada. With different teams at the four facilities, the author used several different experimental or commercially available imaging scanners to successfully analyse the 2006 preserved specimens.
limb deformities among late-stage tadpoles and newly metamorphosed toads (peri-
metamorphs). A total of 35 peri-metamorphic toads were found with deformities, the majority
exhibiting abnormalities in the hind limbs and three with normal hind limbs but single
missing eyes. The limb deformities included complete absence of limbs, presence of
cartilaginous spikes (tapered cartilage growths at the tip of a truncated limb bone), reduced
hind limbs, and one individual with epidermal webbing binding a reduced hind limb,
prohibiting full use. A newly metamorphosed Common frog (*R. temporaria*) with an
abnormal hind limb and an adult Smooth newt (*L. vulgaris*) with a partial hind limb with
missing foot were also observed. All the animals were alive at the time of surveys except one
toad metamorph with completely missing hind limbs. Exact population counts of normal
individuals were not generated in the pilot study but were estimated at greater than or equal to
100 (R. Sunter and the author’s field notes, 2006).

Systematic collections at Havercroft and the two other sites over the summers of 2007
and 2008 yielded deformed peri-metamorphic toads, including some fresh injuries and freshly
amputated hind limbs, at all three ponds (figure 29). The proportion of deformed toads ranged
from 16 out of 1,214 toads (1.3%) at Havercroft, 22 out of 1,879 (1.2%) at Campsall Clay,
and 4 out of 41 toads (9.8%) at Upton Colliery for both summers combined. Except for the
last site, these rates of deformities all fall well within the suggested baseline (less than or
equal to 5%, as discussed in the previous chapter) for deformities in natural populations of
amphibians. Surveys at Hoyland Bank Pond, a nature reserve, found no abnormal frogs or
toads. Of several wetlands located within the grounds of the Yorkshire Sculpture Park
surveyed throughout 2006–2008, only one metamorphic *R. temporaria* was found with an
abnormal hind limb, a missing foot.

*Figure 35.* Graph showing major kinds of deformities in wild-caught Common toad (*B. bufo*) from three field sites, presented as percent of deformities in each case (Ballengée and Sessions 2009).

Potential predators found at the sites included Three-spined Stickleback fish (*G. aculeatus*), newts (*Lissotriton helviticus* and *Lissotriton vulgaris*), and several species of
aquatic insect predators including Diving Beetles (*Dytiscus sp.*), Water Scorpions (*Nepa
cinerea*), and predatory Odonata nymphs (including *Sympetrum* sp.). Odonata nymphs were
particularly abundant at sites with higher prevalence of deformed toads, as they have been
historically (Sunter, 1997, 2000). *Sympetrum* sp. (probably either *S. striolatum* or *S. sanguineum*) appeared to have high population densities at the Havercroft and Upton Colliery sites, with greater than 3 collected per dip-net (Ballengée and Sessions 2009). Special attention was given to examination of amphibians and sites for the presence of leech species, but no such exo-parasites/predators were found on any of the collected amphibians and appeared rare at all study localities.

Numerous volunteers (*n*=264) participated in these *Eco-Action* field surveys during the 16-week seasons of 2007 and 2008. These included student groups from local Yorkshire primary and secondary schools, families (as they were offered as free public events through YSP on Saturdays), and several YSP staff or affiliates. The majority of participants only attended one survey, however 5 individuals (all YSP staff or affiliates) participated in greater than 4 events during field seasons. Their responses to these experiences and my own responses to working with such large numbers of ‘single-event’ volunteers were presented in chapter 6.

### 8.6.2. Experimental Simulations

Experiments testing for hereditary defects among wild populations of Havercroft *Bufo* and for teratological agents (from agricultural and residential run-off) in the Havercroft water both yielded null results, with no deformities observed among any of the experimental animals reared under varied conditions. Tests for potential snail-borne parasites also yielded no deformities in young toads. In fact the only observed free-swimming cercarce (of an unidentified species) appeared not to infect *Bufo* tadpoles in experimental enclosures. However predation appeared to be a major cause of tadpole injuries in experimental trials, including the removal of full limbs in developing tadpoles. Many such tadpoles survived predatory attacks, eventually healing, though often with deformed partial limbs. In all, the only experiments conducted between 2006 and 2008 that yielded abnormalities in anurans at the time of metamorphosis where those resulting from injuries from several aquatic predators (table 10).

These experiments were conducted with the aid of trained volunteers within the grounds of the park and at the *Public Bio-Art Laboratory* established at Yorkshire Sculpture Park. Although many volunteers (*n*=134) aided in some aspect of laboratory work (the majority underwent short-term training to perform a single task), only 4 individuals underwent more in-depth training and consistently helped with multiple activities over the seasons 2007–2008. The reactions of these volunteers and my own were presented in chapter 6.

### 8.6.3. Aquatic Predator/Tadpole Prey Experiments

During the summer of 2008, numerous experimental simulations were conducted between anuran larvae and potential aquatic predators, which also included auto-predation trials. Preliminary experiments involved Common toad and Common frog tadpoles at varied stages in varied concentrations with potential predators including: adult Palmate newts (*L.*
helveticus); adult Smooth newts (L. vulgaris); adult three-spined stickleback (G. aculeatus); larval and adult Great diving beetles (Dytiscus marginalis); adult Water scorpions (Nepa cinerea); and three species of dragonfly nymphs (Aeshna mixta, Libellula depressa, and Sympetrum sp., probably either S. striolatum or S. sanguineum; table 2). Auto-predation studies with varied concentrations of ‘crowded’ tadpoles were also performed. Substantially more Bufo tadpoles were utilized in experiments, as they were much more readily available in all three seasons at field sites, and they appeared to have higher prevalence of abnormalities in the wild than R. temporaria.

Most predators were observed (and filmed) partially eating both frog and toad tadpoles during preliminary tests (table 10). A single toad tadpole survived a limb attack by an adult Smooth newt, which resulted in a missing foot at the time of metamorphosis (figure 30 in appendix). Stickleback and dragonfly nymphs were consistently recorded injuring tadpoles, sometimes even removing one or both hind limbs (figures 31 and 32). Common frog (R. temporaria) simulations resulted in varied tail and limb injuries but were not continued due to 100% mortality among tadpoles within 72 hours post-trauma. Many of the toad (Bufo) tadpoles were recorded surviving injuries from both stickleback and nymphs, which led to larger primary studies (discussed below). Lastly, toad and frog tadpoles were preliminarily tested to study potential auto-predation. Toad tadpoles were observed nibbling on one-another in crowded temporary enclosures while frog tadpoles were not (figures 33 and 34 in appendix). However, none of the crowded frog or toad tadpole auto-predation injures resulted in deformities at the time of metamorphosis.

Figure 36. Severe limb and tail injuries induced by G. aculeatus/ on R. temporaria late-stage tadpole in preliminary study.
8.6.4. Selective Predation Experiment 1 (B. bufo//G. aculeatus)

Of the 250 Bufo tadpoles added to aquariums containing varied concentrations of fish, many were non-lethally injured, while many died from stickleback attacks (please see breakdown of data available in appendix). Fish were observed (and filmed) vigorously biting toad tadpole tails, limbs, heads, and abdomens. Extensive nibbling resulted in removal of tail tissue and even sometimes the majority of the tail (figure 35; figure 36 in appendix). Unlike recorded stickleback attacks to Rana tadpoles, the fish would bite but release Bufo limbs, perhaps because of the presence of distasteful bufo-toxins in developing tadpole skin. Lethal injuries were common in all experimental sets and directly correlated with stickleback densities, with the highest tadpole death rate (100%) recorded in experimental sets with the most fish ($n=20$). In conclusion, the experiments resulted in increased mortality among tadpoles subjected to higher predation densities (mostly from extensive damage to tails) but no non-lethal injuries resulting in missing limbs, limb segments, or any other deformities.
8.6.5. Selective Predation Experiment 2 (B. bufo/Sympetrum species)

In our experimental observations, we examined a total of 427 Bufo tadpoles that had been predated by Sympetrum dragonfly nymphs. Selective predation, removing body parts (often limbs) and inducing a range of both lethal and non-lethal injuries were observed in 14 out of 20 tanks beginning in the first few hours after introduction of prey tadpoles. Nymphs were observed (and video recorded) capturing tadpoles and chewing on selected body parts before releasing them (figure 37). Recapture of injured tadpoles was occasionally observed, though it appeared nymphs were attracted more to movement in non-injured tadpoles than returning to less active, previously injured prey (figure 38 in appendix). Our observations suggest that Sympetrum prefer visual to tactile hunting techniques, at least when prey are abundant. Occasionally, tadpoles were able to escape after being captured (‘predation attempt’), but this was rarely observed. Most nymphs continued to feed for several days, some for the entire duration of the experiment. Only two of the 20 nymphs did not feed at all.
Figure 39. Dragonfly nymph attacking one of two toad tadpoles, shortly after selectively removing the hind limbs (visible in the nymph’s mandibles, arrow). Published in Ballengée and Sessions 2009.

Full consumption by nymphs of an entire Bufo tadpole was never observed in the toad/dragonfly interactions. Selective predation or non-lethal injuries by nymphs included facial/cranial damage such as missing eyes, but the most common injuries were to the tails and hind limbs, including partial and sometimes full amputation of both hind limbs (figure 37; figure 39 in appendix). Damage to developing limbs occurred frequently in younger and older (figure 40a, 40b) Bufo tadpoles, but with different developmental consequences (figure 41). Lethal damage (DOAs) most often included major injuries to the cranium and abdomen and/or the loss of greater than 75% of the tail (figure 40a, 40b).
Figure 4a, 4b. Lethal (DOA) and non-lethal (Surv) injuries among tadpoles of two age groups by dragonfly nymphs; a: attack at Gosner stage 33–34; b: attack at Gosner stage 36–37. Published in Ballengée and Sessions 2009

Figure 41. Percent missing limbs in surviving toad tadpoles selectively predated by dragonfly nymphs at two different stages (Gosner, 1960). Differences are statistically significant (p < 0.01). Published in Ballengée and Sessions 2009
Our observations also showed that the extent of deformity varies with the developmental stage at which the injury occurred. Selective predation of hind limbs in older tadpoles (stage 35–37; 16/75 tadpoles = 21.3%) was more than three times as likely to result in permanent missing limb deformities than amputation in younger tadpoles (stage 32–34; 4/64 tadpoles = 6.3%) (figure 41). Even extreme injury in a late-stage tadpole, such as complete removal of a hind limb, including portions of the body wall and pelvic girdle, was not always fatal and could be followed by complete healing with no obvious scarring and no regeneration within a few days (figure 42).

Figure 42. Selective predation by dragonfly nymph on a toad tadpole resulting in amputation of the right hind limb; left: immediately after attack; right: same tadpole 10 days after attack. Right hind limb area has completely healed, resulting in permanent limb loss. Published in Ballengé and Sessions 2009.

Tadpoles that survived the dragonfly-induced injuries showed partial to complete regeneration of their tails and hind limbs. Regenerative responses to hind limb injury (removal) ranged from complete regeneration to partial regeneration to healing with no regeneration (figures 42 and 43; figures 44 and 45 in appendix). By metamorphosis, this variation in regenerative response manifested itself as various kinds of limb deformities, including missing limbs and limb segments, identical to the full range of limb abnormalities present in field collected Bufo (figure 46).
Figure 43. Nymph-induced, permanent missing limb deformity (note no obvious signs of scarring) in metamorphic toad. Photograph by Brandon Ballengée.

Figure 44. Deformed hind limbs in wild-caught *B. bufo* tadpoles (top row) compared with hind limb deformities in tadpoles (bottom row) induced by selective predation by captive dragonfly nymphs. Note protruding bone in the tadpoles second from left end in each row. Published in Ballengée and Sessions 2009.

8.6.6. Post-Mortem Analysis of Field-collected, Deformed Anurans

Imaging and visual analysis of 36 (35 toads//1 frog) total cleared and stained deformed anurans collected at the Havercroft site in 2006 were performed in 2008. Several subtle deformities, which included asymmetry of pelvic girdle (figure 51), long bones, and several others, were found that were not visible prior to chemical treatments. Such non-obvious, minor abnormalities closely resembled toads injured by nymphs in experiments, including those with cartilaginous spikes. All severe and minor abnormalities were found in the hind limb region, with no deformities found among the upper regions such as the cranium or forelimbs, suggesting prior injuries to back limbs by predators. In addition, no parasitic
cysts from trematodes were encountered in analyses, further suggesting mechanical perturbation by Odonate nymphs or other predators as a plausible explanation for deformities among wild populations of anurans at the Havercroft study site.

Figure 45. Scan of cleared and stained Common toad collected from Havercroft, 25 June 2006. Complete missing hind limb and ischium. Note asymmetry of pelvic girdle.

8.7. Conclusions from Findings

The results of these studies suggest ecological findings important to the amphibian research community and provide evidence that participatory biology programs (involving the public) can make viable contributions to science.

Solely from the scientific perspective, the data collected from field and laboratory studies demonstrated that predation was a major source of traumatic injury to developing hind limbs in larval anurans, which often resulted in the permanent deformities (loss of limb regions, full limbs, or sometimes even both hind limbs) at the time of metamorphosis. This was an important insight into an ecological phenomenon of deformed amphibians that had not previously been well explored. As discussed in the previous chapter, past attempts were unable to identify underlying causes for such missing-limb deformities in the wild.

Secondly, this work identified a specific group of predators that appeared to favour developing limbs in anurans: dragonfly nymphs, especially *Sympetrum* sp. Without exception,
these Odonate nymphs practiced selective predation in which they ate no more than a portion of the tadpole. Subsequent regenerative response in surviving tadpoles produced abnormal morphologies in the peri-metamorphic toads that were identical to wild-caught, abnormal metamorphic toads, found at Havercroft and other field sites. The resulting array of deformities appeared to encompass the range of limb deformities most commonly found in natural populations of anurans internationally (i.e. those that are associated with reduced or missing hind limbs, as discussed in chapter 7).

Within the context of the overall research topic of this dissertation, the findings of these studies along with additional evidence were presented in the paper ‘Explanation for Missing Limbs in Deformed Amphibians’ (co-authored with my advisor Stanley K. Sessions) and accepted into the peer-reviewed publication *Journal of Experimental Zoology* in 2009 (Ballengée and Sessions 2009, in appendix). The acceptance and publication of the paper resulting from this research suggested strongly that participatory biology programs, which involved field and laboratory work conducted with the aid of volunteers, may produce viable scientific data and that such studies may be important means to involve the public in larger amphibian conservation efforts.

In short, public participants (non-science specialists) aided in the identification of a local problem, utilized rigorous scientific methods to explore this issue, and found significant insights into a regional and potentially larger ecological phenomenon, gaining a better understanding of amphibians and their ecosystems in the process. As such these actions are attuned with transdisciplinary approaches as put forward by Mittelstraß and Gibbons et al. (1994) They also provide an underlying reasoning for participatory science as suggested by Irwin, Miller-Rushing et al. (2012), and others.

In conclusion the primary research conducted within my transdisciplinary art and participatory biology *Eco-Actions* and *Public Bio Art Laboratory* resulted in important ecological insights into the problem of deformed amphibians. These findings were disseminated to the larger scientific community and have continued to have an impact. Since these findings were published, more than a dozen related studies have emerged to offer a growing body of research evidence that has suggested hind-limb deformities featuring missing hind limbs and limb segments in wild-caught anurans are the result of natural regenerative responses to traumatic injuries from selective predation, a relevant ecological insight.

### 8.8 Unanswered Questions

Although this case study provided evidence for the belief that data collected during participatory science programs could provide new knowledge of ecological phenomena, numerous unanswered questions arose. Firstly, could the variation in the incidence of such anuran deformities involve changes in population densities of predators, or perhaps even of the tadpoles themselves in the context of extremely complex ecosystems? Sites where predation was occurring at preternatural rates indicate other ecological factors favouring predators, for example, some species of dragonflies. As the highest frequency of deformities found in these studies occurred at sites exposed to organic pollution (from agriculture and
residential run-off), could this factor have effected changes in the natural food web between tadpoles and their predators? Were the predation-induced frog deformities specific to Yorkshire, or could these represent a larger international ecological phenomenon? These questions and others were the impetus for the further amphibian studies conducted in southern Quebec and will be discussed in the next chapter.
Chapter 9. Case Study IV: The Occurrence and Causes of Amphibian Deformities at Selected Localities in Southern Quebec

This chapter presents as a case study the scientific research that followed the middle-England experiences described in the previous chapter. In these participatory programs, fewer public participants were involved, but participants contributed over longer periods of time. Because of this, a more in-depth analysis of the occurrence, ratios, and potential causes for deformities among natural populations of anurans at select localities in southern Quebec was performed. Many questions arose along the way: Are these recent deformities occurring at beyond natural levels? What role could predatory dragonfly nymphs and some fishes have in inducing limb (and other) deformities in post-metamorphic anurans? Are such intra-specific tadpole predation pressures increased as ecological quality of wetlands declines? Do these findings offer an underlying explanation for deformities not explored in prior research in the region? Were the insights from this participatory research program valuable to the larger amphibian research community?

9.1. Introduction

In this final case study, I will further demonstrate the means by which science was performed with the aid of public volunteers in my Quebec Eco-Actions and Public Bio-Art Laboratory. The results of these dual art-science programs contributed original and relevant insights about amphibians and their ecosystems to the field of primary research biology. This is further evidence to suggest that transdisciplinary art and participatory biology activities can make contributions to science.

As with the prior amphibian studies conducted in England, these Quebec field and laboratory studies sought to better ascertain the ecological phenomenon of anuran deformities through rigorous scientific analysis. Aligned with approaches of transdisciplinarity as suggested by Gibbons et al. (1994), inquiries addressed the localized ecological problem of high regional frequency of amphibian malformations, and studies involved working with local volunteers (non-science specialist members of the public) to unravel this issue.

In addition, controlled experiments were conducted in the open environment of a Public Bio-Art Laboratory installed within a cultural venue,238 which facilitated visitor understanding of the regional phenomenon of elevated levels of malformed frogs.239 This approach aligned with participatory science facilitating public environmental education, as Funtowicz and Ravetz (2003), Kapoor (2001) and others have noted and as discussed previously. At a larger civic level these Quebec citizen science programs and primary research were facilitated through grants from the Canadian government as well as from local cultural and scientific organizations.240

The high incidence of deformed frogs and toads in southern Quebec was the proximate reason for making this a study region. As discussed in chapter 7, studies in the

238 At Société des Arts Technologiques in Montréal, Quebec.
239 As discussed in chapter 6
240 This research was funded by Environment Canada, Société des Arts Technologiques, the Biology Department, McGill University, the Biology Department at Hartwick College, and the Sun River Nature Center.
1990s by Bonin et al. (1997) and Ouellet et al. (1997) found the region to be a ‘hotspot’ for such malformations. Although agrochemicals were nominated by Bonin et al. (1997) and Ouellet et al. (1997) as a likely reason, definitive causes remained elusive. Under my new studies in this region, I utilized and adapted methods from the prior UK studies to focus on predators as well as complex ecosystems influenced by agricultural and urban activities.

To conduct these studies, my role was again that of a primary investigator conducting research science but also as an environmental educator in the training of volunteers. In this case I worked with fewer number of trainees in order to insure that they received a more in-depth understanding of local amphibians, scientific methods, and ecology in general. Once again these experiences inspired my own artistic responses (chapter 5).

9.2. Background to Study

Since the 1990s southern Quebec has been considered a region of anuran deformity ‘hotspots’ (chapter 7; Bonin et al. 1997; Ouellet et al. 1997; Lannoo 2008). However, in spite of prior research efforts to clarify a reason for this phenomenon, an underlying cause for such high numbers of malformed frogs remained elusive. In response, during two field seasons (2009–2010) I investigated the incidence of morphological deformities and injury among natural populations of anuran amphibians representing all age classes at selected southern Quebec wetlands.

In an effort to test for potential impacts to amphibian health from wetland habitat quality, two categories of field sites were chosen: ‘degraded sites’ directly exposed to potential agricultural or residential runoff sources (e.g. direct drainage from cornfields, parking lots, others), and ‘pristine sites’ that had no direct exposure or very limited risk of agricultural or residential runoff (e.g. nature reserves). Once again visual examinations were performed on site with all age classes of frogs and toads collected, through VAFID with core study volunteers during Eco-Actions.

In addition, following the findings of the prior UK work, the potential role that predatory larval Odonates and other predators played in causing anuran deformities and injuries were investigated through laboratory studies. Such experiments between tadpoles and selected aquatic predators were conducted in the transparent format of a Public Bio-Art Laboratory established at Société des Arts Technologiques (SAT) in Montréal, Quebec. Correspondingly, attempts were made to estimate predatory densities at field sites. Laboratory analysis and parasitic assays were performed on deformed frogs, including post-fixed clearing and staining and necropsies.

I was awarded the title of Visiting Scientist at McGill University, under the employment of David M. Green, director of the Redpath Museum.
9.3. Roles of Volunteers in This Research

During two consecutive field seasons (2009–2010), a small core group of volunteers participated in the Quebec primary studies through the Eco-Actions and a Public Bio-Art Laboratory (chapter 6). This decision was based on my prior experiences in England, where great numbers of people participated in programs but I spent a tremendous amount of time training and organizing, while very few participated in more than a single field trip or laboratory activity. For the Quebec study this involved a preliminary screening of applicants, with those that were chosen moving on to receive in-depth training in amphibian observation, handling, and wetland analysis techniques. The core group helped collect and record data in both field and laboratory settings as well as documenting the entire program. These volunteers also conducted outreach about studies and amphibians when visitors came the lab, created their own artistic reflections, and participated in early analysis of data.

9.4. Materials and Methods

This study involved field observations and laboratory experiments focused primarily on four native Quebec anuran amphibians: North American Green frogs (L. clamitans), North American bullfrogs (L. catesbeianus), Northern Leopard frogs (L. pipiens), and North American woodfrogs (L. sylvaticus). Pickerel frogs (Lithobates palustris), Spring peepers (Pseudacris crucifer), Gray treefrogs (Hyla versicolor) and North American toads (A. americanus) were also analyzed, along with their predators. Field observations were complemented by laboratory experiments, which utilized larval anurans in controlled predation experiments with several different tadpole predators. Laboratory analyses were also performed to primarily test for Ribeiroia trematode cysts in field-collected, deformed frogs.

9.4.1. Field Observations

Anuran amphibians (representing all age classes) were sampled from eight pre-selected wetlands242 in southern Quebec (2009–2010), to determine the occurrence of injury and deformities in populations of free-living, native Quebec amphibians. These sites included both permanent and temporal (vernal) wetlands, chosen based on site characteristics from ‘pristine’ and compared with those that were categorized as ‘degraded’. All sites fell within a small geographic range of less than 100 square km. Each site was visited three times (within 5 weeks over the course of 15 total weeks) to monitor for ontogenetic changes in frequencies of anuran abnormality and injury each season. Field sampling was conducted through dip and seine-netting techniques and timed in 15-minute intervals, averaging three human-hours per visit per site. Green frogs were monitored as a ‘control’ anuran species, since they were found at all field sites and accounted for the majority of amphibians sampled. These field investigations, contextualized as Eco-Actions, were conducted with my core group volunteers.

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242 Primary sites were selected after early spring 2009 pilot studies based on environmental characteristics and viable populations of anuran amphibians. Of selected primary study sites, some had multiple collection areas (as some wetlands had more than one collection location and differing inflow origins of water).

243 Please see Ballengée and Green 2010, 2011 in appendix materials for detailed diagrams and site characteristics of primary study sites.
who underwent preliminary training, as most had little to no prior experience in amphibian research.

All sampled anurans were carefully examined (utilizing jeweller’s glasses to perform VAFID) and scored for obvious signs of injuries and deformities (following the criteria in table 3 in appendix; please also see appendix for field collection data sheets). Small numbers of injured specimens were collected and reared in laboratory conditions to monitor and document healing and any regeneration. Most animals were released following examination, except for small numbers of severely injured or deformed specimens. Severely deformed specimens were photographed and fixed in a 10% buffered formalin solution, and most were later cleared and stained for further analysis (Sessions and Ruth 1990). Additional ‘normal’ specimens were collected (only during the 2010 field season) for parasitic assay from sites where deformed frogs featured super-numeric limb structures.

The presence of potential tadpole predators, vertebrate and invertebrate, was recorded at each site per sampling event. Attempts to estimate predator population densities, such as Odonate nymphs and some fishes, were made at each sampling event. We used three techniques to do this: mark-and-recapture surveys of late instar dragonfly nymphs (primarily of Green darners) and other species; one-meter transect sweeps utilizing seine nets modelled from McCauley et al. 2008; and lastly, observational recording based on total number of predators collected with all sampled anurans, a method utilized successfully in prior UK studies by the author (Ballengée and Sessions 2009). Small numbers of voucher Odonate nymphs and other predators were collected per visit and preserved in a 90% ethanol solution for later positive identification by Ethan Bright of the University of Michigan (please see Bright report in appendix materials).

9.4.2. Experimental Simulations

Numerous experimental simulations were conducted to examine the role that potential aquatic predators played in injury-induced deformities in metamorphic anurans. We exposed four Ranid species (\textit{L. catesbeianus}, \textit{L. clamitans}, \textit{L. pipiens}, \textit{L. sylvaticus}) at different developmental stages and in varied group sizes to several species of aquatic predators (those occurring naturally at field sites) in experiments. Based on the results of the author’s prior research (Ballengée and Sessions 2009), predatory Odonate nymphs were a group of central focus. The entirety of these experiments were conducted open to the public within the SAT Public Bio-Art Laboratory. My core group of volunteers aided in animal care, maintenance, recording observations, and even offering insights into the design of some sets, even though the vast majority of the volunteers had no special prior training in science.
9.4.3. Selective Predation Experiment 1 (Lithobates sylvaticus//Aeschna umbrosa)

A total of 200 Woodfrog tadpoles representing Gosner stages 32–38 were collected from a vernal wetland in Grand Bois of Mont-Saint-Gregoire, Le Haut-Richelieu Regional County, Quebec (2009-20/10 Study Site 3). This site was selected because it contained a high density of Woodfrog tadpoles, and several hundred could easily be collected via dip-net in less than an hour. Although more than 5% of sampled field specimens displayed injuries or deformities, 200 were selected that showed no evidence of severe injuries or deformities for use in experiments. Tadpoles were kept for observation in indoor tubs with 20 l aged water for 4 days and were fed fish-food flakes daily to minimize any potential competitive injuring effects such as auto-predation. Removal of faeces and 10% water changes occurred daily prior to feeding. After initial observations and acclimation, tadpoles were sorted and grouped according to Gosner staging. Any tadpoles with previously unnoticed injuries or other abnormalities were rejected along with tadpoles at stage 31 or earlier or stage 39 or later. Remaining tadpoles (stages 32–38) were retained for experiments and kept at ambient room temperatures (24–26 °C) in groups of 10, with a natural daylight/night cycle, in acrylic tubs filled with 5 l aged water for 24 hours prior to experiments. Feeding and cleaning methods continued daily. One hundred twenty tadpoles were utilized in primary experiments with 50 remaining as controls.

A total of 23 Shadow darner dragonfly nymphs (Aeschna umbrosa) were collected from the same collection site as the Woodfrog tadpoles. This site was selected because of the presence of dragonfly nymphs and because deformed and freshly injured tadpoles and newly metamorphic Woodfrogs had been found in prior visits. Dragonfly nymphs were grouped according to estimated developmental instar based on size and wing development. Each of a total of 17 individuals from the same stage were placed in individual containers with 5 l aged water and kept at ambient room temperature with a 50% daylight/night cycle. Enclosures contained a thin layer of dead leaves collected from the wetland; leaves were scrubbed, rinsed, and dried, then re-hydrated before placement in experimental tanks to reduce risk of potential introduction of other aquatic species (e.g. aquatic snails via egg cases and others). Leaves were used to mimic natural conditions, creating habitat and keeping the water slightly acidic (pH 4.5–5) throughout the experiment. Nymphs were separated to prevent cannibalism and maintained by feeding one young Woodfrog tadpole (less than Gosner stage 31) every 24 hours. Twelve of the nymphs were selected for the experimental groups and five were reserved as controls or potential replacements.

The 12 experimental nymphs were deprived of food for 48 hours prior to introduction of Green frog tadpoles. Ten Woodfrog tadpoles were then added to each tank containing a single hungry nymph. Simulations ran for 10 days in which fatalities and injuries were documented and noted daily. Lethally injured tadpoles and remains from all tanks were described, photographed, and fixed in 10% buffered formalin. Non-lethally injured tadpoles with severe visible trauma to the limb(s), abdomen, cranium, or tail (if severe enough that less than 50% of tail remained), were removed, described, photographed, and placed in isolated tanks containing 1 l aged water, fed and cleaned daily to allow tadpoles to continue to develop post-injury. Post-injury tadpoles were allowed to develop until tail absorption or natural
death, at which point they were described, euthanized in MS222, photographed, and fixed in 10% buffered formalin.

9.4.4. Selective Predation Experiment 2 (Lithobates sylvaticus/Culaea inconstans)

A total of 97 Woodfrog tadpoles representing Gosner stages 32–38 were collected from 2009–2010 Study Site 3 (the same collection site as Experiment 1). Tadpoles were kept for observation in indoor tubs with 20 l aged water for 4 days and were fed fish-food flakes daily to minimize any potential competitive injuring effects such as auto-predation. Removal of faeces and 10% water changes occurred daily prior to feeding. After initial observations and acclimation, tadpoles were sorted and kept in aquariums with 75 l aged water at ambient room temperatures (24–26 °C), in groups of 20 with a natural daylight/night cycle for 24 hours prior to experiments. Feeding and cleaning methods continued daily. Eighty tadpoles were utilized in primary experiments with 17 remaining as controls.

A total of 12 adult Brook stickleback (Culaea inconstans) were collected from the same study site where the Woodfrog tadpoles were collected. This site was selected because of moderate numbers of Brook stickleback during prior sampling events, and because deformed and freshly injured tadpoles and newly metamorphic Woodfrogs had been found at the site on a prior visits. Brook stickleback were placed in individual containers with 10 l aged water and kept at ambient room temperatures with a 50% daylight/night cycle. As with treatments in Experiment 1, enclosures contained detritus to mimic natural conditions (pH 4.5–5) throughout the experiment. Stickleback were separated to prevent intraspecific aggression and were maintained by feeding on small portions of live tubifex species worms daily. Four of the fish were selected for the experimental groups and eight were reserved as controls or potential replacements.

The four experimental fish were deprived of food for 24 hours prior to being introduced to tanks with Woodfrog tadpoles. Simulations ran for 10 days in which fatalities and injuries were documented and noted daily. Lethally injured tadpoles and remains from all tanks were described, photographed, and fixed in 10% buffered formalin. Non-lethally injured tadpoles with severe visible trauma to the limb(s), abdomen, cranium, or tail (if severe enough that less than 50% of tail remained), were photographed daily and remained in experimental tanks for the duration of the experiment. Tadpoles and fish were euthanized in MS222, photographed, and fixed in 10% buffered formalin following the 10-day experiment.

9.4.5. Selective Predation Experiment 3 (Lithobates clamitans/Sympetrum costiferum)

A total of 35 Green frog tadpoles representing Gosner developmental stages 26–30 were collected from the same permanent wetland utilized in Experiment 1 (2009 Study Site 1). Tadpoles were kept for observation in indoor acrylic tubs with 5 l aged water for 3 days and were fed fish-food flakes daily to minimize any potential competitive injuring effects such as auto-predation. Removal of faeces and 10% water changes occurred daily prior to feeding. After initial observations and acclimation, tadpoles were divided into seven groups of five tadpoles per container. The tadpoles were kept at ambient room temperatures with a
natural daylight/night cycle in acrylic tubs with 5 l aged water for 24 hours prior to experiments. Feeding and cleaning methods continued daily. A total of 25 tadpoles were utilized in primary experiments with 10 remaining as controls.

A total of 10 Saffron-winged meadowlark nymphs (*S. costiferum*) were collected from McGill University’s Lake Hertel, Gault Nature Preserve (2009/10 Study Site 7). This site was selected because moderate numbers of Saffron-winged meadowlark nymphs were collected during each sampling event and deformed/injured tadpoles were found at the site in prior visits. Dragonfly nymphs were grouped according to estimated developmental instar based on size and wing development. Each of a total of five individuals from the same stage were placed in individual containers with 5 l aged, and mechanically aerated, water, and kept at ambient room temperature (24–26 °C) with a 50% daylight/night cycle. Enclosures contained one sprig of Bushy pondweed (*Najas* species) for partial habitat creation. Nymphs were separated to prevent cannibalism and maintained by feeding one young Green frog tadpole (less than Gosner stage 31) every 48 hours. Five of the nymphs were selected for the experimental groups and five reserved as controls or potential replacements.

The five experimental nymphs were deprived of food for 48 hours prior to introduction of young Green frog tadpoles. Five tadpoles were then added to each tank containing a single hungry nymph. Simulations ran for 10 total days in which fatalities and injuries were documented and noted daily. Lethally injured tadpoles and remains from all tanks were described, photographed, and fixed in 10% buffered formalin. Non-lethally injured tadpoles with severe visible trauma to the limb(s), abdomen, cranium, or tail (if severe enough that less than 50% of tail remained), were removed, described, photographed, and placed in isolated tanks containing 2 l aged mechanically aerated water, were fed and had tanks cleaned daily to allow tadpoles to continue to develop post-injury for up to 120 days. Surviving tadpoles were monitored for healing/regeneration for 120 days at which point they were described, euthanized in MS222, photographed, and fixed in 10% buffered formalin.

9.4.6. Selective Predation Experiment 4 (*Lithobates clamitans/Anax junius*)

A total of 139 Green frog tadpoles representing Gosner developmental stages 32–41 were collected from a permanent wetland in Brome-Missisquoi Regional County Municipality, Quebec (2009 Study Site 1). This site was selected because it contained a moderate population of Green frog larvae that could be collected easily via seine-net, and fewer than 5% of the sampled specimens displayed severe injuries or deformities. Tadpoles were kept for observation in indoor acrylic tubs with 20 l of aged water for 5 days and were fed fish-food flakes daily to minimize any potential competitive injuring effects such as auto-predation. Removal of faeces and 10% water changes occurred daily prior to feeding. After initial observations and acclimation, tadpoles were sorted and grouped according to Gosner stages. Any tadpoles with injuries or other abnormalities were rejected along with tadpoles at stage 31 or earlier and those at stage 42 or later. Remaining tadpoles (stages 32–42) were subdivided into two sets according to developmental stage: Experimental Group 1 (stages 32–36), and Experimental Group 2 (stages 37–41). The two sets of tadpoles were kept at ambient room temperatures with a natural daylight/night cycle in acrylic tubs with 20 l aged water for
48 hours prior to experiments. Feeding and cleaning methods continued daily. A total of 100 tadpoles were utilized in primary experiments with 20 remaining as controls.

A total of 32 Green darner dragonfly nymphs (A. junius) were collected from a permanent fish-free residential wetland (2009/10 Study Site 8). This site was selected because of the large population of Green darner nymphs (20+ per 2 meter by 1 meter seine-net), and because deformed/injured tadpoles and metamorphic specimens were found at the site during prior visits. Dragonfly nymphs were grouped according to estimated developmental instar based on size and wing development. Each of a total of 25 individuals from the same stage were placed in individual containers with 10 l aged mechanically aerated water and kept at ambient room temperature (24–26 °C) with a 50% daylight/night cycle. Enclosures contained one artificial branch (30 cm. length), a 1 cm. layer of aquarium gravel, and 5 sprigs of Bushy pondweed (Najas sp.) for partial habitat creation. Nymphs were separated to prevent cannibalism and were fed one young Green frog tadpole (less than Gosner stage 31) every 48 hours. Twenty of the nymphs were selected for the experimental groups and 12 were reserved as controls or potential replacements.

The 20 experimental nymphs were deprived of food for 72 hours prior to introduction of Green frog tadpoles. Ten experimental nymphs were selected to feed on the younger Green frog tadpoles (Set 1, stages 32–36) and 10 were selected to feed on the older tadpoles (Set 2, stages 37–41). Five tadpoles were then added to each tank containing a single hungry nymph. Simulations ran for 10 days in which fatalities and injuries were documented and noted daily. Lethally injured tadpoles and remains from all tanks were described, photographed and fixed in 10% buffered formalin. Non-lethally injured tadpoles with severe visible trauma to the limb(s), abdomen, cranium, or tail (if severe enough that less than 50% of tail remained), were removed, described, photographed, and placed in isolated tanks containing 5 l aged mechanically aerated water, fed and cleaned daily to allow tadpoles to continue to develop post-injury. Post-injury tadpoles were allowed to develop until tail absorption or natural death, at which point they were described, euthanized in MS222, photographed, and fixed in 10% buffered formalin.

9.4.7. Post-mortem Analyses

During the field season 2009–2010, attempts were made to further analyse the degree of morphological abnormality and potential proximate cause(s) among small numbers (n=less than 200) of severely deformed and injured anuran specimens collected from field sites. Specimens were divided into two groups for varied analysis. The first group was made up of those sacrificed as standard preserved study vouchers, of which a subset were cleared and stained (methods by Stopper et al. 2002) for the collection of the Redpath Museum, McGill University. Cleared and stained specimens were imaged using high-resolution microscopy for parasitic cyst screening at the Flux Media Laboratory (an arts and technology program) at Concordia University. The next group was sacrificed for parasitic assay conducted at the Fluvial Ecosystem Research Section part of the Aquatic Ecosystem Protection Research Division of Environment Canada (Montréal, Quebec) primarily examining for the presence of the trematode, R. ondatrae.
9.5. Results of Field and Laboratory Studies

9.5.1. Field Observations

During the field seasons 2009–2010, a total of 10,189 amphibians\textsuperscript{241} of varied age classes were examined for injuries and deformities from primary study sites. Of these, 9,974 (97.9\%) were anurans and represented 8 native species (\textit{L. clamitans}, \textit{L. catesbeianus}, \textit{L. palustris}, \textit{L. pipiens}, \textit{L. sylvaticus: crucifer}, \textit{H. versicolor}, and \textit{A. americanus}). Green frogs were the most commonly found species in our 2009–2010 surveys, representing 65.8\% (\textit{n}=6,566) of all anurans sampled, followed by 2,229 American toads, 572 Woodfrogs, 140 Northern Leopard frogs, and small numbers of other species (please see Ballengée and Green 2011 for details). Anuran specimens were divided by the following age classes: Early/middle tadpoles between (Gosner stages 30–35); Older tadpoles (Gosner 36–41); peri-metamorphic/metamorphic (Gosner 42–46); and juvenile/adult anurans (post–Gosner 46). Totals examined of the varied age classes included: 3,200 early/middle tadpoles; 2,861 older tadpoles; 3,523 peri-metamorphic/metamorphic anurans; and 390 juvenile/adult anurans. The majority of anurans sampled (35.3\%) were peri-metamorphic/metamorphic frogs and represented a ‘target’ age group from my own prior UK deformed amphibian studies (Ballengée and Sessions 2009).

The core group of volunteers during these Eco-Actions averaged one trip per person per week for 12 total weeks. Without their dedication, perseverance, and hard work ethic, these studies would not have been possible. Of these initial ten members, nine remained for the full duration of the project. Their responses to these experiences and my own responses to working with such a core group was presented in chapter 6.

9.5.2. Results of Anuran Injury Rates at Study Sites

Late-stage tadpoles exhibited the highest overall frequency of obvious injuries at 73\% out of 2,861 examined combined species and sites for both years. This was followed by younger tadpoles, which exhibited an injury frequency of 59.8\% of 3,200 examined. The most common obvious traumas to tadpoles of both age-classes were to the tails, frequently seen with minor rips and tears to the caudal fins. Severe tail injuries were also observed that included greater than 75\% loss of the tail, similar to those resulting from predatory attacks in prior studies (Ballengée and Sessions 2009). Several tadpoles were found to have had one or both hind limbs or limb buds damaged or fully removed. Injuries also occurred to the eyes, cranial/facial region, and abdomens (detailed breakdowns of injuries can be seen Ballengée and Green 2010, 2011 in appendix materials). Among 3,523 peri-metamorphic/metamorphic frogs, 14.3\% were found injured, which included both minor and severe traumas to the hind limbs (even full limbs removed), forelimbs, digits, eyes, cranial/facial, abdominal punctures,

\textsuperscript{241} Wild-collected amphibians totalling 10,189 (9,994 anurans, 195 caudates) were observed during the 2009–2010 field seasons. Of these, 9,974 anurans came from primary study sites and an additional 20 anurans were observed in pilot studies of sites not included in overall data, as sites were not chosen based on varied grounds (for details please see Ballengée and Green 2010). Please note data collected on injury and deformity ratios among caudates is not included in this chapter but included in Ballengée and Green 2010,m 2011.
scratches, abrasions, reddening, and overall swelling. For juvenile/adult frogs, 36.8% exhibited signs of trauma, the vast majority being minor injuries such as reddening, scratches, abrasions, and freshly removed hind and forelimb digits. The only severe injury for this age-class was a single juvenile Northern Leopard frog found with both hind feet and associated tissues freshly removed.  

The frequency of injuries among all age-classes and species combined were higher at field sites we deemed degraded in comparison to collections at more pristine sites. Of observed anurans (n=5,065) at four degraded field sites, 43.1% exhibited obvious signs of injury during sampling events compared with 41.7% of those (n=4,909) from four pristine sites. Although not statistically significant, this slight increase may indicate that as environmental quality of wetlands declined, frequency of injury appeared to be more prevalent. It is also important to note that these numbers reflect overall rates of injury among all anuran species, and using this method may not be effective for accurate comparisons, as not all species occurred at each site. Overall diversity of anuran species at pristine sites was much higher (more than three-fold at some sites) than at field sites deemed as degraded (presented in Ballengée and Green 2011 in appendix). Injury ratios may appear very high, as some tadpoles of certain species (e.g. Gray treefrogs, Spring peepers, and Woodfrogs) are known naturally to have high injury rates as larvae; likewise, scoring Bufo larvae for injury is notoriously difficult because of their rapidly regenerating integument skin (Ballengée 2009; Ballengée and Sessions 2009).

Utilizing 2009–2010 field data only on Green frogs (n=6,566) further confirmed that environmental quality may have an effect in injury frequency. Green frogs sampled from pristine wetlands (n=3,344) had significantly fewer frequencies of injury at 47.96% compared with 59.03% of those observed at degraded sites (n=3,222) during 2009–2010. This trend was seen consistently in both field seasons, as injury rates at pristine sites in 2009 were 47.3% of 2,059 examined, and 49% of 1,285 examined in 2010. In comparison, frequencies of injury at degraded sites were 56.5% out of 2,128 in 2009 and 64% out of 1,094 examined in 2010. As ratios of injury are lacking from prior reports of the region, this important finding suggests that as wetland quality decreases, ratios of injury increase among anurans (at least among Green frogs).

Since young tadpoles would have less potential long-term exposure to environmental factors (e.g. parasites, predators, agricultural run-off), and because juvenile and adult frogs may migrate to and from study sites (so injuries may have occurred elsewhere), Green frogs of two age classes, late-stage tadpoles and peri-metamorphic/metamorphic (n=1,092), were further analyzed with similar results. Here 65.5% of 493 late-stage tadpoles sampled were found with some sign of injury at pristine sites compared with 79.7% of 991 observed at degraded wetlands. This finding is similar among peri-metamorphic/metamorphic Green frogs but less pronounced, where of 540 observed at pristine wetlands, 22.8% were injured compared with 25.4% of 1,210 sampled at degraded sites (figure 55). Overall ratios of obvious injury were less varied among peri-metamorphic/metamorphic Green frogs at pristine wetlands. This specimen was kept alive and observed at the laboratory for several weeks. Although the frog healed remarkably from the severe wounds, no regeneration of feet or hind digits occurred. Rapid tissue growth quickly sealed gaps in the epidermis, and within a few weeks all inflammation and reddening disappeared. This left the frog with hind limbs that had permanent abnormalities but were partially functional (photographs available upon request).
sites compared to those at degraded sites, but gauging obvious signs of injury among this age-
class are somewhat unpredictable; anurans during this stage undergo rapid development, and
healing can easily mask prior signs of perturbation (Sessions and Ballengée 2010a, b).

Figure 46. During the 2009–2010 field seasons, 20.3% of 991 total older Green frog tadpoles at degraded wetlands showed no
obvious signs of injury compared with 33.5% out of 493 found at wetlands characterized as pristine. Likewise, incidence of
injury among peri-metamorphic/metamorphic Green frogs was higher at degraded wetlands: 25.4% out of 1,210 sampled,
compared to 22.8% out of 540 examined from wetlands deemed as more pristine.

9.5.3. Results of Anuran Deformity Rates at Study Sites

Four hundred fifty-nine deformed individual anurans were found (4.6% of 9,974
examined) and represented five species (L. clamitans, L. palustris, L. pipiens, L. sylvaticus, and A. americanus) during the 2009–2010 studies. Of these, peri-metamorphic/metamorphic anurans (representing all species) exhibited the greatest frequency of abnormal\textsuperscript{246} individuals at 9.9% (\textit{n}=348) out of 3,523. Juvenile and adult frogs exhibited an overall minor deformity (primarily missing or abnormal digits) ratio of 10.3% in 2009 and increased to 10.9% in 2010, out of 390 total observed. During both field seasons, the vast majority of deformities occurred
to the hind limbs and varied in degrees of severity (please see Ballengée and Green 2010,
2011 for breakdowns of types in each season). As with injuries, deformity ratios were higher
at sites deemed as degraded compared with those characterized as more pristine.

\textsuperscript{246} Abnormalities were both minor and severe, with the vast majority occurring to the hind limbs. Breakdowns of deformity types and frequencies are reported in Ballengée and Green 2010, 2011.
Combined 2009–2010 deformity ratios at pristine sites were significantly less, at 1.9% of 4,909 anurans sampled in comparison to 7.2% of 5,065 frogs from degraded sites. As reported in prior regional studies (e.g. Levey et al. 2003), overall deformity ratios were seen to fluctuate between field seasons at study sites: pristine sites exhibited a 2.4% deformity rate (of 2,535) in 2009 and 1.3% (of 2,374) examined in 2010; degraded sites exhibited 6.5% (of 2,311) in 2009 and 7.9% (of 2,754) in 2010 (Ballengée and Green 2010, 2011). In 2009/ and 2010 all sites characterized as degraded can be considered hotspots, as they were above the suggested baseline of less than 5% deformity ratio among all anurans and age classes recorded: Site 2 at 9.52% (2009) and 17.9% (2010); Site 5 at 15.4% (2009) and 7.2% (2010); Site 6 at 15.4% (2009) and 7.7% (2010); Site 8, 16.9% (2009) and 9.8% (2010). It is also important to note that three pristine sites fell within hotspot ranges during the 2009 field season, but did not during 2010: Site 3, 9.5% (2009) and 0.3% (2010); Site 4, 8.3% (2009) and 1.5% (2010); Site 7, 7.8% (2009) and 0.6% (2010). These seasonal changes in deformity frequencies exemplify the necessity of multi-year surveys for more accurate abnormality ratio assessments at field sites as suggested earlier by the author with Sessions (2010a, b). Our combined 2009–2010 field data nevertheless suggests that at sites with a higher degree of environmental compromise, ratios of anuran hind limb deformities were consistently higher compared with those with that were more pristine.

Utilizing 2009–2010 field data on peri-metamorphic/metamorphic Green frogs (n=1,750: as model anurans, of a target age class), we found similar results with an overall abnormality ratio of 10.7% (similar to the overall 9.9% out of 3,523 of all anurans of this age class sample). However, significant variation was seen in abnormality ratios among pristine sites in comparison to degraded sites. Overall abnormality rates at degraded localities were 13.1% (of 1,210) compared to 5.4% (of 540) sampled at pristine wetlands (figure 57). Combined 2009–2010 abnormality frequencies for each degraded site were the following: Site 2, 9.5% of 190 sampled; Site 5, 12.4% of 509 sampled; Site 6, 12.9% of 62 sampled; Site 8, 15.6% of 449 sampled. In comparison, 2009–2010 occurrence ratios at pristine sites were: Site 3, 0.0% of 4 sampled; Site 4, 9.1% of 22 sampled; Site 7, 6.4% of 188 sampled; Site 10, 4.6% of 324 sampled (figure 57). This data strongly suggests that as environmental quality of wetlands declined, deformity ratios increased among peri-metamorphic/metamorphic Green frogs.
The vast majority (85.6%) of deformities among peri-metamorphic/metamorphic age class Green frogs occurred to the hind limbs and mostly included missing limbs and limb segments. Other deformities among sampled frogs included 21 with one or more missing forelimb digits, 4 with missing eyes, and 2 with abnormally shaped lower jaws. The 161 frogs with missing limb deformities closely resembled those in our experimental simulations and prior studies on predatory injury caused by larval Odonates or some fishes (Ballengée and Green 2010; Sessions and Ballengée 2010a; Sessions and Ballengée 2010b; Bowerman et al. 2010; Ballengée and Sessions 2009). Several sampled young anurans were also found to have super-numeric digits in the hind limbs (n=8), a deformity diagnostic of *R. ondatrae* (Sessions and Ruth 1990; Sessions et al. 1999; Johnson et al. 1999; Ballengée and Green 2010).

Also of importance was that 14.2% of 359 juvenile and adult Green frogs examined during 2009–2010 exhibited minor deformities (the most common were missing digits to the fore or hind limbs, without obvious signs of prior trauma). Of Green frogs sampled at degraded sites, 15.9% of 145 exhibited deformities. Of those collected from more pristine wetlands, 13.1% were deformed out of 214 examined. Combined, 2009–2010 abnormality frequencies for each degraded site were the following: Site 2, 19.4% of 62 sampled; Site 5, 7.1% of 14 sampled; Site 6, 18.2% of 33 sampled; Site 8, 11.1% of 36. In comparison 2009–
2010 occurrence ratios at pristine sites were: Site 3, 0.0% of 14 sampled; Site 4, 12.5% out of 104 sampled; Site 7, 15.9% of 44 sampled; Site 10, 15.4% of 214 sampled. As adult and juvenile anurans may travel to and from wetlands, it is impossible to ascertain if prior injury resulting in permanent deformity occurred at our study sites. Nevertheless, our findings do suggest minor deformities increased among Green frogs of this age-class as wetland quality declined.

Data from sampled American toads in 2009–2010 further strengthen our finding that as environmental quality of wetlands declined, deformity ratios were increased. A total of 2,273 late-stage tadpoles (n=676) and peri-metamorphic/metamorphic (n=1,597) toads collectively were found at three of our field sites in 2009–2010. Among 407 late-stage tadpoles found at pristine wetlands (Sites 7 and 10) none exhibited obvious deformities, whereas 4.8% of 269 sampled at degraded Site 5 were found with deformities (even severe limb abnormalities which included supernumerary structures). Similarly, 9.2% of 1,430 peri-metamorphic/metamorphic toads found at degraded Site 5 were deformed, compared with only 1.2% of 167 toads of the same age class at pristine wetlands (Sites 7 and 10). Among deformed toads at Site 5, many were found with missing limbs and segments characteristic of Odonate nymph and other predatory injuries based on prior studies (figure 58; Ballengée and Sessions 2009). Additionally, several individuals were found to have supernumerary hind limb structures, including mirrored-limb duplications, supernumerary digits, skin webbing, and fusions (figure 59). Such severe deformities, along with others, are diagnostic of the trematode *R. ondatrae* (Sessions and Ruth 1990; Sessions et al. 1999; Johnson et al. 1999; Sessions 2003; Sessions and Ballengée 2010).
9.5.4. Results of Observations of Predators at Study Sites

Data on all anuran larval predators identified to be capable of inducing anuran deformities was collected at all field sites throughout the 2009 and 2010 field seasons (figure
To our knowledge, there is no standard commonly used technique for estimating Odonate nymph populations or other anuran larval predators that has yet been established for sites with varied environmental characteristics. To address this issue, we chose three techniques: 1) mark-and-recapture surveys of dragonfly nymphs, primarily of late instar Green darners (*A. junius*); 2) one-meter transect sweeps utilizing seine nets modelled from McCauley et al. 2008; 3) observational recording based on total number of predators collected with all sampled anurans, a method utilized successfully in prior studies by the author (Ballengée and Sessions 2009).

**Figure 50.** Total number of anuran tadpole prey (all species combined) averaged per visit compared with averaged total number of ‘missing limb’ tadpole predators found at all sites, 2009–2010. ‘Missing limb’ tadpole predators included adult Brook stickleback (*C. Inconstans*), larval Green darners (*A. junius*), and Shadow darners (*A. umbrosa*). Saffron-winged meadowlark (*S. Costiferum*) were a ‘target’ species when monitoring predator populations at our 2009–2010 field sites.

Although over 893 dragonfly nymphs were recorded at our study wetlands utilizing methods one and two, data were sporadic and insufficient to estimate population densities. Instead, method three proved the most useful, whereby all aquatic predators were counted when collected during anuran surveys. Subset counts were established for predators observed in laboratory simulations to induce ‘missing limb’ deformities in anurans (discussed below). Here 2,465 ‘Missing Limb’ (ML) tadpole predators were recorded with significant population variations observed between sites with varied environmental characteristics (figure 60). On average, sites characterized as pristine had significantly fewer ML predators, averaging 11.8 out of 6 total surveys at per site compared with 50.9 averaged out of 6 total surveys at each of the degraded wetlands (figure 60). Our data suggests that degraded sites’ populations of ML predators appeared to be higher. This offers a direct cause-and-effect explanation for why anuran larvae at degraded study sites have increased ratios of injuries and why young frogs at these sites more often had ML deformities compared to the same species found at more pristine wetlands.
In its entirety, this data suggested that ecological quality of wetlands appeared to be a factor for frequencies of predators, tadpole injury, and deformity level among young anurans (at least among Green frogs). Degraded wetlands showed higher frequencies of injured late-stage tadpoles, higher levels of Odonate nymphs (specifically *A. junius*), and increased levels of deformed peri-metamorphic/metamorphic frogs.

Pristine sites (Sites 3, 4, 7, and 10) had an average injury rate of 65.5% among 493 late-stage tadpoles sampled compared with 79.7% of 991 observed at degraded wetlands (Sites 2, 5, 6 and 8). Pristine sites, however, had significantly fewer *A. junius* nymphs, averaging 2.7% out of 6 surveys compared with 20.1% at degraded wetlands. Overall deformity ratios among young Green frogs at pristine sites was 5.2% out of 538 sampled compared with 13.1% of 1,210 sampled at degraded wetlands.

Our data on Green frogs of these age-classes suggests a direct correlation between decreased environmental quality resulting in higher numbers of injured tadpoles and young deformed frogs in association with increased populations of anuran larval predators.

### 9.5.5. Results of Experimental Simulations

Numerous experimental simulations were conducted involving anuran larvae and potential aquatic predators found at field sites. Preliminary experiments involved small numbers of *Rana* tadpoles representing four species (*L. catesbeianus, L. clamitans, L. pipiens, L. sylvaticus*) at different developmental stages and in a range of group sizes with the potential aquatic predators collected from survey sites. The predators included seven species of vertebrates: Jefferson salamander (*Ambystoma jeffersonianum*) larvae; Eastern newts (*Notophthalmus viridescens*) aquatic adults and larvae; Redfin pickerel (*Esox americanus americanus*) juveniles; Bluegill (*Lepomis macrochirus*) juveniles; Fathead minnow (*Pimephales promelas*) adults; Central mudminnow (*Umbra limi*) adults; Brook stickleback (*C. inconstans*) male and female adults. Invertebrate predators included: a crustacean (Virile crayfish, (*Orconectes virilis*) male and female adults; a beetle (Predaceous Diving beetle, *Dysticus* species) adults and larvae; a hemipteran bug (Giant water bug, family Belostomatidae) adults and juveniles; an annelid (Common North American leech, *Macrodella decora*) adults and juveniles; and seven species of masticating Odonate larvae, including the Green darner (*A. junius*, family Aeshnidae), Shadow darner (*A.a umbrosa*, family Aeshnidae), Swamp darner (*Epiaeschna heros*, family Aeshnidae), Twelve-Spotted skimmer (*Libellula pulchella*, family Libellulidae), Widow skimmer (*Libellula luctuosa*, family Libellulidae), Common whitetail (*Plathemis Lydia*, family Libellulidae), and Saffron-Winged meadowlark (*S. costiferum*, family Libellulidae). Most predators were observed injuring or maiming anuran larvae, but three species of Odonate and one fish appeared to consistently damage developing tadpole hind limb regions, resulting in permanent deformities among metamorphic frogs (table 11).
### Table 11.

<table>
<thead>
<tr>
<th>Predator</th>
<th>Anuran sp./Gosner stage</th>
<th>Exp. Con. pred/prey/# of sets</th>
<th>lethmal injurYNLI to tails injured</th>
<th>Non-lethal injury</th>
<th>NLI to hind limbs/buds</th>
<th>Resulting in hind limb deformity</th>
</tr>
</thead>
<tbody>
<tr>
<td>larval Ambystoma jeffersoniam</td>
<td>L. sylvaticus, (32-38)</td>
<td>1/20, 4 sets</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Larval/adult Notophthalmus viridescens</td>
<td>L. catesbeianus, (26-30) L. clamitans, (26-30)</td>
<td>1/10, 4 sets, 1/20, 4 sets</td>
<td>N/Y</td>
<td>N/N</td>
<td>N/Y</td>
<td>N/N</td>
</tr>
<tr>
<td>juv. Esox americans</td>
<td>R. clamitans, (32-36)</td>
<td>1/5, 4 sets</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>juv. Lepomis macrochirus</td>
<td>L. clamitans, (32-36)</td>
<td>1/5, 4 sets</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>adult Pimephales promelas</td>
<td>L. clamitans, (32-36)</td>
<td>1/5, 4 sets</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>adult Umbra limi</td>
<td>L. clamitans</td>
<td>1/5, 4 sets</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>adult Culaea inconstans</td>
<td>L. sylvaticus, (32-38)</td>
<td>1/20, 4 sets</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>adult Orconectes virilis</td>
<td>L. clamitans, (32-36) L. pipiens, (32-36)</td>
<td>1/5, 10 sets, 1/5, 5 sets</td>
<td>Y/N</td>
<td>Y/Y</td>
<td>Y/Y</td>
<td>N/N</td>
</tr>
<tr>
<td>larval/adult Dysticus sp.</td>
<td>L. clamitans, (26-30)</td>
<td>1/5, 3 sets/1/5, 3 sets</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>larval Anax junius</td>
<td>L. catesbeianus, (37-41) L. clamitans (32-36, 37-41)</td>
<td>1/5, 3 sets, 1/5, 10+10 sets</td>
<td>Y/Y</td>
<td>Y/Y</td>
<td>Y/N</td>
<td>N/Y</td>
</tr>
<tr>
<td>larval Aeschna umbrosa</td>
<td>L. sylvaticus, (32-38)</td>
<td>1/10, 12 sets</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>larval Epiaeschna heros</td>
<td>L. clamitans, (26-30)</td>
<td>1/5, 5 sets</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>larval Libellula pulchella</td>
<td>L. clamitans, (26-30)</td>
<td>1/5, 5 sets</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>larval Plathemis Lydia</td>
<td>L. clamitans, (26-30)</td>
<td>1/5, 5 sets</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>larval Sympetrum costiferum</td>
<td>L. clamitans, (26-30)</td>
<td>1/5, 5 sets</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>adult M. decora</td>
<td>L. catesbeianus, (37-41) L. clamitans (32-36, 37-41)</td>
<td>1/5, 4 sets, 1/5, 4+4 sets</td>
<td>Y/Y</td>
<td>N/N</td>
<td>N/N</td>
<td>N/N</td>
</tr>
</tbody>
</table>

Tadpole predators demonstrated in our 2009–2010 experiments capable of inducing both lethal and non-lethal injuries among varied anurans. Species (in bold) were demonstrated to induce limb-bud and limb injuries to tadpoles, resulting in permanent deformities among metamorphic anurans in 2009 experimental simulations (Ballengée and Green 2010; Sessions and Ballengée 2010b). Therefore, adult Brook stickleback (C. Inconstans), larval Green darners (A. junius), Shadow darners (A. umbrosa), and Saffron-winged meadowlark (S. Costiferum) were ‘target’ species when monitoring predator populations at our 2009–2010 field sites.

These experiments were conducted with the aid of the core group of volunteers at the
Public Bio-Art Laboratory established at SAT. Two volunteers were present at the lab 7 days a week for 12 total weeks, and on average volunteers worked 18.3 hours per week towards the project. The majority (80%) of volunteers worked in the laboratory with varied degrees of involvement in experimentation. As with the field studies, without the volunteers’ commitment and strong dedication to the project, this work would not have been possible. The reactions of these volunteers to these experiences and my own were presented in chapter 6 and in the video interviews in the appendix.

9.5.6. Results of Selective Predation Experiment 1 (Lithobates sylvaticus/Aeschna umbrosa)

Of 120 Woodfrog tadpoles (stages 32–38), 108 (90%) were injured by Shadow darner nymphs during experiments in 8 out of 12 tanks beginning within the first 48 hours after introduction of prey tadpoles. Nymphs were observed (and photographed) capturing tadpoles and chewing on selected body parts before releasing the tadpoles (figure 61). Recapture of injured tadpoles was occasionally observed, though it appeared nymphs were attracted more to movement in uninjured tadpoles than to less active, previously injured prey (often floating). Occasionally tadpoles were able to escape after being captured (‘predation attempt’), but this was more rarely recorded than successful capture followed by selective predation (e.g. of a limb or limbs) and release. Most nymphs continued to feed for several days, some for the entire duration of the experiment. Only 2 of the 12 nymphs did not feed at all. Full consumption of an entire Woodfrog tadpole was never observed in the tadpole/dragonfly interactions. Instead, nymphs performed selective predation. Non-lethal injuries included facial/cranial damage such as missing eyes, but the most common injuries were various degrees of damage to tails and hind limbs, including partial and sometimes full amputation of both hind limbs. Damage to developing limbs occurred frequently in tadpoles, suggesting that nymphs demonstrate a feeding preference on specific regions of tadpole bodies (figures 61, 62; figure 63 in appendix). Lethal damage most often included major injuries to the cranium and abdomen and/or the loss of greater than 75% of the tail (figure 62). Nymph-induced injury to the hind limbs generated the full range of missing limb deformities among perimetamorphic/metamorphic frogs (figure 64). Of the 50 control tadpoles, nine died, and minor injuries to tails occurred in few of the remaining animals, presumably made by other tadpoles. None of these specimens developed hind limb deformities at the time of metamorphosis.
Figure 51. Shadow darner dragonfly nymph *selectively predating* hind limbs in late-stage Woodfrog tadpole in experimental simulations. Note full removal of hind limb and surrounding tissue. Photograph by Brandon Ballengée.

Figure 52. Non-lethal injuries (Series 1) and lethal injuries (Series 2) among Woodfrog tadpoles predated by Shadow darner dragonfly nymphs in 2009 experimental studies. Note 45.13% of overall injuries involved the hind limbs.
Many of the tadpoles that survived dragonfly-induced injuries exhibited partial to complete regeneration of their tails and hind limbs. Regenerative response ranged from complete regeneration to partial regeneration to healing with no regeneration. By metamorphosis, this variation in regenerative response manifested itself as various types of limb deformities including missing limbs and limb segments, resembling field-sampled, deformed Woodfrogs. Types and rates of injuries and deformities observed in experiments were similar to those observed among wild frogs at study sites (figures 64, 65).
Figure 5.4. Ratios of injuries in wild-captured Woodfrog larvae from Site 3 (Series 1) compared with those injured in 2009 Shadow darner/Woodfrog laboratory experiments (Series 2). Note similarities in levels of hind limb injury (within 6%). Variation in frequency of recorded tail injury may be caused by different recording methods: wild Woodfrog larvae were scored for any injury to the tail whereas laboratory tadpoles were only scored daily for fresh injuries (e.g., bleeding).

9.5.7. Results of Selective Predation Experiment 2 (Lithobates sylvaticus/Culaea inconstans)

Of 80 Woodfrog tadpoles (stages 32–38), 33 (41.3%) were injured by sticklebacks during experiments in 3 out of 4 tanks beginning within the first 72 hours after introduction of prey tadpoles. Sticklebacks were observed (and photographed) repeatedly biting tadpole tails, heads, and hind limbs. Only one stickleback of four did not feed on tadpoles during the experiment. Remaining stickleback appeared to be attracted to tadpole movement, often attacking frog larvae as they swam to the surface. Repeated injury to tadpoles was observed, though it appeared stickleback would attack the most actively swimming tadpoles. Stickleback bites induced minor injuries, most often removing small portions of caudal fin, although two tadpoles received injuries to the eyes and five to hind limb digits. Total mortality among tadpoles with active stickleback was 61.3%, with 51 surviving to metamorphosis. Of these young surviving frogs, one had an abnormal eye (1.3%) and two had single missing hind limb digits (2.5%; figure 66). Of 19 control tadpoles, 2 died in enclosures and none exhibited deformities at the time of metamorphosis.
Figure 55. Top: Adult Brook stickleback from larval Woodfrog experiments. Left: Stickleback-injured late-stage Woodfrog tadpole. Right: Metamorphic Woodfrog healed with missing digits. Photographs by Brandon Ballengée.

9.5.8. Results of Selective Predation Experiment 3 (Lithobates clamitans/Sympetrum costiferum)

Twenty-four out of 25 young (stages 26–30) Green frog tadpoles (96%) were injured by Saffron-winged meadowlark nymphs during experiments in all tanks beginning within the first 24 hours following introduction of tadpoles. All nymphs were observed (and photographed) capturing tadpoles and eating selected body parts (mostly tails) before releasing them. No nymphs were observed fully consuming an entire tadpole. Recapture of injured tadpoles was rarely observed, as most tadpoles were killed or immobilized after initial attacks and removed shortly thereafter to allow for possible healing. Three tadpoles died immediately from cranial/bodily injury, with only sections of tails remaining. All remaining recorded tadpole injuries occurred to the tails and sometimes included the damage to the hind limb regions. Of those with tail injuries, only three individuals had more than 50% of their tails remaining following initial attacks. These three survived and partially regenerated their tails after 120 days in captivity with no obvious signs of damage to limb buds. Only four tadpoles survived severe tail injuries (greater than 50% tail loss), three of which also had hind limb buds (one or both) removed from initial attack. Of these only one survived to 120 days, at which point it had healed with a partially regenerated tail but no hind limb buds (figure 67 in appendix). None of the ten control tadpoles exhibited severe injuries to the tails or hind
limb buds when kept up to 120 days.

9.5.9. **Results of Selective Predation Experiment 4 (Lithobates clamitans/Anax junnis)**

Ninety of 100 green frog tadpoles (both age groups, stages 32–36 and 37–41; 90%) were injured by Green darner dragonfly nymphs in experimental enclosures. Selective predation was observed in 8 out of 10 tanks beginning within the first 48 hours after introduction of tadpoles. Nymphs were observed (and photographed) capturing tadpoles and chewing on selected body parts before releasing the injured tadpoles. Recapture of injured tadpoles was occasionally observed, though it appeared nymphs were attracted more to movement in uninjured tadpoles than to less active, previously injured prey. Occasionally tadpoles were able to escape after being captured or injured from nymph strikes, but this was infrequently recorded relative to successful capture followed by selective predation and release. Compared with Shadow darner nymphs from Experiment 1, larval Green darners were much more active predators, observed actively stalking prey tadpoles throughout enclosures. Most nymphs continued to feed for several days, some for the entire duration of the experiment. Only 2 of the 10 nymphs did not feed at all. Full consumption of an entire Green frog tadpole was never observed in the tadpole/dragonfly interactions. Nymphs performed selective predation, inducing a range of both lethal and nonlethal injuries in both age classes (figures 68, 69).

![Figure 56. Non-lethal injuries (Series 1) and lethal injuries (Series 2) among Gosner stages 32–36 Green frog tadpoles (younger group) predated by Green Darner dragonfly nymphs in experimental studies. Note that all lethal injuries were multiple and involved the abdomen, and most also involved one or both hind limbs (88.89%). Minor tail injuries were the most common non-lethal injury (96.18%), while 2.67% involved the hind limbs.](image-url)
Non-lethal injuries included minor cranial and abdominal damage, but the most common injuries were various degrees of damage to tails and hind limbs, including partial and sometimes full amputation of hind limb (figure 70 in appendix; figure 71). Damage to developing limbs occurred frequently in tadpoles (5.54% of all injuries in younger age-class, 8.25% in older age-class), suggesting that nymphs may have a feeding preference for specific regions of tadpole bodies (figures 68 and 69). Lethal damage most often included major injuries to the abdomen, injury or full consumption of hind limb(s), and loss of greater than 75% of the tail (figures 68 and 69). In some cases, hind limbs in tadpoles were removed with almost surgical precision, while others were recorded being rapidly chewed off, leaving jagged wounds (figures 70 in appendix; figure 71).
The majority of the older tadpoles (slightly less mortality than in younger tadpoles) survived the dragonfly-induced injuries and re-grew portions of their tails and hind limbs. Regenerative response ranged from complete regeneration (tails) to partial regeneration, to healing with no regeneration (often hind limbs) and no obvious sign of prior injury (e.g. scarring, figure 72). By metamorphosis, this variation in regenerative response manifested itself in various forms of hind-limb deformities including full missing legs to singular missing hind-limb digits; one severely injured tadpole regenerated a partial hind limb with extra digits (suggesting cellular intercalation, as discussed in chapter 7; figure 74). Dragonfly-induced deformities occurred among both age classes of tadpoles and ranged in severity, suggesting developmental stage and extent of injury may predict idiosyncratic ranges of abnormalities, as suggested by Ballengée and Sessions (2009), Sessions and Ballengée (2010a, b). These dragonfly-induced limb deformities closely resembled field-sampled, deformed Green frogs reported at several field sites, suggesting larval Shadow darner as one of the proximate causes (figure 75).
Figure 59. Green darner dragonfly nymph induced deformed metamorphic Green frog with no obvious signs of prior injury, such as scarring, from experimental simulation. Traumas incurred to tadpoles can often be masked by the healing ability of amphibians (Sessions and Ballengée 2010a; Bowerman and Johnson 2010). Photograph by Brandon Ballengée.

Figure 60. Detail of severely deformed hind limb from metamorphic Green frog. Note extra digits on abnormal limb, suggesting cellular intercalation (Sessions and Ballengée 2010a). Photograph by Brandon Ballengée.
9.5.10. Results of Post-mortem Analyses

A subset of more than 100 collected field deformed anurans with representative voucher specimens from all study sites were cleared and stained (methods by Stopper et al. 2002) and analyzed using high-resolution microscopy for parasitic cyst screening. Animals collected at field sites deemed as degraded (Sites 2, 5, 6, and 8) had significantly higher numbers of parasitic cysts than deformed individuals collected from pristine sites (figure 76 in appendix; figure 77). Abnormal peri-metamorphic/metamorphic Green frogs collected from sites 2, 6, and 8 with the highest deformity rates (11.1% to 19.4%) were found to have high levels of parasitic cysts in proximity to abnormal limbs (figure 78 in appendix). Parasites were initially not identified by species, and observations from cleared and stained specimens were qualitative (presence/absence) rather than quantified.
Figure 6.2. Parasitic cysts (stained blue) from a yet-to-be-identified species in close proximity to abnormal limb (stained red, lower right hand corner) in Green frog collected from Site 8. Photograph 2010 Flux Media Laboratory, Concordia University.

Necropsies were later performed by the Fluvial Ecosystem Research Section (Aquatic Ecosystem Protection Research Division of Environment Canada) and were conducted on fewer than 25 voucher specimens representing all sites. Parasites of the following genera were identified in analysis: *Alaria; Clinostomum; Echinostomatidae; Fibricola; Gorgoderina; Haematoloechus; Proteocephalidae; Ribeiroia*. Single *Ribeiroia* species metacercariae were found in two Green frogs from Site 6 collected in 2010. Currently, research is continuing to identify encountered parasites at the species level.

9.6. Conclusions from Findings

As a case study, this research provide further evidence that participatory biology programs like this one, which included non-specialist volunteers, are able to generate relevant scientific insights into ecological phenomena. Firstly, larval Odonates and some fishes in Quebec were shown to induce a variety of lethal and non-lethal injuries, resulting in permanent limb deformities among young frogs. Our field results indicated that higher predation densities increased incidence of injuries and deformities in wild frogs, a link previously that had not been established in prior studies of the region or elsewhere (please see chapter 7).

In addition, during this participatory science study, volunteers and I were able to identify parasitic infection by the trematode *Ribeiroia* (presumably *R. ondatrae*) as a further potential cause for some of the anuran deformations encountered. Some of the deformity
types (e.g. supernumerary limbs and limb segments) are diagnostic of *R. ondratae* infection (please see chapter 7 for more detailed information). In addition, presence of *Ribeirioia*-like parasitic cysts were found in samples of cleared and stained deformed frogs at several of our degraded wetlands. Necropsies also confirmed *Ribeirioia* species metacercariae in anurans from at least one of the degraded study sites. This was an important finding, as *R. ondratae* had not been suspected as a potential cause for amphibian malformations in the region and only once had been reported in Canada at all (on the west coast; see chapter 7).

At the larger level, our data on Green frogs suggested a direct correlation between decreased ecological quality of wetlands and higher numbers of injured tadpoles and young deformed frogs. Further, such degradation from agricultural and urban runoff resulted in wetlands with increased populations of some anuran larval predators occurring at the sites we studied. This is a very important finding, as on the one hand it re-confirmed early regional findings by Ouellet et al. (1997) and Bonin et al. (1997) that anuran deformities may be increased in proximity to agricultural activity, but importantly it provided a mechanism (e.g. predatory injury and parasitic infection) that gave an enhanced understanding of this phenomenon.

These relevant scientific findings, stemming from research conducted during *Eco-Actions* and within a *Public Bio Art Laboratory*, were disseminated to the larger scientific community through several means, including two Canadian governmental reports247 (Co-authored by my employer David M. Green; please see appendix) and presented at the Joint Meeting of the American Society for Ichthyologists and Herpetologists in Providence, Rhode Island as ‘Predation-induced Limb Deformities in Southern Quebec Anurans’, July 2010.

This provides further evidence to suggest that participatory biology programs (even those embedded with transdisciplinary art practices) are able to generate viable scientific insights into complex ecological phenomena. Additionally, the science conducted during such programs may contribute significantly to specific areas of study, as this Quebec work, along with the prior UK studies since published, have been cited in a growing number of international research papers that have further suggested predatory injury as a potential cause for anuran deformities (Johnson and Bowerman 2010; Reeves et al. 2010, 2011; Novarini and Boldrin 2011; Bionda et al. 2012; Roberts and Dickinson 2012).

In closing, my core group of volunteers (non-science specialists) aided in uncovering insights into local ecological phenomena (the first such attempt in more than a decade) of the occurrence and origins of limb deformities in Southern Quebec anurans. We utilized rigorous scientific methods to analyse this issue, resulting in important discoveries. As discussed in chapter 6, volunteers achieved a better understanding of amphibians and ecology along the way. This provides an example of how transdisciplinary approaches along with participatory science may be combined to address real-world issues through creative and collaborative means, in hopes of finding ways to protect amphibians and other organisms at some future

point.

9.7. Unanswered Questions

Although this work helped to provide new underlying knowledge of the phenomenon of deformed amphibians, many questions will still need to be addressed. Firstly, we were able to study only a small number of wetlands during two field seasons, so data is limited. Larger-scale studies that extensively cover the region and involve more wetlands and personnel are importantly needed. Such studies may be able to identify if this phenomenon is biome-wide or only limited to some wetlands.

Secondly, if wetland quality is a factor in changes to the complex aquatic food chains that involve larval anurans, could remediation of agricultural runoff and urban effluents help to alleviate above-natural levels of deformed frogs? As Lannoo suggested in his 2008 book *Malformed Frogs: The Collapse of Aquatic Ecosystems*, much effort has been made to find deformed frogs, but almost no work has been conducted to address the problem of them becoming malformed in the first place.
Chapter 10. Interweaving of Art and Science in a Time of Ecological Crisis

10.1. Introduction

Art and science combined may be important tools for imparting knowledge of ecology to larger audiences. In chapter 2 of this work, I presented evidence that historic practitioners such as Alexander von Humboldt, Erasmus Darwin, and John James Audubon combined scientific knowledge with the engaging tools of art to reach large audiences with fundamentally environmental messages. In this way they helped to change Western perceptions of the natural world and questioned human relationships to nature. Throughout this research I have sought to determine whether such creative, combinatory art and science strategies may still be effective to disseminate knowledge of ecological phenomena to wider audiences of non-specialists.

In chapters 6 through 9, evidence was presented that new knowledge could be gained about amphibians and about potentially larger ecological phenomena through participatory biology programs (e.g. Eco-Actions and Public Bio-Art Laboratories). However as discussed in chapter 4, art was shown to have been the primary tool utilized to disseminate these scientific findings to a larger, non-specialist public. Could such a combined art and science approach in my own practice as well as in the practices of artists like the Harrisons, TC & A, Cornelia Hesse-Honegger, and others (discussed previously in chapters 3 and 4) be considered a genuine fusion of both fields?

Before addressing this question directly, I found it was important to firstly examine key discourses that identified the initial division between art and science as well as more recent ideas about their potentially synergistic relationship. The varied approaches of transdisciplinarity as well as participatory science are further examined, as they may shed light on the potential synthesis of these ‘two towers of knowledge’. It should be noted that critics of the growing art and science movement would question the legitimacy of such claims and even warn against such efforts in the first place. Further, others have condemned creative efforts in environmentalism as overtly reactionary and lacking scientific grounds.

In closing I will argue for a combined art and science approach as a step towards ecological conservation in light of evidence suggesting that such strategies are effective. Likewise, today there is a strong impetus for such combinatory, creative practices in an effort to stave off the complex environmental problems we and other species currently face.

10.2. The Two Towers: Crumbling, Hybridizing, or Undergoing Mutagenesis?

Over recent decades there has been tremendous interest in the intersections between art and science. Already by the mid-twentieth century, physicist and novelist Charles
Percy Snow had diagnosed ‘a gulf of mutual incomprehension’ between the humanities and the sciences.\footnote{Of which Snow stated, ‘I believe the intellectual life of the whole of Western society is increasingly being split into two polar groups … literary intellectuals at one pole—at the other scientists, and as the most representative, the physical scientists. Between the two is a gulf of mutual incomprehension’ (1959: 4).} Such a divisions, Snow claimed, could be rooted in specialization,\footnote{Such specialization and rampant development of physics separated science from society at large, as Snow stated: ‘The great edifice of modern physics goes up, and the majority of the cleverest people in the Western world have about as much insight into it as their Neolithic ancestors would have’ (1950: 16). Likewise the humanities had undergone their own rampant specialization; the writings of Charles Dickens ‘had been transformed into the type-specimen of literary incomprehensibility’ (Snow 1950: 13). In larger terms both Shakespeare and the Second Law of Thermodynamics were equally in inaccessible to much of the populace.} which had occurred in both ‘cultures’\footnote{Snow referred to the ‘the scientific culture’ as ‘really … a culture, not only in an intellectual but also in an anthropological sense. That is, its members need not, and of course often do not, always completely understand each other; biologists more often than not will have a pretty hazy idea of contemporary physics; but there are common attitudes, common standards and patterns of behavior, common approaches and assumptions’ (1959: 10).} simultaneously (yet divergently) and was reflected in ‘our fanatical belief’ (Snow 1959: 18) in discipline-centric education. Snow considered such a fragmented approach (single, focused attempts towards understanding the world) as highly limited and a ‘sheer loss to us all’.\footnote{As Snow further stated, ‘It is at the same time practical and intellectual and creative loss, and I repeat that it is false to imagine that those three considerations are clearly separable’ (1959: 12).} He called for the revision in our approach towards education to remedy such limited views, as this would be necessary to achieve wisdom and perhaps even long-term survival\footnote{As Snow warned, ‘Closing the gap between our cultures is a necessity in the most abstract intellectual sense, as well as in the most practical. When those two senses have grown apart, then no society is going to be able to think with wisdom’ (1959: 53). In terms of the use of the term ‘survival’, Snow meant this in the cultural, not biological sense, speaking during the Cold War within the context of the ‘Communist countries’ and those that were not. He stated that if changes were not made, ‘At best, the West will have become an enclave in a different world—and this country will be the enclave of an enclave. Are we resigning ourselves to that? History is merciless to failure. In any case, if that happens, we shall not be writing the history’ (1959: 53).} (Snow 1959: 12).

In a later ‘revisited’ volume, Snow discussed the emergence\footnote{Of which Snow stated, ‘It is probably too early to speak of a third culture already in existence … When it comes, some of the difficulties of communication will at last be softened: for such a culture has … to be on speaking terms with the scientific one’ (1964: 71).} of a ‘third culture’ (Snow 1964: 70). Snow was not alluding directly to a synthesis between the arts and sciences, but instead to an emerging group of specialists (‘social historians’\footnote{As he stated, ‘Some social historians, as well as being on speaking terms with scientists, have felt bound to turn their attention to the literary intellectuals’ as well as gaining a better understanding of our own species within the context of societies past and present as they studied ‘concepts such as the organic community or the nature of pre-industrialized society or the scientific revolution’ (Snow 1964: 71). These are what we would currently refer to as being more within the realm of the social sciences.} who through their study of human societies could expand understanding and stand in complement to the approaches utilized within the sciences and humanities (Snow 1964: 71). However, Snow advocated for a more inclusive approach in scholarship\footnote{Recent attempts at such integrations have been attempted through the integrative education programming of STEAM (Science, Technology, Engineering, Art, and Math); for a review see Roger Malina’s blog http://malina.diatrope.com/2014/08/29/what-does-steamp-have-to-do-with-it/} that would include communicating knowledge from both the arts and sciences to students (more of a unified method in education than a fusion between disciplinary cores), which would be for the betterment of all mankind.\footnote{This division, he said, was ‘making us more obtuse than we need be’ and through such changes ‘we can educate a large proportion of our better minds so they are not ignorant of imaginative experience, both in the arts and in science, nor ignorant either of the endowments of applied science, of the remediable suffering of most of their fellow humans, and the responsibilities which, once they are seen, cannot be denied’ (Snow 1964:100).}

Snow’s term ‘third culture’ was extensively used by author John Brockman;\footnote{Also literary agent and founder of the Edge Foundation, an organization of science and technology intellectuals.} however, he excluded the humanities as well as other fields to suggest that science has become the primary source of relevant knowledge production (or, as he alludes to it, the ‘big
counterbalancing the reductionist tendencies of science…

Brockman stated that such efforts today may no longer be required, as ‘scientists are communicating with the general public … in a manner accessible to the intelligent reading public’ (1995: 18). So complete is Brockman’s exclusion of other pursuits of inquiry, he further stated that science alone is ‘defining the interesting and important questions of our time’ (1995: 18). As such, how would those from other disciplinary perspectives even attempt to critique or collaborate, let alone synthesize with science?

Brockman even eliminated the necessity for artistic figures of speech, as ‘There is a new set of metaphors to describe ourselves, our minds, the universe, and all the things we know of it’ that are being provided by scientists alone (1995: 21). Ironically, Brockman’s framework perpetuates the idea of viewing reality through a monocular, discipline-focused lens, working in antithesis to Snow’s ideas. Secondly, under such a deterministic canon, science becomes dangerously synonymous with ‘the’ truth instead of ‘a’ truth: a realization of Nicolescu’s concerns (discussed previously in chapter 1). Likewise, one needs to question whether the approach of scientific knowledge fed ‘top-down’ to the masses (as Brockman employed the term) is even effective; as critics of such hierarchies like Mueller et al. (2012) reminded us, we may fall back into old patterns of ‘elitist’ science.

To offer perspective however, Brockman’s sensational claims of the near-omnipotence of science, though perhaps shared by some scientists participating in this ‘Third Culture’ movement, are certainly not seen in the writings of others such as Stephen Jay Gould and Lynn Margulis, for example. In and of itself, spreading to non-specialists awareness of scientific knowledge about organisms and ecology may be fundamental (and required) for larger steps towards conservation, although the methods utilized by Brockman deserve critique. As author and science journalist Jonah Lehrur stated, the third culture ‘failed to bridge the divide between our two existing cultures. There is still no dialogue of equals. Scientists and artists continue to describe the world in incommensurate languages’ (2007: 191). Lehrur further suggested what will be required is a ‘fourth culture’ where science and art form a complementary relationship, as neither discipline is capable of reaching a greater truth without the other, and perhaps not even then (Lehrur 2007, 2008). What is required to deeply understand reality is an approach that embraces ‘pluralism’, with art counterbalancing the reductionist tendencies of science (Lehrur 2007: 192; 2008). Science

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260 He further stated, ‘The intellectuals with these new ideas and images—those scientists doing things and writing their own books—are those who drive our times’ (Brockman 1995: 18).

261 To be fair, not all scientists Brockman included among ‘third culture thinkers’ reject of other disciplines, as evidenced by Stephen Jay Gould’s championing of the arts. Likewise, scientists who practice some form of networked, interdisciplinary, or other research strategies to understand complex systems in nature include Steve Jones, Lynn Margulis, Brian Goodwin, Stuart Kauffman, and others.

262 As Lehrur suggested, ‘Our two existing cultures must modify their habits. First of all, the humanities must sincerely engage with the sciences … not ignore science’s inspiring descriptions of reality … at the same time, science must recognize that their truths are not the only truths. No knowledge has a monopoly on knowledge’ (2007: 197).

263 Lehrur further clarified, ‘Physics is useful for describing quarks and galaxies, neuroscience is useful for describing the brain, and art is useful describing our actual experience. While each of the levels are obviously interconnected, they are autonomous: art is not reducible to physics … this is what our third culture should be about. It should be a celebration of pluralism… Thus, in our current culture, we have two epistemological extremes reflexively attacking the other. Postmodernists have written off science as nothing but another text, and many scientists have written off art and the humanities as hopelessly false. Instead of constructing a useful dialogue, our third culture has only inflamed this sad phenomenon’ (Lehrur 2007: 191—192).

264 Lehrur illuminated this complementary relationship thus: ‘Science needs art to frame the mystery, but art needs science so not all things are mystery’ (2007: x). He also stated, ‘Art is a necessary counterbalance to the glories and excesses of
alone could never reach an absolute truth, a position of Lehrur borrowed, at least in some respect, from science philosopher Karl Popper (discussed in more detail below).

No core synthesis between art and science emerged (or was even suggested) in the ideas of Snow, Brockman, or Lehrur. Could such a fusion be found in the writings of scientists within the context of transdisciplinarity? For example, a cornerstone of Nicolescu (a physicist), the transdisciplinary attitude requires a plurality of approaches for interpreting the world outside, within, and beyond ourselves, as ‘disciplinary knowledge has reached its own limitations with far reaching consequences not only for science, but also for culture and social life’ (Nicolescu 2006: 2). To begin this process (as discussed previously in chapter 1), Nicolescu called for revisions to reductionist approaches in the sciences (as well as the larger ‘scientism’ in the West), as the ‘transdisciplinary viewpoint allows us to consider a multidimensional Reality, structured by multiple levels replacing the single-level, one-dimensional reality of classical thought’ (2005: 9). Hereby, within post-Enlightenment reasoning, all phenomena could be broken down to their smallest bits and understood through the mechanisms in relation to one another (the ‘mechanistic’ view simplified from Nicolescu, 2002). Such approaches, though, led to numerous advances in the sciences but left modern society within the shadow of the ‘death of nature’ (Nicolescu 2002: 57).

To resurrect our view of nature (and ourselves), Nicolescu affirmed that we must move beyond the binding lenses of traditional disciplines and the dogma of empiricism to embrace pluralities of approach. Kagan (2011: 208) distilled Nicolescu’s thoughts into a more cohesive form, here a vision of nature that should be made of a structure of three parts:

1. ‘Objective Nature’ correlated with the sciences (e.g. empiricism);
2. ‘Subjective Nature’ correlated with plural levels of perception, as in the world’s regions, varied non-empirical traditions, and even the arts;
3. ‘Trans-Nature’ correlated with the ‘domain of the sacred’ and described in the relationship between the ‘object and subject.’

Certainly within such a context, art and science are equal and even coalesce towards embracing complexity. However, from a taxonomic standpoint, would such a model be more chimerical (e.g. a sum of divergent parts to make a whole?) or a completely new holotype of converged worldviews (e.g. a fusion of core-values)? It certainly seems in his Manifesto of Transdisciplinarity (2002) and later writings that Nicolescu has advocated for the latter, as his vision seeks foremost towards integration and moving beyond disciplines. As such, this new holotype has yet to be fully described; indeed, it is still emerging (as suggested by Kagan 2011), and if it comes to fruition, such a rigid, cladistic analysis may become obsolete.

Within the context of my overall study and guided by Nicolescu’s canon,
transdisciplinary art and participatory biology could become synergetic (even in light of some of the problems discussed previously in chapter 1). More importantly such a cohesion of world-views could not only increase non-specialist understanding of ecology but also expand our understanding of the complexity found in nature and within ourselves (reflected upon in chapters 3 and 4 in relation to the transdisciplinary works by Johanson, the Harrisons, and others, and discussed extensively in Kagan 2011). Although perhaps not keenly pragmatic in terms of steps needed to undertake such a transformation (likewise we may not yet have evolved to this point), such pursuits, especially in a time of environmental crisis, are of great worth.

Seemingly at odds with Nicolescu’s philosophy were Wilson’s ideas for the consilience of knowledge coming from the sciences, humanities, and other disciplines (1998). Wilson certainly advocated for the combining of art and science, however for such a synthesis the humanities need to abandon much of their core and accept the truth provided by material sciences. As Lehrur critiqued Wilson’s view, ‘The humanities should be “rationalized”, their “lack of empiricism” corrected by reductionist science’ (2008: 191). However, as Nicolescu suggested, there are truths beyond those generated by material science, and perceptions from the varied disciplines may work in concert towards better overall understanding of nature.

Likewise there was no evidence by which I could establish that any of the artists (discussed in chapters 4 and 5, whom I referred to as practitioners of varied degrees of TAE, as discussed in chapter 1) subscribed to Wilson’s consilience movement. Even among historic scientists who created art (discussed in chapter 2), none appeared to share the same dogma of materialism in science that Wilson subscribed to in Consilience (1998). In defence of Wilson, however, he is a traditionally trained biologist who has spent decades witnessing the holocaust of biodiversity at a global scale (2002). As such, his approach for combing knowledge from divergent disciplines such as art and science (albeit somewhat rudimentary and misguided on many levels) with the goal of informing the populace of this decline is of worth. In actuality it is an obvious plea towards remedying the great death of species we are experiencing in our current, anthropocene era. Wilson, in desperation, lets his objective approach become affective (who could blame him?). However, his own science-centric belief,

\[268\] As argued in chapter 1.
\[270\] To be clear, Nicolescu as a practicing scientist was not against science but rather suggested that the overall reduction approach in the material sciences was limited. He further stated of such limitations: ‘In spite of an almost infinite diversity of methods, theories, and models which run throughout the history of different scientific disciplines, the three methodological postulates of modern science have remained unchanged from Galileo until our day. Only one science has entirely and integrally satisfied the three postulates: physics. The other scientific disciplines only partially satisfy the three methodological postulates of modern science. However, the absence of rigorous mathematical formulation in psychology, history of religions, and a multitude of other disciplines does not lead to the elimination of these disciplines from the field of science … In other words, there are degrees of disciplinarity which can respectively take into account more or less completely the three methodological postulates of modern science’ (Nicolescu 2007: 110).
\[271\] To clarify, Wilson did not suggest a fusion of disciplinary cores but a combined approach: ‘The key to the exchange between them is not hybridization, not some unpleasantly self-conscious form of scientific art or artistic science, but reinvigoration of interpretation with the knowledge of science and its proprietary sense of the future’ (1998: 230).
\[272\] As he stated, ‘The central idea of the consilience world view is that all tangible phenomena, from the birth of stars to the workings of social institutions, are based on material processes that are ultimately reducible, however long and tortuous the sequences, to the laws of physics’ (Wilson 1998: 291).
\[272\] As Nicolescu stated, a transdisciplinary attitude is not at odds with varied approaches: ‘As in the case of disciplinarity, transdisciplinary research is not antagonistic but complementary to multidisciplinary and interdisciplinary research. Transdisciplinarity is nevertheless radically distinct from multidisciplinarity and interdisciplinarity because of its goal, the understanding of the present world, which cannot be accomplished in the framework of disciplinary research’ (1999: 3).
which nears theology, ironically limits the effectiveness of his plea for environmental sustainability.

Wilson, like Mittelstraß, described the boundaries of specialization as beginning to give way (perhaps ‘crumbling’) within the evolution of science itself. For Mittelstraß transdisciplinarity is a form of integrative, problem-driven research that comes fundamentally from the sciences but may cope with problems that fall outside the scope of scientific resolution. In the case of what he termed ‘practical transdisciplinarity’, some complex issues such as ‘Ecological problems require the collaboration of many disciplines … these contribute with their specialised knowledge to the solution of these problems’. However, they retain their specialization cores (Mittelstraß 2011: 336). An example of ‘practical transdisciplinarity’ within the context of this dissertation would be Revival Field by artist Mel Chin and Rufus Chaney (discussed in chapter 3). Here both artist and scientist combined their different areas of expertise to address effectively a complex, real-world ecological problem.

The ideas of Mittelstraß (like Wilson’s) are heavily science-centric, though helpful in my thinking about participatory biology (discussed in chapter 6). Further, they were similar to methodologies derived from the social sciences utilized within the Z-Node research group, of which I am part.

Further to other works that combined art and science discussed in this dissertation are the ideas of Gibbons et al. (1994) regarding Mode 2 transdisciplinarity. Attuned with Mittelstraß, they suggest that research is oriented towards addressing complex problems, though at a scale I believe more relevant to most artists interfacing with ecology (at least the majority of those of which I am aware). Under the Mode 2 framework, research is conducted in local issues by local stakeholders (be they residents of such areas, artists, scientists, or others) and as such is reflective of localized needs and shared with a greater community. One only need think here of Johanson’s Leonhardt Lagoon, where a specific ecological system was remediated (using integrated methods of science and art) with the aid of local scientists and non-specialist members of the community to benefit the community at large, including humans, non-human animals, plants, and others (discussed in chapter 3). This certainly would be a model I deem as a hybridization between art and science.

Importantly, unlike the ideas of Wilson or Mittelstraß, science itself is among an assembly of specialized lenses among a ‘theoretical’ structure utilized to address a complex issue; it is not the ultimate principle to which all other disciplines find themselves as

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273 As Wilson stated, ‘Disciplinary boundaries within the natural sciences are disappearing, to be replaced by shifting hybrid domains in which consilience is implicit. These domains reach across many levels of complexity, from chemical physics and physical chemistry to molecular genetics, ecological chemistry, and ecological genetics. None of the new specialties is considered more than a focus of research. Each is an industry of fresh ideas and advancing technology’ (1998: 11). Mittelstraß cited several examples of transdisciplinary principles of research applied by labs and working groups such as the Center for Imaging and Mesoscale Structures at Harvard University, Center for Nanoscience at the University of Munich, and others (2001, 2011).

274 Of which Mittelstraß further stated, ‘Transdisciplinarity should allow us to solve problems that could not be solved by isolated efforts … the claim that transdisciplinarity implies a transcending of the scientific system, and is therefore actually a trans-scientific principle, would mean that transdisciplinarity was itself unbounded, or that it was bounded by arbitrary terms which were themselves beyond scientific determination. Put otherwise: transdisciplinarity is—and remains deliberately—a science-theoretical concept which describes particular forms of scientific cooperation and problem-solving, as opposed to forms lying outside of scientific boundaries’ (2011: 232).

275 Mittelstraß stated that in such situations, the integration of such specialized disciplines requires ‘a wise and efficient coordination, but not an extension or transformation of these disciplines’ (2011: 336).

276 As discussed in chapter 3, the work by Chin and Chaney helped to establish the large field of phytoremediation employed internationally today (Spaid 2002).

277 Which Gibbons et al. posited as an ‘evolving framework to guide problem solving efforts’ (1994: 5).
subordinates under Mode 2 programs (Gibbons et al. 1994: 5). As a case in point, consider Hans Haacke’s *Rhine-Water Purification Plant*, whereby scientists and other civic workers collaborated with Haacke, an artist, to make a work that addressed a localized environmental problem and at least to some degree aided in the remediation of that problem because of public awareness of the issue (discussed in chapter 3). This use of art-science hybridity to disseminate knowledge of ecological phenomena to a larger populace of non-specialist constituted an action towards real-world problem-solving.

This reflective approach towards research, moving towards a greater degree of openness, may be part of a larger shift (or potential *mutagenesis*) occurring in science (discussed previously in chapters 1 and 6). This evolution of scientific structures was addressed, to a degree, in the ideas of transdisciplinarity presented by Mittelstraß and Wilson. The core or nucleus of science stayed unaltered, however, as addressed in some approaches to participatory science in relation to ecology (discussed in chapter 1, e.g. Cooper’s analogy to ‘Jeffersonian democracy’; Funtowicz and Ravetz’s ‘post-normal science’, and Mode 2 research as discussed by Gibbons et al. 1994), a change closer to the core of science may be required that questions the limitations of the empirical method, the existence of a singular ‘truth’, and the very definition of what constitutes a ‘scientist’.

Such thinking may be reflective of larger developments in the philosophy of science in the post-war years by philosopher and physicist Karl Popper (among others sometimes referred to as the ‘postpositivist’ scientists). As Popper stated, a fundamental restriction of empirical science is that it ‘is intended to represent only one world: the “real world” or the “world of our experience”’ (2005: 16). As a physicist Popper questioned such mono-interpretive models, as ‘The actual procedure of science is to operate with conjectures: to jump to conclusions — often after one single observation’ (Popper 1963: 31). Important to this position was questioning of the deductive method, as there was no true objective frame to pose a research question, since all framing came through the individual, ‘psychological’ lens of the person posing the question. Thus, it had to be viewed with a degree of subjectivity and could never reach ‘the’ truth. This position is attuned with ideas of valuing multiple perspectives.

More in alignment with the overall premise of art and science presented in this thesis,

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278 Such a level playing field of outlooks as that of Gibbons et al. (1994) is concurrent with thoughts by Nicolescu on the fundamentally equal value of all perspectives.

279 As Haacke stated, ‘In response to the exhibition, a regional newspaper reported extensively on the city’s part in the pollution of the river’ (1986: 106). He further stated in an interview I conducted, ‘Together with a host of initiatives by others, this exhibition may have contributed to building a political consensus to support sustained efforts in curbing pollution’ (2011, please see appendix).

280 It is relevant to note that Gibbons et al. (1994) defined two distinct forms of knowledge: firstly that which is ‘codified’: ‘Knowledge which needs not be exclusively theoretical but needs to be systematic enough to be written down and stored. As such, it is available to anyone who knows where to look’ (167); and that which is ‘Tacit’: ‘Knowledge not available as a text and which may conventionally be regarded as residing in the heads of those working in a particular transformation process, or to be embedded in a particular organizational context’ (168). In the case of Haacke, Johanson, and other artists discussed in this dissertation, it is often also both that are disseminated to audiences, dependent on means of delivery (e.g. artifact, action, conversation, science paper, etc.).

281 A full analysis of these ‘shifts in science’ is not the topic of my overall research; however I will attempt to overview major ideas within the context of art and science combinatory approaches relevant to this dissertation.

282 To clarify, Mittelstraß stated that within transdisciplinarity the underlying science with ‘the standards of rationality, and with them the methods and forms of theory construction, are not changing. It is the forms of organisation of science and research which are doing so’ (2011: 335).

283 It is imperative that we give up the idea of ultimate sources of knowledge and admit that all knowledge is human; that it is mixed with our errors, our prejudices, our dreams, and our hopes; that all we can do is to grope for truth even though it is beyond our reach. There is no authority beyond the reach of criticism’ (Popper 1963: 39).
Popper discussed the inductive process as among the most creative\textsuperscript{284} processes in science, utilized within biology. In the context of this dissertation, my research into proximate causes for frog deformities would be an example (chapters 9 and 10). Likewise, it was through the inductive process that the Harrisons developed methods to rear their rare crabs, that TC&A developed novel means of tissue scaffolding, and that Cornelia Hesse-Honegger could correlate mutation rates in insects to radioactive pollution.

A central praxis to induction is that we can never find a singular truth; we can only observe evidence to support phenomena.\textsuperscript{285} If enough evidence is gathered, a hypothesis is formed and, through convergence of evidence, a theory. But such theories are always at risk, as new data may arise, overthrowing this set of ideas. As Popper concluded, we in this field of science must accept the ‘idea that truth is beyond human authority. And we must retain it. For without this idea there can be no objective standards of inquiry; no criticism of our conjectures; no groping for the unknown; no quest for knowledge’ (Popper 1963: 30). This is precisely the limitation but also the beautiful fragility associated with the scientific study of life.

10.3. Of Hybrids, Chimeras, Mosaics, Bastards, or the Yet-Unknowns?

Within the context of art and science combinatory practices discussed in this dissertation, could these be considered genuine fusions of the two disciplines? Not all who work in art and science necessarily seek to answer this question in the same way. In fact, where one stands on this question (even whether one is looking for a synthesis or not) depends on where one is placed at the interface between art and science practice. In addition, to define synergy is dependent on how one fundamentally differentiates between what constitutes art as well as science.

The questions primary to my research sought to shed light on how transdisciplinary art and participatory science could increase non-specialist understanding of ecological phenomena. Further, I inquired whether knowledge (relevant to science) could be generated through these novel practices. Already a schism is formed through the framing of my questions: artistic practice, even if transdisciplinary, is contextualized as art; biology, even if participatory, is science. However the reality of these practices is far less dichotomous and far more messy (with varied degrees of synthesis between art and science). Such messiness does not fit neatly into taxa from a cladistical standpoint (or perhaps from the approach of epistemology); however, they may be loosely placed, based on characteristics, into the following categories: hybrid, chimerical, mosaic, bastard, and yet-to-be-identified (unknown).

As further explanation, consider photography scholar Christopher Webster’s suggestion that early photograms were a result of developments of science combined with the sensibility of the photographer to make an artefact that embodied both this new technology

\textsuperscript{284} As Popper explained, ‘Induction is the creative part of science. The scientist must carefully study a phenomenon, then formulate a hypothesis to explain the phenomenon. Scientists who get the most spectacular research results are those who are creative enough to think of the right research questions. Natural sciences (physics, chemistry, biology, etc.) are inductive. Evidence is collected. The Scientific Method is applied. Start with specific results and try to guess the general rules. Hypotheses can only be disproved, never proved. If a hypothesis withstands repeated trials by many independent researchers, then confidence grows in the hypothesis. All hypotheses are tentative; any one could be overturned tomorrow, but very strong evidence is required to overthrow a “Law” or “Fact”’ (1963: 35–36).

\textsuperscript{285} All the more reason why Brockman’s attempts at establishing third culture science as ‘the’ truth are so disconcerting.
but also the romantic intention of the artist. This was a relationship of two divergent sets of ideas (two ‘cultures’, to use Snow’s analogy) into one concrete, yet bastard form. More relevant to the overall discussion of this thesis is Hans Haacke for *Rhine-Water Purification Plant*. Here Haacke collaborated with scientists to help create his sculpture and further utilized graphics of scientific information. Although Haacke had no intention of becoming a scientist nor of conducting science, he utilized work by scientists (their data) and, through collaboration, their methods, to further his message about an ecological issue (Matilsky 1992). Through this combined art and science approach, public awareness of waste-management problems was achieved, which in turn led to changes in policy.

A similar view of the blending (but not marriage) of art and science can be seen with Mel Chin and Rufus Chaney’s *Revival Field*. Chin, an artist, facilitated scientific research by Chaney, a scientist, to culminate in a project that was dually science and art (Spaid 2002). Although Chin made steps towards learning the language and to some degree the scientific methods of phytoremediation, his intention was to remain an artist (Finkelpearl 2000). Within a larger art-historical context, the short-term, project-oriented relationship between Chin and Chaney is reminiscent of the temporal partnerships between artists and scientists involved in TAE (for example, early works by the Harrisons, discussed in chapter 4; also see Bijvoet 1997).

A further fusion between art and science (closer to hybridity) was achieved in *Leonhardt Lagoon* by Patricia Johanson. Johanson had to a degree become an ecologist to make her sculpture function in ecological terms. This involved the extensive acquisition of scientific knowledge on the part of Johanson, aided through collaboration with scientists Walter R. Davis, Richard F. Fullington, and others, which included species-specific ‘food and habitat requirements for different animals’, regional natural history, the biochemical processes of littoral zones, and other matters (Kelley 2006: 20; Matilsky 1992; Johanson 2014). Likewise, scientists working on the project needed to acquire a certain amount of knowledge of art: more specifically, that sculpture could restore an ecosystem. As Davis stated of the outcomes of *Leonhardt Lagoon*, ‘Those who understand the intricacies of a functioning ecosystem find particular satisfaction here’. Such truly hybrid practices, though still be rare in art and science, are required for genuine, creative ecological conservation.

The combinatory, art-science approaches of the Harrisons, TC&A, and Cornelia Hess- Hesse-Honegger could best be described as chimerical. Like Johanson, these artists had to achieve a high degree of specialized scientific knowledge and methods to create their works. Differing from Johanson, the Harrisons, TC&A, and Hesse-Honegger exhibited their works as art but also published their results as science (e.g. Harrison, N. 1975; Catts et al.

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286 It is important to remember that among the early experiments with camera obscura and light-sensitive photographic media, the photographer and the scientist were often the same person, such as Thomas Wedgwood (1771–1805) and Joseph Niépce (1765–1833).

287 Webster further stated, ‘Photography … is the natural child of alchemy, born into a rationalist age from the esoteric parentage of the retort and the camera obscura’ (2006: 6).

288 Haacke described this visualized data thus: ‘This documentation records the level of untreated sewage the city of Krefeld spews into the Rhine annually (42 million cubic meters). The left panel lists data on volume, rate of pollution (official code), breakdown into industrial and household sewage, and fees charged per volume. The right panel lists data on volume of disposable and dissolved matter, and breakdown by volume and name of major contributors of Krefeld sewage’ (1986: 106).

289 Haacke stated, ‘The artist’s application of scientific knowledge is naturally not scientific in itself because it does not intend contributing to the body of knowledge’ (Haacke 1967: 295).

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2000; Hesse-Honegger and Wallimann 2008). Although these practitioners identify themselves as artists, they contributed knowledge to the sciences (at a peer level with scientists) and as such offer rare examples of art genuinely contributing to the sciences: a novel synergy between disciplines.

Viewed from the perspective of participatory science, the research conducted by the Harrisons, TC&A, and Hesse-Honegger is reminiscent of citizen contributions to larger scientific programs designed and led by academically trained scientists (as discussed by Irwin, Cooper, and others in chapter 1). However, these artists assumed the role of primary investigators (though none had previous academic training in science) and used creative methods to address complex, real-world issues: a position aligned with the idea of activated locals discussed in Mode 2 transdisciplinarity by Gibbons et al. (1994) and also in approaches to ‘post-normal science’ by Funtowicz and Ravetz (2003). Under both these paradigms, science is issue-driven and conducted by stakeholders within the context of the complicated and unstable world.291

Funtowicz and Ravetz discussed the important inventive role of such stakeholders, as in the context of environmental problems they can be ‘quite ingenious and creative in finding practical means for its improvement, integrating the social and technological aspects. For local people can imagine solutions and reformulate problems in ways that the accredited experts, with the best will in the world, do not find “normal” (2003: 7). One can think here about the inventiveness of the Harrisons, with their idiosyncratic attempts at crab breeding and other novel experiments, towards developing sustainable foods: approaches that would hardly qualify as ‘normal’ scientific methods of research but as such went beyond the limitations292 of traditional science.

Further, such creative stakeholders form their own ‘extended peer communities’ for questioning standard science approaches and judging the effectiveness of projects which may in turn move science in further novel directions (Funtowicz and Ravetz 2003). As Funtowicz and Ravetz stated of such groupings, ‘They assess the quality of policy proposals, including a scientific element … They have proved their competence using the science they master during the exercise combined with their knowledge of their own situation in all its dimensions … These extended peer communities will not necessarily be passive recipients of the materials provided by experts. They will also possess, or create, their own “extended facts”’ (Funtowicz and Ravetz 2003: 7). One can think here of TC&A working within the field of biomedicine but offering an important critique of the larger biomedical industrial field. Similarly, Hesse-Honegger’s findings on malformed insects challenged the assumptions of scientists prior to her research and as a result forced further scientific study in this area. In a sense artists, through chimerical practices, can alter science.

291 As Funtowicz and Ravetz further clarified of post-normal science (PNS): ‘[It] is a new conception of the management of complex science-related issues. It focuses on aspects of problem solving that tend to be neglected in traditional accounts of scientific practice: uncertainty, value loading, and a plurality of legitimate perspectives … The approach used by normal science to manage complex social and biophysical systems as if they were simple scientific exercises has brought us to our present mixture of intellectual triumph and socio-ecological peril. The ideas and concepts belonging to the umbrella of PNS witness the emergence of new problem-solving strategies in which the role of science is appreciated in its full context of the complexity and uncertainty of natural systems and the relevance of human commitments and values’ (2003:1).

292 As Funtowicz and Ravetz posited of such limitations, ‘The traditional “normal” scientific mindset fosters expectations of regularity, simplicity, and certainty in the phenomena and in our interventions. But these can inhibit the growth of our understanding of the new problems and of appropriate methods for their solution’ (2003: 2).
Within my own combinatory practice as an artist and biologist, a more ‘mosaic’ approach is utilized. Here art and science are two divergent methods towards comprehension of a complex world driven by a sense of ecological urgency: the global plight of amphibians at this point in history (as discussed extensively in chapters 5, 6, 8, and 9). Although fundamentally divided, my art and science are complementary and work to inform and inspire one another in a creative feedback loop, of sorts. From my perspective this division is required, as through the objective lens of science and a reductionist approach I am able, through experimentation, to make targeted inquiries into complex ecological phenomena that I then share with a community of specialist peers. Also, through art I am able to affectively give voice to what these findings suggest about ecological decline and loss of biodiversity, which I share with a larger audience of non-specialists.

A strong sense of synergy occurs, not in the methods (which are very different), but in my base intention, which underlies both practices: I desire to the best of my abilities to help in any way possible to protect amphibians and other species from untimely extinction. Such a goal is not rare in the amphibian research community nor, I imagine, among other groups of biologists studying rapidly declining groups of species (Gascon et al. 2006; Mendelson et al. 2006; Kriger 2010; Bishop et al. 2012). It goes without saying that such a desire to protect species certainly is felt in the arts (the work of Hesse-Honegger, the Harrisons, the writings of Aldo Leopold, the works of Audubon, to cite only the examples presented within this thesis). Although key approaches, methods, and outcomes are often very different, the underlying impetus of the current ecological crisis drives all these practices: another potential overlap between arts and sciences as discussed in this thesis.

As a case in point, my artworks, more often than not, are made within a science laboratory that simultaneously is a participatory biology environment (e.g. the Public Bio-Art Laboratories), which is manifest of my underlying goal of trying to protect amphibians by educating people about them. Conversely, while creating the artworks I become inspired to conduct new scientific research. The neural mechanism that underlies this phenomenon is not known to me. Perhaps it is even a key unknown, a mystery that by remaining unsolved draws me back to this combinatory art and science practice.

Within the context of unknowns, how would one describe Joseph Beuys’s Bog Action in terms of art-science synergy? Though Beuys was inspired by science (as discussed in chapter 3) and certainly his impetus for protecting such ecosystems came from ecology, through his unique form of holism he was able to marry these scientific understandings with a sense of the metaphysical (Adams 1992). Through Beuys’s aktion the bog was framed as a place not only in the scientific terms of complex bio-chemical and multiple species interactions but also a place that should be deemed sacred: an approach certainly attuned with ideas of transdisciplinarity discussed previously by Nicolescu.

Through such a fusion of art with scientific ideas, Beuys was also able to delivery a larger message of biological unity in a metaphysical and scientifically didactic way: as Spaid stated, such an action is delivered as a message of ‘interconnection between human life and

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290 Certainly this approach does have limitations (discussed in more detail in the conclusion following this chapter), nor am I implying that other means may not be utilized, as discussed previously. However, it is relevant to this discussion that no realistic argument could be made that objectivity and reductionism in science has not aided humanity up to this moment in history.
nature’ (2002: 22). Further, through an embodied experience in such a wetland (that went beyond that of just seeing) a reawakening of the senses occurred (reminiscent of Louv’s and Reed’s pleas for physical mind-to-body connected experiences, discussed in chapter 5), a key to my own practice in participatory science programs such as the Eco-Actions. Such an act of agency was described by artist and scholar Timothy Collins, who stated of such eco-artists that their ‘role is to develop interfaces and new knowledge that explicates the complex meaning of nature and culture, as well as the relationship between nature and culture, in affect acting as an agent of change’ (2007: 108).

All of the artworks discussed in this dissertation are examples of synergy between art and science294 as well as agencies for ecological change; to what quantifiable degree this consilience occurred remains a relative mystery and a matter of perspective. The artists themselves became to varied levels both artists and scientists, but more relevantly, through their addressing of ecological issues, agents of social change. As engaged citizens they utilized science as a means to an end in that their research, which was issue-driven in a time of ecological urgency; they were practitioners of post-normal science (Funtowicz and Ravetz 2003). Further, they could all be considered to have acted within the field of transdisciplinarity as described by Gibbons et al. (1994), Nicolescu, or perhaps even a canon that has yet to be described.

10.4. Refortifying the Towers: The Criticisms by Steinberg and Elkins of Art-Science Synthesis

Throughout this thesis I have argued for a combined approach of art and science to increase non-specialist understanding of ecological phenomena. Yet art-science collaborations or the affinities between the two fields are not without their criticisms.295 Art critic and historian Leo Steinberg, who alluded to the incompatibility of art and science in his 1986 text *Art and Science: Do They Need to be Yoked?* Here, Steinberg argued there are some similarities296 between art and science; however; fundamentally ‘they differ in purpose and in the response they elicit’ (1986: 2). As for collaboration between artists and scientists,

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294 Collins discussed a division between artists and scientists in the context of ecological system remediation: ‘While there are some similarities in the intent to restore nature, it is important not to confuse the work of scientists with the work of artists. The difference is that artists primarily work on restoration at the level of perception, conceptualization, experience, and value; our colleagues in engineering and the natural sciences are working on restoration with knowledge developed through replicable experimentation. Their focus is upon the renewal of structural systems and interacting networks of nutrients and organism. The actions of our colleagues are about a successful, replicable, and practical restoration of health to complex systems. The actions of these artists call into question the cultural relationship to nature. And, at times we use the tools of science to give strategic form to our cultural interests’ (2007: 109). To counter, I have suggested that the degree by which artist use the ‘tools of science’ exceeds such a clean division between fields. More to the point, my evidence suggests an emerging trend of art-science immersion utilized to address complex, real-world ecological problems; there is a rich gradient of degrees of synergy that are not easily located with standard definitions of art or science.

295 I will analyze only texts by Steinberg and Elkins here, as I found them the most relevant to the works discussed in this dissertation. Other writings deserve mention, however, such as the critiques by biologist and writer Marc Wolpert, whose argumentation lies primarily in his opinion that artists and the public are largely ignorant of science and as such have little to offer the sciences.

296 Steinberg further stated, ‘So when we speak diachronically of affinities between science and art, it might be pertinent to distinguish the science of a culture that construes its reality by way of myth from the science of a culture whose chief explanatory instrument is theology; or the science whose supreme authority is a corpus of ancient texts from a culture whose truths, ideally, derive from, or submit to, experimental verification. Even if the condition of art were unchanging, its relation to changeable science would be inconstant. But in fact we are trying to throw a bridge between two moving bodies’ (1986: 3).
Steinberg suggested that these arise primarily as a result of mutual disciplinary envy.\textsuperscript{297}

According to Steinberg’s perspective, works of art are timeless and unique, while works of science are temporal and inevitable ‘truths’ that others will uncover as they describe phenomena occurring in a universe of constant laws (e.g. Newtonian physics). Steinberg cited the works of art and science of Leonardo Da Vinci as an example.\textsuperscript{298} ‘Unlike his surpassed scientific work, Leonardo’s artistic creation is unrepeatable, like the life on a man’ (1986: 3). He further stated that it is through works of visual art, and not works of science, that we find strong emotive responses\textsuperscript{299} from viewers to a subject: ‘We love and hate Art in a psychic continuum’ (Steinberg 1986: 9). To further clarify the differences between art and science, Steinberg listed three characteristics of works of art: ‘involvement with the specific materiality of things; elegance of composition; and the emotion of delight’ (1986: 5). Yet he avoids furthering the difference through a discussion on materiality\textsuperscript{300} and somewhat contradicts his own position here, as both works of art and works of science may be elegant and induce a sense of delight\textsuperscript{301} in their creators.

To counter, firstly a praxis of Steinberg’s opinions relies heavily on a single strata of works of art, those that are representational and ‘original’ (e.g. hand-made paintings and sculptures—at least, these are all that he cited). Such a limited definition ignores much work in the field of twentieth-century art theory, which questions the originality of art in the context of technology and reproduction as well as the larger political ramifications of such developments (e.g. Walter Benjamin, Herbert Marcuse, and Rosalind Krauss’s perspectives on photography, among numerous others). As a case in point, consider the works discussed in this thesis where artists utilized scientific methods (fundamentally repeatable) to create their works and, even in the case of TC&A have recreated or, better termed, ‘re-grown’ their creative artefacts for varied exhibitions. By relying on a small data set of ‘original’ works of art, Steinberg overlooked a whole trajectory of art present from the time of John James Audubon and Ernst Haeckel onwards.

Further Steinberg’s analysis of art\textsuperscript{302} is based on the visual aspects in the capability of the form and quality of a work to induce emotive response in viewers (inversely he was very critical of scientists discussing their work in the context of aesthetics). Yet, such a traditional

\textsuperscript{297} As he said, ‘More often they are merely breaking the Tenth Commandment: When scientists claim to be not unlike artists; when artists (or their spokesmen) say they are operating like scientists, neither group speaks from professional competence … the artist envying science its arcane complexity, its apparent validity and sine qua non status in modern culture; the scientist envying art its supposed fancy-freedom, its power to move the heart, and its perdurable glory. Each covets his neighbor’s goods’ (Steinberg 1986: 2).

\textsuperscript{298} In relation to Da Vinci’s science, Steinberg stated, ‘Every one of his correct intuitions has surfaced again independently; not one that was not repeatable; not one insight among them that remained unsuperceded. Whereas there is no Leonardo painting that can be conceived again’ (1986: 3).

\textsuperscript{299} Steinberg recalled arts scholar David Freedberg’s argument ‘that the response to images, from the “normal” to the fantastic and the insane, is of a piece; that we love and hate Art in a psychic continuum—and I agree’ (1986: 9). He cited such strong emotive responses to representational works of visual art such as the case of Mary Richardson, who axed Diego Velazquez’s Rokeby Venus (1647–51), as well Mark Twain’s angered response to Titian’s Venus of Urbino (1538) and his own uncanny responses to Dirck Jocobsz’s painting Portrait of the Artist Jacob Cornelisz and His Wife (1550) among others.

\textsuperscript{300} As he stated, ‘The question of art’s relation to materiality has lately grown somewhat intractable in view of developments such as conceptual art. It demands philosophical thinking, like Arthur Danto’s. The subject is interesting and important, but too large for the present’ (Steinberg 1986: 5).

\textsuperscript{301} Of the terms ‘elegance’ and ‘delight’, one should note the use of irony here on the part of Steinberg, as he was alluding to the use of these terms by scientists to describe the visual artifacts resulting from their research as well as how few artists could actually describe their practice in terms of delightful or the results being elegant.

\textsuperscript{302} At least within the context of the Art and Science: Do They Need to be Yoked? work. In his seminal work Other Criteria (1972), Steinberg’s analysis was more inclusive of emerging fields in art and even valorized the work of Robert Rauschenberg, one of the founders of the art and technology movement.
approach may be limited in relation to the works of art that are combined with science (or technology), as such works may not from their intention be rooted in visual artefacts or non-sustainable, art-world contexts (Kagan 2011). In addition Steinberg also narrowly stated, ‘To predict and control is seldom the objective of art’ (1986: 2). However as argued throughout this dissertation, hypothesis and the gathering of evidence is an underlying prerequisite for artists working with organisms and in the larger contexts of ecosystems. As Collins stated of eco-art, ‘It expands the combined disciplines and provides the artist with a new path to social engagement. Inherent in that path is the responsibility for the artist to educate him/herself in several disciplines. In turn, the work needs to be received and evaluated for the totality of its intention’ (2007: 112–113). As such, new approaches towards aesthetic analysis are required to further comprehend and not impede emerging combinatorial art and science practices.

Lastly, Steinberg’s critique of art-science partnerships as resulting from professional envy is further off point from any of the evidence of such relationships found during my research (Chin and Chaney, Johanson and Davis, or the Harrisons with Isaacs, as examples). In fact, precisely because such relationships are formed between individuals with divergent backgrounds, partnerships can make them problematic but attractive (discussed by Tröndle et al. 2011, in chapter 1) yet fruitful (works in this dissertation; further examples found in Kagan 2011 and successful art-science partnerships in Jill Scott’s 2006 book, Artists-in-Labs: Processes of Inquiry). Additionally such cross-disciplinary cooperation could fall under the canon of Mode 2 Transdisciplinarity described by Gibbons et al. whereby ‘specific clustering and configurations of knowledge … is brought together on a temporary basis in specific contexts of application’ (1994: 29).

More recently such clustering of art and science knowledge was further critiqued by art critic and historian James Elkins. Elkins, much like Steinberg, was critical of the use of terms such as ‘beauty’ utilized by scientists to describe visual artefacts resulting from their research and the ‘popular treatments of “art of science”’ (Elkins 2008: 35). Elkins, like Steinberg, largely places his critique on the use and misuse of the term ‘aesthetics’ by scientists and secondly that such criteria for art are based on retinal sensory phenomenon alone. This position has limitations, as addressed often in this thesis, as well as previously in the ideas of Spaid (2002), Collins (2007), Kagan (2011), to some degree by Bishop, even earlier by Lippard in the collection of essays Six Years: The Dematerialization of Art (1973),

303 As discussed previously in chapter 1 in relation to Transdisciplinary Art with Ecology (TAE), Kagan’s ‘Aesthetics of Sustainability’ (2011), varied ideas of eco-art by Spaid (2002), Matlisky (1992), and others, as well as earlier ideas by Burnham (1968) of the shift from object to art to art systems (discussed in relation to works by the Harrisons in chapter 4) and the limitations of traditional aesthetic approaches towards such types of new media work (1971, 1975; discussed in relation to works by Haacke in chapter 3).

304 Inversely Steinberg stated that science, unlike art, ‘is not judged as taste’ (1982: 2), which implied two distinctly different societal roles for these fields: firstly, that art is only of value through subjective analysis (‘taste’), and secondly that science is not, as instead it has real-world, pragmatic value and equates to ‘the’ truth, a position discussed by Brockman and Wilson above as problematic.

305 As Collins further stated, ‘Modernist aesthetics have little value for artists that have embraced post-studio practices. Artists with an interest in environment, social, or political issues; working with objects, texts, or actions do not easily fit within this classical method of aesthetic analysis’ (2007: 116).

306 As Elkins stated, ‘Art history’s disenchantment with science is inversely proportionate to the enchantment of some scientists with what they perceive as deep consonances between art and science. Those arguments should take place within aesthetics, because they turn on the idea that science and art share central values such as simplicity, elegance, harmony, and beauty. That argument, which I think should be called the aesthetic argument about science, can be found for example in Subrahmanyan Chandrasekhar’s book Truth and Beauty: Aesthetics and Motivations in Science, and in various popular treatments of the “art of science”’ (2008: 35).
and also by Burnham and others from the 1960s onward.

Elkins further developed his critique of what he referred to as the ‘standard art-science narrative’ that consists of four arguments that have been used to prove art-science interface. To paraphrase, they are: firstly, that such an focus on art-science would cover only a small subset of artists, not a larger trend in the arts; secondly, that the usual examples of art-science hybridity consist of relatively few historic practitioners (with which he listed the painters Ludovico Cigoli, Henri Valenciennes, Gerard Ter Borch, and graphic artist M. C. Escher); thirdly, that in recent decades artists have had increased interest in technology and new media but not in true scientific methods (their ‘conceptual apparatus of hypothesis and experiment hardly figures in art’), and lastly, that what appeared in modern art in fact is not science but instead popular perceptions of science—‘or at least misunderstood, or reimagined science’ (2008: 38). I will address each of these in order below.

To rebut Elkins’s first and second arguments, what has been argued in this thesis is that there has been a transfer of knowledge from scientists through the arts since the eighteenth century; although there may have been a modest number of these hybrid practitioners, their impact on society at large was enormous and was fundamental to the shaping of the current environmental movement (Nash 1989; Kellert 1996; Rhodes 2004; Sachs 2006). Likewise visual artworks by Ernst Haeckel and John James Audubon directly altered the course of art history (Haeckel to Art Nouveau, Audubon to contemporary art through the works of Peter Edlund, Walton Ford, Mark Dion, and others).

In addition Elkins ignored more recent trends of artists engaging with science in the context of ecology, with figures like the Harrisons, Johanson, Haacke, Chin, and numerous others (for a review, see Spaid 2002; Weintraub 2012). By disregarding the cultural significance of figures like Audubon and Haeckel and more recent practitioners like the Harrisons, Elkins is simultaneously elitist (representing the insular community of ‘art about art’ instead of art interested in the larger social or ecological trends, discussed in chapter 1) and perhaps represents a larger ignorance of Western history on the part of the arts community. Such omissions as Spaid (2002) and Kagan (2011) addressed have remained common practices among art critics focused on the larger, still object-centric artworld.

Elkins’s third argument dealt with the embracing of technology but not true immersion into science or research on the part of artist. Yet as Stephen Wilson stated, ‘Artists can act as research-and-development innovators, inventing or refining new technologies and mak[ing] use of emerging science’ (2010:12). As such the artist is not the consumer of new technology or scientific methods but enabling advancement (a position I further presented evidence for in chapter 4). Likewise, as presented in this dissertation, there is strong evidence that artists are utilizing science beyond the casual degree Elkins suggested.

Elkins’s fourth claim of the use of pseudo-science in works of art has merit; this is a somewhat common practice in the arts community as, for example, with Eduardo Kac’s infamous GFP Bunny (2000). Kac commissioned a biologist to genetically engineer a rabbit with genes from a jellyfish (Aequorea victoria) so that it would phosphoresce when exposed to ultraviolet light (Miller 2014). This scientific methods employed to create such a transgenic organism were real, yet the images of the ‘glowing’ rabbit released by Kac were created in a

307 Elkins 2008: 38
photographic editing program: scientific fantasy—not science fact—as art: a case in point to Elkins’s position. Although such sensational works may generate considerable discourse (and controversy), they may also mislead the public: an area I am especially concerned about in relation to combinatorial art-science practices. As explained in previous chapters in the context of works by Haeckel as well as the special degree of scientific knowledge needed to work with organisms and ecosystems, there can be no room for deceit or artistic license in such combinatorial art and science projects, as the stakes are too high in ethical and ecological terms.

In closing, Elkins’s argumentation exclusively omitted any artists working in the context of ecology, likewise any who have worked directly at the interface with the biological sciences. Elkins alleged, ‘It is fair to say that interest in the theme of science and art is small within art history’ (2008: 35). One must ask if such a conclusion was drawn because he is not aware of such practices, though this seems somewhat doubtful, as he has been a long-time professor at the School of the Art Institute of Chicago (which has an Art and Science initiative in programming with faculty such as Tiffany Holmes, an eco-artist, Andrew Yang, an artist and entomologist, and even Eduardo Kac, all working at the interface between art and the life-sciences. Perhaps Elkins’s decision was because such works are more difficult to categorize (Rockwood 2008) and perhaps do not easily fit within his context of more-mainstream art history. It could also be his personal choice, as Elkins stated there are ‘few art historians [who] care very much about science’ (2008: 35) an opinion one may hope that other art historians do not share.

10.5. By Any Means Necessary: Combining Art with Science for the Sake of Ecology

Critics of the environmental movement such as Ronald Bailey (also a self-described art critic308) have suggested that those concerned with the state of ecosystems have cried out like Chicken Little (Bailey 1993, 2002). For decades Bailey was considered among the most outspoken opponents of environmental conservation in favour of economic growth; under this ‘libertarian’ system of ideas, growth of technology, if left unimpeded, will presumably solve future ecological problems (Bailey 2002; Holt et al. 2009). As a regular contributor to Reason, Forbes, Smithsonian, and other large-circulation publications as well as his own book, Bailey utilizes selective ‘facts’ to discredit larger scientific findings of environmental problems such as ozone thinning, climate change, and opposition to biotechnology, among others (Union of Concerned Scientists 2013).

Bailey’s use of ‘selective’ data is relevant in the context of combinatorial art and science practices communicating ecological understanding to larger, non-specialist audiences. As has been shown in this thesis, art is an effective tool for reaching audiences, but as Bailey has shown, the way in which ‘facts’ are utilized may have political and questionable ends. In the previously described works by Kac, Haacke, Beuys, and Haeckel, misinformation of science as well as actual risks to organisms and ecosystems may have potentially been caused by such art-science projects, even if well intentioned (as discussed previously in chapters 2, 3, and 4; Elkins 2008). Yet at its core, knowledge achieved by science and even that gained

through transdisciplinary means was described as a ‘public good’ according to Kötter and Balsiger (1999: 110).

Yet, those of us working in biology more often than not fear we have already heard Nero’s fiddle in larger ecological terms. At this point, even Bailey has publically affirmed that climate change is real and a result of human activity, as he stated, ‘Temperatures are increasing largely because humanity is pumping greenhouse gases like carbon dioxide from burning fossil fuels into the atmosphere’ (2007: 1). Of amphibians known to science, 41% have suffered declines and many have already gone extinct in the last 35 years; no less than seven species have vanished in the short time I have been a student at Plymouth University (Hoffman et al. 2010; IUCN Red List of Threatened Species 2014). A recent report by the World Wildlife Federation found that 10,380 representative populations of non-human vertebrates (mammals, birds, reptiles, amphibians, and fish) have declined by 52% since 1970 (McClellan et al. 2014: 9). An Intergovermental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) is expected within the year that is composed of findings by greater than 2,000 scientists. More than 30,000 pieces of evidence support the conclusion that climate change is not only real but induced by human behaviour (IPCC.org 2014). The facts are in, no matter how we spin them, that human beings are responsible for the vast majority of threats facing organisms, changes to climate, and inevitably to the long-term survival of our own species (Flannery 2005; Lovelock 2006; Gascon et al. 2007; Stuart 2012; McCabe 2013).

In light of these overwhelming and dismal facts, what is one to do? The answer is, the best we can, by any means necessary. This is not a call for violence but instead for creative actions that work to ‘preserve the integrity, stability, and beauty of the biotic community’ under Aldo Leopold’s ethic (1949: 224): actions attuned with the socially transformative ideas of biological unity from Alexander Von Humboldt, David Henry Thoreau, and Charles Darwin, as well as the utilization of effective strategies to engage audiences such as the captivating visuals and prose by Erasmus Darwin, John James Audubon, and Ernst Haeckel.

We are living in post-normal times that require of us post-normal approaches, be they transdisciplinary art or participatory science (Gibbons et al. 1994; Funtowicz and Ravetz 2003). The goal is nothing short of transforming society from unsustainable approaches to surviving as one species among many on a fragile, finite planet (Collins 2007; Kagan 2011). As Collins has stated, ‘The project of ecological restoration (like preservation and conservation before it) requires critical and radical (socially transformative) cultural components as well as pragmatic and rigorous science if it is to succeed’ (2007: 102). The art and science actions of Patricia Johanson, Mel Chin, the Harrisons, TC&A, and Cornelia Hesse-Honegger are movements towards these directions. To varied degrees they all worked to disseminate knowledge of ecological phenomena to non-specialist audiences while addressing real-world, complex issues.

A cornerstone of such aspirations towards our species’ sustainability, the conservation of other species and ecosystems, lies in the dissemination of these issues to audiences not yet aware and, to varied degrees, their involvement in remediation (Wilson 2002; Ellis and Waterton 2004; Cooper 2012; Brandt et al. 2013). In relation to my own

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309 To borrow from Malcolm X (1964) who borrowed from Jean-Paul Sartre (1963), this is attuned with ideas by environmental theorist Roderick Frazier Nash (as discussed in chapter 2), who viewed environmentalism as a further extension of earlier suffrage movements (1989).
practice as an artist and biologist towards protecting amphibians, I attempted through my own modest means to answer the call by Mendelson et al. (2006) and the IUCN’s *Amphibian Conservation Action Plan* (Gascon et al. 2007). Raising of public awareness of the plight amphibians face was suggested as paramount to success for long-term conservation.

As discussed in chapter 6, quantitative data from participant questionnaires and qualitative evidence from interviews with longer-term volunteers in my participatory biology programs, *Eco-Actions* and *Public Bio-Art Laboratories*, showed signs of increased understanding of amphibians. In a subset survey (conducted at the beginning of the program and at the end) of embedded volunteers in the 2009 Quebec studies, I found that they (n=9) answered general questions about amphibians with a higher degree of accuracy than they did prior to program experiences. The questions and results were as follows:

<table>
<thead>
<tr>
<th>Question:</th>
<th>Before: 15 May 2009</th>
<th>After: 1 September 2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Which one of these animals is important to the health of the environment?</td>
<td>77.8 % (7/9) correct</td>
<td>88.9% (8/9) correct, 1 did not answer</td>
</tr>
<tr>
<td>Can you describe the difference between frogs and toads?</td>
<td>33.3% (3/9) correct, 4 did not answer</td>
<td>66.7% (6/9) correct</td>
</tr>
<tr>
<td>Can you describe the difference between newts and salamanders?</td>
<td>11.1% (1/9) correct, 5 did not answer</td>
<td>33.3% (3/9) correct, 4 did not answer</td>
</tr>
<tr>
<td>How old are amphibians; how long have they been around on this planet?</td>
<td>0% (0/9) correct, 5 did not answer</td>
<td>11.1% (1/9) correct, 3 did not answer</td>
</tr>
<tr>
<td>Do you think that you have an effect on the environment?</td>
<td>88.9% (8/9) correct</td>
<td>100% (9/9) correct</td>
</tr>
</tbody>
</table>

Table 12: Pre- and post-experience results of questionnaires from core volunteers in 2009 Quebec amphibian studies.

Such results, although very modest in scale, do provide further evidence that such participatory biology combined with a transdisciplinary art approach can increase non-specialist understanding of amphibians. Although it is not possible to gauge if participating in the 2009 Quebec *Eco-Actions* and *Public Bio-Art Laboratory* actually had any long-term bearing on the volunteers’ approaches towards amphibian or environmental issues in general, my hope is that at least in some small measure their appreciation and concern for amphibians stayed with them.

Additionally, it is important to recall that it was precisely that within these participatory biology programs that new insights into the ecological phenomenon of deformed amphibians was achieved (as discussed previously in chapters 8 and 9 and further in the conclusion to follow this chapter). Through these primary studies, the discovery was made that predatory attacks on tadpoles by larval dragonflies (notably *Sympetrum* species, *A. junius*, and *A. umbrosa*) and some species of fish (*C. inconstans*) resulted in the partial or whole
removal of one or sometimes both hind limbs. This, at the point of metamorphosis, resulted in permanent limb deformities in young anurans. Such an insight offered an explanation (proximate cause) for the most commonly reported type of deformed frogs and toads, those featuring missing limbs and limb segments (as discussed in chapter 7). In a related analysis of field results, data suggested that populations of such predators appeared to increase in proximity to runoff (from agricultural and urban sources). These findings were shared with the larger scientific community through peer-reviewed and governmental publications, which provided evidence that such participatory programs involving the public can generate knowledge viable to science (Ballengée and Sessions 2009; Sessions and Ballengée 2010b; Ballengée and Green 2010, 2011).

10.6. Conclusion

As discussed throughout this chapter and through the entirety of this thesis, today’s environmental issues are complex and often beyond the scope of single disciplines to address. As such, a combined or even transdisciplinary approach that involves artists, scientists, and all citizens to participate towards solutions may be required. From a taxonomic standpoint (and perhaps from that of epistemology) such emerging arenas of creative entanglement may prove challenging to describe and place within finite categories. From the perspective of Snow (1959), they often weave between polarized cultures of knowledge production (the arts and the sciences).

Such combined art and science practices stand in contrast to the dogmatic ideas of Brockman (1995) and Wilson (1998), who furthered the cultural divide through an attempt to minimize the worth of the humanities to modern society. Lehrur (2008), on the other hand, reaffirmed the value of both the artistic and scientific fields and presented similarities in approach and outcomes as a form of hybridity but with no evidence of synthesis. Nicolescu suggested the revision and potential removal of boundaries between disciplines altogether (e.g. a crumbling or perhaps even an abolishment of traditional ‘towers of knowledge’, a potential yet not fully described form of synthesis) and as well ideas by Kagan (2011) on the restructuring of society towards sustainability as beginning with moving away from reductionist approaches in sciences.

Mittelstraß (2002, 2011) called for further efforts in the sciences for effective integration of disciplines: inter-scientific specialization to address complex problems that transcend the boundaries of the discipline. Gibbons et al. (1994) called for democratic approaches to research that included science and other areas of specializations (including the arts) along with citizen participation (a full mutation, giving rise to new models of approach).

The practices of artists like Johanson, Chin, the Harrisons, TC&A, Hesse-Honegger, and the author synergize with scientific methods to address complex ecological issues. Such combinatory art and science practices rebut critical claims made by Steinberg (1986) and more recently by Elkins (2008). These artists, as well as numerous others, are acting in line with suggestions by Funtowicz and Ravetz (2003) for post-normal actions in urgent, high-stakes, ‘post-normal’ situations such as those we find ourselves in terms of the environment. Transdisciplinary art and participatory biology answer such a call to action, and the
effectiveness of such combined disciplinary programs will be further analyzed in next in the conclusion to this thesis.
Conclusion and Suggestions for Further Research

The river’s tent is broken: the last fingers of leaf
Clutch and sink into the wet bank. The wind
Crosses the brown land, unheard. The nymphs are departed.
Sweet Thames, run softly, till I end my song.
The river bears no empty bottles, sandwich papers,
Silk handkerchiefs, cardboard boxes, cigarette ends
Or other testimony of summer nights. The nymphs are departed.
And their friends, the loitering heirs of city directors;
Departed, have left no addresses.

—“III The Fire Sermon”
The Waste Land, T. S. Eliot, 1922

We stand a pivotal moment in human history; our current and future practices will weigh on the lives of countless other organisms, ecosystems, and perhaps our own long-term survival. Will we continue our quest to hold onto a grail of materiality, or will we finally free the Fisher King, embracing alternative pathways, actions that could lead our species towards sustainability with a more symbiotic relation to the rest of life found on this finite planet? Certainly, making people more aware of other life forms and ecosystems will be required. As such, combinatory art and science practices may be an effective means to increase popular understanding of non-human organisms as well as ecosystems along with the threats they and our own species currently face.

To support such a claim, this thesis research sought to address two primary questions: Firstly, whether understanding of ecological phenomena among non-specialists could be achieved through the novel means of transdisciplinary art and participatory science. Secondly, it sought to ascertain whether new scientific knowledge could be gained during such combinatory art and science practices. These inquire are very relevant in light of the necessity of increasing public consciousness of the host of complex ecological issues we and other species currently face: an important step towards conservation (Wilson 2002; Mendelson et al. 2006; Gascon et al. 2007). If people are not aware of other organisms or ecosystems, how we can expect a larger populace to move towards protecting them (Kriger 2010)?

Evidence generated this study took varied forms but suggested a larger pattern:

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310 To address these questions, evidence was gathered from a mixed-method approach described by Creswell (2003), which in the case of my study included reviews of relevant pre-existing discourses as well as conducting my own interviews and questionnaires (table 1, presented in section 1.5 of the introduction of this thesis; chapters 1 through 7, and 10). Gathered data was then thematically analyzed through an approach that was reflexive, interpretive, and adaptive, in an attempt to look for a larger pattern (Braun and Clarke 2012; performed throughout chapters; further discussed below).

311 To further address the second question, which dealt with the viability of scientific data generated from such integrated art and science practices, qualitative means were used to examine the works of the Harrisons, Chin, TC&A, and Hesse-Honegger (chapters 4 and 10; further discussed below). Both quantitative as well as post-reflective analysis was performed in the context of my own work (chapters 8 and 9; further discussed below).

312 These data sets included answers from short-term volunteers/visitors to my amphibian surveys and labs in England (chapter 6); answers from short-term volunteers/visitors to my amphibian surveys and labs in Quebec (chapter 6); answers
combinatory art-science practices were a successful means to transfer knowledge of ecological phenomena to larger audiences of non-specialists. Although the precise degree of effectiveness of each of these individual hybrid projects or even the art-science practitioners themselves was impossible to quantify, an over-arching pattern of effectiveness was identified from previous writings about these works and their own responses (as discussed previously in chapters 2, 3, and 4). Such findings are relevant, as rarely (if ever) have such practices been analyzed within the specific context of combining art and science to effectively deliver knowledge about ecology to wider audiences in comparison to prior inquiries into ‘bio’ or ‘eco’ art by Hauser (2008), Matilsky (1992), Spaid (2002), and others.

More material evidence was amassed through analyses performed during my own transdisciplinary art and participatory science programs that further demonstrated art and science working in coalescence did increase non-specialist understanding of ecological phenomena (in this case amphibian declines and deformations, as discussed in chapters 6, 7, and 10). In comparison to prior studies of participatory science (Cohn 2008; Bonney et al. 2009a; Miller-Rushing 2012) or transdisciplinary art (Davis, 2005; Tröndle et al. 2011), these new findings call for a combined approach of art and science to effectively reach audiences with an environmental message.

The specific modes of knowledge exchanged between disciplines as well as specific tools utilized to transfer information to larger audiences were able to be identified in the works I analysed (as discussed in chapters 2–6 and 10). Such specific forms and means of exchange were not addressed to such an extent in prior studies of combinatory art-science practices (Miller 2014; Wilson 2010; Anker and Talasek 2008). Within this current study, to further clarify, at least four primary forms of transference of knowledge occurred: science-to-art; art-to-science; art-science to public; public to art-science. These were coupled with various effective strategies for delivery of this information to audiences (table 13).

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313 These results, although they are modest, also provided support to a larger yet still growing body of proof that suggests art as an important means to address environmental issues (with recent contributions by Brown 2014; Weintraub 2012; Moyer and Harper 2012; Kagan 2011; Collins 2007; and others).

314 In light of the fact that I was able to directly conduct question visitors, participants, arts professionals, and other biologists to gain a fuller, precise, and concrete body of evidence (albeit modest).

315 These findings are relevant to the larger amphibian research community, as they provided specific yet novel means of outreach not previously explored in pre-existing models such as the Amphibian Conservation Action Plan (ACAP) by Gascon et al. (2007), nor organizations like Amphibian Ark (AArk). Because of the effectiveness, even though modest, of such combinatory art and science programs, currently I am in the planning stages of future such projects with Amphibian Survival Alliance (ASA), Save the Frogs (STF), and the Dutch organization RAVON. Although to a degree effective, issues still arose which will be discussed further below.

316 Although my sample size of such art-science practitioners was modest (n=15), I chose to dig deep into the practices of a modest number of workers instead of casting a wider net into the chasm of history involving combinatory art and science. There are numerous other artists who have employed scientific methods or to some degree interfaced with science within the context of ecology in recent times that for reasons of limits of space I did not include in my analysis. However, they require mention: Henri Durant’s long-term work with caddisfly larvae; Joseph Scheer, who has amassed countless images and data on thousands of species of moths; Jackie Brookner’s work with gray water remediation through living sculpture; Betsy Damon’s wetland restoration projects; the myco-remediation experiments of Georg Dietzler; and numerous others (for a recent review, see Weintraub’s To Life! Eco-Art in Pursuit of a Sustainable Planet, 2012).
<table>
<thead>
<tr>
<th>Type of Knowledge transfer</th>
<th>Practitioner</th>
<th>Means of Delivery</th>
<th>Recipient of knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science to art</td>
<td>Humboldt</td>
<td>Engaging writings</td>
<td>Delivered to public and scientific community</td>
</tr>
<tr>
<td>Science to art</td>
<td>Darwin, E.</td>
<td>Engaging and provocative writings</td>
<td>Delivered to public and scientific community</td>
</tr>
<tr>
<td>1. Science to art</td>
<td>Haeckel</td>
<td>Visually captivating artworks</td>
<td>Delivered to public and scientific community</td>
</tr>
<tr>
<td>2. Art to science</td>
<td>Audubon</td>
<td>Visually captivating artworks</td>
<td>Delivered to public and scientific community</td>
</tr>
<tr>
<td>Science to art</td>
<td>Thoreau</td>
<td>Engaging and provocative writings</td>
<td>Delivered to public and scientific community</td>
</tr>
<tr>
<td>Science to art</td>
<td>Darwin C.</td>
<td>Engaging and provocative writings</td>
<td>Delivered to public and scientific community</td>
</tr>
<tr>
<td>Science to art</td>
<td>Leopold</td>
<td>Engaging and provocative writings</td>
<td>Delivered to public and scientific community</td>
</tr>
<tr>
<td>Art combined with science</td>
<td>Haacke</td>
<td>Conceptually and visually captivating artworks</td>
<td>Delivered to public and policy makers</td>
</tr>
<tr>
<td>Art combined with science</td>
<td>Johanson + Davis</td>
<td>Visually captivating and immersive public artwork</td>
<td>Delivered to public, scientific community, and policy makers</td>
</tr>
<tr>
<td>Art (potentially)</td>
<td>Beuys</td>
<td>Conceptually engaging action</td>
<td>Delivered to public and policy makers</td>
</tr>
<tr>
<td>influenced by science</td>
<td>Chin + Chaney</td>
<td>Conceptually engaging artwork</td>
<td>Delivered to public, scientific community, and policy makers</td>
</tr>
<tr>
<td>Art to science</td>
<td>The Harrisons +</td>
<td>Conceptually engaging artwork</td>
<td>Delivered to public and scientific community</td>
</tr>
<tr>
<td>Senanayake</td>
<td>TC&amp;A</td>
<td>Conceptually engaging artwork</td>
<td>Delivered to public and scientific community</td>
</tr>
<tr>
<td>1. Art combined with</td>
<td>Hesse-Honegger</td>
<td>Visually captivating artworks</td>
<td>Delivered to public and scientific community</td>
</tr>
<tr>
<td>science</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Art to science</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Science to art</td>
<td>My own practice</td>
<td>Visually captivating artworks and participatory science programs</td>
<td>Delivered to public and scientific community</td>
</tr>
<tr>
<td>2. Art combined with</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>science</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Public to art-science</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table: 13. From practitioners analyzed in this thesis, a number of types of ‘knowledge transfer’, strategies, or means of delivering information and the audiences that received this information were identified.

These findings were relevant, as they suggest that there are plural levels of knowledge transference between the disciplines of art and science as well as even larger audiences, affirming the transdisciplinary approaches of Gibbons et al. (1993); yet to a degree counter to those of Wilson (1998); potentially symptomatic of movements beyond disciplines all together (Nicolescu). Also by comparison, these new findings rebut the anti-utilitarian form of art suggested by Morris (quoted in Kastner 1998, discussed in chapter 3) and countering criticisms of ‘use-less’ combinatory art-science practices (e.g. Steinberg, Elkins, and Wolpert, discussed in chapter 10).

The specific means of delivery (e.g. ‘what worked’) to disseminate an environmental message to the public deserved further attention (discussed in chapters 2 through 6). Recent
art-science practitioners, including myself, have to varied degrees utilized similar tactics as historic figures did to reach audiences; engaging writings (E. Darwin, Leopold, the Harrisons); captivating visuals (Audubon, Haeckel, Hesse-Honegger); intriguing and provocative concepts (Humboldt, C. Darwin, Haecke, TC&A); directed actions (Thoreau; Johanson; Beuys); and others. Although Nash (1989), Orr (1999), Foster (2000), and others have analyzed the way in which environmentalists reach audiences, these new findings may provide a historic trajectory for some of today’s combinatory art-science practices (not previously explored in art history by Brown 2014 or Miller 2013), suggesting that such works are still an effective means to reach audiences.

Wilson (2010), Collins (2007), Lehrer (2004), and others have discussed commonalities between artists and scientists, but fundamental differences exist in approach and outcomes. The specific art-science works of the Harrisons, TC&A, Hesse-Honegger, and my own offered a challenge to this division. As a case in point, each of the hybrid workers utilized the scientific method of research that was disseminated the larger scientific community while making art: at an artifactual level they assumed the role of both artist and scientist. Likewise, the reductionist approach of material sciences was critiqued by Mason (1993), Lehrer (2007), Kagan (2011), and others (discussed in chapters 1, 2, and 10), although all the art-science workers presented within this thesis utilized to some degree reductionist methods of science within their hybrid practices. Within the context of art practices that interface with ecology and organisms, I have strongly argued that a firm comprehension of material science is required, lest one may act in good intentions but achieve negative results.

It was precisely through the reductionist method applied in my scientific research that a mechanism (non-lethal injury by predators) responsible for some types of deformed frogs was identified. In comparison, numerous prior authors had prematurely rejected a role for predators in the induction of deformed frogs (as discussed in chapter 7; Gardiner and Hoppe 1999; Meteyer et al. 2000; Lannoo et al. 2003; Levey et al. 2003; Skelly et al. 2007; Lannoo 2008; please also see Ballengée and Sessions 2009; Ballengée and Green 2011). As discussed

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317 It is important to note that these are not neatly fitted categories, and often practitioners utilized more than one strategy to reach audiences.

318 This may be a helpful insight for conservation efforts, as it identified several creative and novel means to effectively deliver an environmental message to wider audiences.

319 They conducted research with hypothesis formation, testing, and analysis of results, as well as producing scientific publications in addition to artworks exhibited in cultural venues.

320 More in context, each delivered knowledge of ecological phenomena to larger audiences, whether the public or specialists in science, as discussed in chapters 4, 5, 6, and 10. As such I would suggest that the Harrisons, TC&A, and Hesse-Honegger came closer to what Collins (2007) would term as artists who are ‘agent[s] of change’ as well dually being ‘post-normal’ scientists attuned with the ideas of Funtowicz and Ravetz (2003), discussed in chapter 10.

321 As argued previously in this thesis, reducing phenomena down to the smallest material level to understand it in relation to other material is still the of basis of biology and remains important, if even limited as a strategy to understanding physical phenomena.

322 E.g. Ten Turtles Set Free by Haecke, which posed a risk to wildlife populations; Bog Action by Beuys, which may have damaged the wetland he so strongly was trying to protect; or worse yet, spreading misinformation, as did Haeckel to large audiences (discussed in chapters 3 and 10).

323 Lannoo (2008), for example, argued extensively against ‘predation attempts’ as a cause of anuran limb deformities in frogs, because most predators would swallow or kill tadpoles at early stages of limb development and would not be able to precisely remove hind limbs without causing lethal damage to the rest of the tadpole. However, I found that dragonfly nymphs often released badly injured tadpoles, which survived at least to metamorphosis. Likewise, stickleback were documented removing whole limbs and limb sections in larval frogs in both my Quebec studies and earlier studies in England.

324 This is perhaps symptomatic of the problems of communication between specialized areas of research that have developed in postwar science, as described by Mittelstrass (2002, 2011).
in chapter 9, by looking at predator populations in context of the ecological quality of wetlands, evidence was found that suggested anthropogenic factors still may influence frequency of anuran deformities; an important link between environmental stressors (e.g. agriculture and others\textsuperscript{325}) and natural factors (parasites and predators) which had not been well established in prior deformed amphibian studies.

C.1. Limitations of Research

In addition to the limitations of scope and scale already discussed above, other issues that occurred during these studies deserve mention. Firstly, the use of terminologies to describe such combinatory art practices are still limited and not standardly applied by workers in either the fields of art and science. ‘Transdisciplinarity’, for example, has very divergent meanings, depending on the context and perspective of the researcher. Even within the larger canons of thought about transdisciplinary approaches, conflicts arise. A case in point is that the views of Nicolescu are at odds with those of Mittelstraß (perhaps even at a fundamental level: even incompatible, according to a personal communication received from Sacha Kagan). To varied degrees, the same could be said for the characteristics of participatory science, as within them, some approaches are more ‘top-down’, science-to-public approaches (described by Sullivan et al. 2010; Hand 2010; Pilz et al., 2006; and others) and are seemingly at odds with community-formed research as suggested by Funtowicz and Ravetz (2003), Bonney et al. (2009) and others (for a review of differences, see Mueller et al. 2012).

Likewise, the examples of combinatory art and science practices discussed in this thesis to do not neatly fit into pre-existing categories of art history (exclusively ignored, as discussed by Rockwood 2008 and Kagan 2011) and not recognized in the larger context of the history of science at all, from what I could surmise. My attempt to categorize such works as transdisciplinary art with ecology (TAE) is at best highly limited, but more likely a failed endeavour to ascertain the complexity of these practices that transcend disciplines within the context of the vast array of complicated issues we find ourselves, other organisms, and ecosystems involved in at this moment in history.

Another issue pertained to a limitation of the small area of specialized biology I work in, which is that many of us\textsuperscript{326} in the field of amphibian studies do not know our own history. A case in point is that many working in the field of amphibian malformation are not familiar with the work of Jean Rostand. Rostand conducted extensive research, over the course of several decades, into this area and identified several proximate causes for anuran deformities. These included genetic factors, disease, and even, to a degree, predatory injury (1947a, b, c; 1949a, b; 1950a, b; 1951a, b; 1952a, b; 1955a, b, c; 1956a, b; 1958; 1959; 1971; Rostand and Darré 1967, 1969; Rostand et al. 1967; as discussed in chapter 7).

However, Rostand has seldom been referenced in recent studies. This may stem from the fact that many of his works are out of print and in almost exclusively written in French (it is only through my unique circumstances\textsuperscript{327} that I could access his works). Regardless of

\textsuperscript{325} A finding that helped to clarify earlier suggestions by Ouellet et al. 1997, Bonin et al. 1997, an others, discussed in chapter 7.

\textsuperscript{326} As discussed with Stanley K. Sessions, David M. Green, Alain Dubois, Kerry Kriger, Annemarieke Spitzen, Franco Andreone, Tim Halliday, and others, all considered experts within the amphibian research community.

\textsuperscript{327} My wife, Aurore Ballengée, is a native French speaker, and my mother-in-law, Sylvie Hamzaoui, is a retired librarian who helped find these publications in France.
reasons why these studies are not known, it points to a larger issue in contemporary science: We may have become so specialized that we are not crossing inter-scientific disciplines as suggested by Mittelstraß (2002, 2011) or else in our forward-thinking methods of trying to create the ‘public good’ of knowledge described by Kötter and Balsiger (1999), we may have forgotten to reflect on the past.

I would suggest that in both art and science, further reflection on our histories as well as our present should be explored. Perhaps here we may find a background and in it, even further motivation towards a full synergy of these still largely separated fields.

C.2. Recommendations for Future Researchers

My hope is that in some modest sense the work conducted during these studies may shed some small amount of light on combinatory art and science practices in the context of ecology. However, numerous future considerations deserve exploration: Could pre-existing conservation programs integrate strategies from art into their programming? Perhaps artistic and other ‘post-normal’ strategies could become a basis for future hybrid organizations and creative environmental efforts.

In the contexts of historians in art and science, could the emerging combinatory art and science of today find their rooting beyond modernism, the postmodern, or beyond what Kagan (2011) referred to as unsustainable practices? Perhaps future theoreticians will find new ways to describe such art-science works, even moving them beyond the context of disciplines.

In terms of amphibians, I hope the findings here can in some small way make a contribution towards the conservation of these wonderful creatures. There are so many questions left unanswered. I would think the most important is whether we can restore damaged wetlands, which in turn may reduce frequencies of deformities in anurans. Why do odonate nymphs seem to show preference for developing tadpole limbs? Could other factors (e.g. stress from chemicals, climate, or others) be impeding post-injury regeneration in tadpoles? Could the reductionist methods so commonly used in biology be integrated with more whole-systems approaches to give us better insights into the complexity of these ecosystems and their inhabitants?

In its entirety this work has provided evidence that transdisciplinary art and participatory biology work to increase audience understanding of ecological phenomena. It has also shown that such combinatory art and science programs are able to generate new scientific insights. My hope is that this modest work can provide inspiration for future art-science practitioners. We need the creativity of art and science combined with knowledge beyond disciplinary boundaries working in synergy to address the complex, real-world problems ecosystems, other species, and our own kind face. The stakes are high, and the situation grows more urgent everyday.

\textsuperscript{328} For example, many practitioners who have been involved in recent deformed amphibians studies come from and stay within the inter-scientific disciplines of developmental biology, toxicology, teratology, zoology, veterinary science, and others.
Ethical Statement in Relation to Animal Research in this Thesis

The animal research included in this dissertation received approval by the animal ethical committee at Hartwick College, McGill University and Plymouth University (please see appendix for institutional letters of approval). I believe that all organisms have intrinsic value, and as such they should be treated with respect and their welfare and wellbeing should be protected during and outside of the research process. A fundamental principle of my research involved the limited use of animals in my overall field and laboratory studies. This was achieved through the creation of a novel field technique that I entitled VAFID (Visual Analysis for Frog Injuries and Deformities) in which wild-sampled amphibians were examined in situ at the wetlands immediately following collection, and the vast majority (greater than 99%) were released. This was done to minimize individual discomfort from out-of-habitat experiences (e.g. being kept in artificial conditions indefinitely or euthanized and scored under laboratory settings, which has been standard practice in most primary deformed amphibian studies). Secondly, this VAFID technique limited impact on studied amphibian populations (e.g. fewer overall frogs were taken, and no adult frogs of breeding age were taken). Finally, only peri-metamorphic and metamorphic frogs that I deemed terminally deformed or injured were taken from the field, and those with minor injuries or abnormalities were photographically documented and released (again a novel approach from prior deformed amphibian studies).

In laboratory settings, efforts were made to minimize animal distress or discomfort beyond those to which they would be subjected to in natural settings (e.g. injury from predators). The decision was made early in research planning that experimental simulations would only involve scenarios between tadpoles and other environmental factors (e.g. predators, parasites, field-collected water, and sediment samples) found within the actual ecosystems they inhabit. This was based on my own ethical concerns for use of teratological chemicals utilized by other several authors in prior deformed amphibian studies (discussed in previous chapters), in which large numbers of animals were sacrificed with little knowledge of actual field phenomena being gained. Secondly all scenarios involved minimal use of animals, both anuran larvae and predators, to lesson overall impact to wild populations and studied ecosystems. Tadpoles were exclusively utilized as anuran study models, as this age class naturally has a very high mortality rate, with estimates at only 4 to 5 adults surviving out of greater than 200,000 larvae (Green 2012). In wetland habitats with stable anuran populations, tadpoles are found in extremely high numbers (in the millions). Tadpoles utilized in my experiments were from such wetlands and as such, the use of less than 1,000 anuran larvae would have little to no impact on the overall population. Additionally, anuran larvae that were not injured leading to deformation during experiments were released at the time of metamorphosis to their original collection site, again to lesson any overall impact from research on that population.

These decisions were informed by careful review of relevant literature on the ethical treatment of animals in research by the International Council for Laboratory Animal Science, International Society for Applied Ethology, Animal Welfare Information Center, Institute for Laboratory Animal Research, and the animal research ethical approval committees of McGill
University (Canada) and Hartwick College (USA). Also, these ideas were supplemented with
the helpful advice of biologists and doctoral advisors Dr. Angelika Hilbeck and Dr. Stanley
K. Sessions. These decisions were also influenced by philosophies discussed earlier in this
dissertation as advanced by Aldo Leopold and Peter Singer and by discussions with other
amphibian biologists who share the author’s concern for the plight of frogs, such as Dr. David
M. Green, Dr. Kerry Kriger, and others.
**Glossary of Terms**

**Acetylcholinesterase**: An enzyme that breaks down the neurotransmitter acetylcholine at the synaptic cleft (the space between two nerve cells) so the next nerve impulse can be transmitted across the synaptic gap. Pesticides of the organophosphate and carbamate types act to paralyze and kill insects by inhibiting their acetylcholinesterase. (MedicineNet.com, 2013)

**Amelia**: No evidence of a limb, the hip region is smooth and the pigment pattern is not disrupted. (Meteyer et al., 2000)

**Androgen**: a male sex hormone (as testosterone). (Merriam-Webster MedlinePlus.com, 2013)

**Anophthalmia**: Absence of the eye, as a result of a congenital malformation (birth defect) of the globe. (MedicineNet.com, 2013)

**Anura**: Anurans (order Anura) are the amphibians commonly called frogs and toads, which mostly lack tails as adults. They generally have large central bodies with long hind limbs for jumping, hopping or swimming (Stebbins & Cohen, 1997). Anurans live in arboreal, terrestrial, semi-aquatic or completely aquatic habitats as adults and the majority of known species develop (as tadpoles) in aquatic or semi-aquatic environments (Duellman & Trueb, 1994; McDiarmid & Altig, 2000). Anurans are widely dispersed and found in all continents except Antarctica and have been following the last ice-age (Vial, 1973). Anuran species are declining more rapidly than any other group of vertebrates with numerous extinctions reported in the past century (Kriger, 2010).

**Apical Epithelial Cap (AEC)**: when a salamander limb is amputated, epidermal cells from the remaining stump migrate to cover the wound surface, forming the wound epidermis, which proliferates to form the apical ectodermal cap (Dye, 2012, p. 11)

**Biomass**: All of the living material in a given region. (Macroevolution.net Biology Dictionary, 2013)

**Blastema (pl blastemas or blastemata)**: bud from which a regenerating limb develops. (Macroevolution.net Biology Dictionary, 2013)

**Brachydactyly**: Short toe; The normal number of metatarsal bones are present but the number of phalanges (bones in the toe) are reduced. (Meteyer et al., 2000)

**Calcinosi**: the abnormal deposition of calcium salts in a part or tissue of the body (Merriam-Webster MedLinePlus, 2013)

**Cellular differentiation**: The normal process by which a less specialized cell develops or matures to possess a more distinct form and function. (Biology-online.org, 2013)

**Cercariae**: a minute, wormlike early developmental form of trematode. It develops in a freshwater snail, is released into the water, and swims toward the sun, rising to the surface of the water in the warmest part of the day. Cercariae enter the body of the next host by ingestion, by direct invasion through the skin, or through a cut or other break in the skin. Some cercariae of the genera Schistosoma, Clonorchis, Paragonimus, Fascioliopsis, and Fasciola are known to infect humans. They encyst and complete their development in various organs of the body. Each species tends to migrate to one organ, such as Fasciola hepatica, which grows to become a liver fluke. (MedicineNet.com, 2013)

**Chlorinated hydrocarbons**: insecticidal substances which are no longer recommended for use on
food animals because of their persistence in animal tissues and entry into the human food chain. Many of them still find industrial and nonanimal use and poisoning of animals can occur. Poisoning is manifested by nervous excitement, tremor, convulsions and death. Includes aldrin, benzene hexachloride, chlordane, DDD, DDT, heptachlor, isodrin, lindane, methoxychlor. (Farlax, 2013)

**Chromatography:** a process in which a chemical mixture carried by a liquid or gas is separated into components as a result of differential distribution of the solutes as they flow around or over a stationary liquid or solid phase (Merriam-Webster MedLinePlus, 2013)

**Chromium:** a blue-white metallic element found naturally only in combination and used especially in alloys and in electroplating—symbol Cr. (Merriam-Webster MedLinePlus, 2013)

**Cloaca:** the common chamber into which the intestinal and urogenital tracts discharge especially in monotreme mammals, birds, reptiles, amphibians, and elasmobranch fishes; also: a comparable chamber of an invertebrate (Merriam-Webster MedLinePlus, 2013)

**Deformity, Malformation, Abnormality:** These terms are used synonymously throughout this dissertation to describe anuran amphibians that exhibit deviations from the normal body plan such as missing limbs and limb segments, supernumerary limbs, partial limbs and limb structures, missing eyes, and others. This approach is reflective of existing scientific literature where these terms are used largely in the same way. However it is my belief that in future studies it may be necessary to further refine these terms or event new terms as inconsistences arise which may confuse meanings. According to the Merriam-Webster MedlinePlus medical dictionary (2012) deformity is defined as “a physical blemish or distortion” thus implying a deviation to an otherwise normal body-plan, whereas malformation is “irregular, anomalous, abnormal, or faulty formation or structure” thus implying a congenital defect at early development. Thus using the term malformation may suggest an intrinsic problem whereas deformity may point to extrinsic factors leading to deviation, a significant difference (Ballengée & Sessions, 2009).

**Digenetic:** having two stages of multiplication, one sexual in the mature forms, the other asexual in the larval stages. (MedicineNet.com, 2013)

**Digits:** Toes; identified by the number of phalanges and relative position on the foot or hand (Meteyer et al., 2000)

**Ectoparasitic:** a parasite that lives on the outside of its host rather than within the host's body. Fleas and lice are examples. (Biology-online.org, 2013)

**Ectrodactyly:** Missing toe; Distinguished from brachydactyly and refers to a completely missing digit including the metatarsal bone and phalanges. (Meteyer et al., 2000)

**Ectromelia:** An incomplete limb with the lower portion of the leg missing. Types of ectromelia refer to the last identifiable bone e.g., ectromelia of the femur, ectromelia of the tibiafibula, and ectromelia of the tibiale and fibulare. Phocomelia and amelia are also considered types of ectromelia. (Meteyer et al., 2000)

**Edema:** an abnormal excess accumulation of serous fluid in connective tissue or in a serous cavity—called also *dropsy*. (Merriam-Webster MedLinePlus, 2013)

**Encystment:** a process which, among some of the lower forms of life, precedes reproduction by budding, fission, spore formation, etc. The animal (a) first contracts its body to a globular mass (b) and then secretes a transparent cyst (c), after which the mass divides into two or more parts (as in d e),
each of which attains freedom by the bursting of the cyst, and becomes an individual animal. (Biology-online.org, 2013)

**Endocrine disruptors:** A compound that mimics hormones or disrupts hormone regulation—e.g., alkylphenols and phthalates, which are present in pesticides, detergents, cosmetics, plastics (Farlax, 2012)

**Endosulfan:** a toxic crystalline chlorinated insecticide and acaricide C₉H₆Cl₆O₃S used especially on food crops (Merriam-Webster MedLinePlus, 2013)

**Epigenetic:** of, relating to, or produced by epigenesis; relating to, being, or involving a modification in gene expression that is independent of the DNA sequence of a gene <epigenetic carcinogenesis> <epigenetic inheritance> (Merriam-Webster MedLinePlus, 2013)

**Epiphyses:** a part or process of a bone that ossifies separately and later becomes ankylosed to the main part of the bone (Merriam-Webster MedLinePlus, 2013)

**Eutrophication:** the process by which a body of water acquires a high concentration of nutrients, especially phosphates and nitrates. These typically promote excessive growth of algae. As the algae die and decompose, high levels of organic matter and the decomposing organisms deplete the water of available oxygen, causing the death of other organisms, such as fish. Eutrophication is a natural, slow-aging process for a water body, but human activity greatly speeds up the process. (Art, 1993, p. 196)

**Fibroblast:** A type of cell found in connective tissue throughout the body that produces collagen and other proteins found in the extracellular (between cells) spaces. (MedicineNet.com, 2013)

**Genotoxic:** describes a poisonous substance which harms an organism by damaging its dna. (Biology-online.org, 2013)

**Gonadotropin:** Hormone secreted by the anterior pituitary gland and placenta; stimulates the gonads and controls reproductive activity. (Biology-online.org, 2013)

**Gosner Staging:** Throughout this dissertation Gosner staging (GS) or Gosner stages are referenced to describe the developmental or estimated age groupings of anurans (Gosner, 1960). This method is a widely accepted standard means to classify life stages of anuran embryos and larvae (McDiarmid & Altig, 2000). The Gosner Stages (generalized) are: Gosner stages 1-19, embryonic, post-fertilization until hatching; Gosner stages 20-25, hatchlings, early-stage tadpoles; Gosner stages 26-27, hind limb bud formation, mid-stage tadpoles; Gosner stages 31-41, toe differentiation and development, development of hind limbs, late-stage tadpoles; Gosner stages 42-45, Forelimb emergence, changes to eyes and mouth, tail begins being absorbed, peri-metamorphic frogs or toads; Gosner stage 46, Tail absorbed, development complete, Metamorphic frogs or toads.

**Hemoparasite:** an animal parasite (as a hemoflagellate or a filarial worm) living in the blood of a vertebrate (Merriam-Webster MedLinePlus, 2013)

**Histology:** The study of cells and tissue on the microscopic level. (Biology-online.org, 2013)

**Homeobox (HOX) genes:** DNA sequence (of about 180 base pairs) contained in a gene (e.g. hox gene), and code for a protein domain (of about 60 amino acids) that is highly conserved, and can bind to DNA to control gene expression. (Biology-online.org, 2013)
Hypothalamus: the area of the brain that secretes substances that influence pituitary and other gland function and is involved in the control of body temperature, hunger, thirst, and other processes that regulate body equilibrium. (MedicineNet.com, 2013)

Ileum: part of the small intestine beyond the jejunum and before the large intestine (MedicineNet.com, 2013)

Immunosuppression: suppression of the immune system and its ability to fight infection. Immunosuppression may result from certain diseases, such as AIDS or lymphoma, or from certain drugs, such as some of those used to treat cancer. Immunosuppression may also be deliberately induced with drugs, as in preparation for bone marrow or other organ transplantation, to prevent the rejection of a transplant. Also known as immunodepression. (MedicineNet.com, 2013)

Instar: an insect or other arthropod that is between molts (molting is shedding its outer shell, or exoskeleton). (Biology-online.org, 2013)

Integumentary: pertaining to or composed of skin. (Biology-online.org, 2013)

Intraerythrocytic: situated or occurring within the red blood cells (Merriam-Webster MedLinePlus, 2013)

Larva: An embryo which becomes self-sustaining and independent before it has acquired the characteristic features of its parents. (AmphibiaWeb.org, 2013)

Labia: Lip-like structure (AmphibiaWeb.org, 2013)

Malathion: an organophosphorus insecticide used as a topical pediculicide. (Farlax, 2013)

Mesoderm: middle of the three germ layers, gives rise to the musculoskeletal, blood, vascular and urinogenital systems, to connective tissue (including that of dermis) and contributes to some glands. (Biology-online.org, 2013)

Mesenchyme: embryonic tissue of mesodermal origin. (Biology-online.org, 2013)

Mesocosm: an experimental apparatus or enclosure designed to approximate natural conditions, and in which environmental factors can be manipulated. Mesocosms characteristically include both natural species assemblages in addition to structured populations (US National Oceanic and Atmospheric Administration, 2013)

Metacercariae: The encysted maturing stage of a trematode in its intermediate host prior to transfer to the definitive host, usually representing the organism's infectious stage. (Farlax, 2013)

Metatarsal: Any one of the metapodial bones in the hind foot. (AmphibiaWeb.org, 2013)

Metacarpal: The rod-shaped bones of the forefoot of tetrapods, articulating with the carpal bones proximally and with the phalanges distally. (AmphibiaWeb.org, 2013)

Miracidia: the free-swimming ciliated first larva of a digenetic trematode that seeks out and penetrates a suitable snail intermediate host in which it develops into a sporocyst. (Merriam-Webster MedLinePlus, 2013)
**Naiad:** an aquatic insect nymph (as of a mayfly, dragonfly, damselfly, or stone fly). (Merriam-Webster, 2013)

**MS222 (tricaine methanesulfonate):** the most commonly used anesthetic for fish. It is dissolved in water and enters into the systemic circulation via the gills, producing a general anesthesia. (Farlax, 2013)

**Odonata:** Odonates (order Odonata) are the group of winged insects that encompass dragonflies (Anisoptera/ Epiprocta) and damselflies (Zygoptera) (Corbet & Brooks, 2008). Larval odonates, called nymphs, develop in aquatic or semi-aquatic environments and are voracious predators on one-another, other invertebrates and aquatic vertebrates including sometimes even eating metamorphic frogs (Corbet, 1999). Nymphs undergo varied stages of development called instars, and in their final instar emerge from the water to shed their skins to arise as fully formed adult dragonflies/ damselflies (Corbet, 1999). As adults they remain predacious and can eat many times their own weight of other insects within a few days. Recently, internet order dragonfly nymphs have been sold as an “environmentally-friendly” form of mosquito control, however the impact of such Odonate introductions on native fish, amphibian and other organisms is not known (Ballengée & Sessions, 2010b).

**Ontogenesis:** the development or course of development especially of an individual organism. (Merriam-Webster MedLinePlus, 2013)

**Organochlorine:** of, relating to, or being a chlorinated hydrocarbon and especially one used as a pesticide (as aldrin, DDT, or dieldrin). (Merriam-Webster MedLinePlus, 2013)

**Parotid Glands:** Poison glands that are used for defense mechanism. They are usually located on the dorsal surface of the body behind the head. (AmphibiaWeb.org, 2013)

**Pearson chi-square technique:** is any statistical hypothesis test in which the sampling distribution of the test statistic is a chi-squared distribution when the null hypothesis is true, or any in which this is asymptotically true, meaning that the sampling distribution (if the null hypothesis is true) can be made to approximate a chi-squared distribution as closely as desired by making the sample size large enough. (Wikipedia.org, 2013)

**Peri-metamorphic:** Gosner stages (43-45) of anuran development when the forelimbs emerge until tail absorption (Gosner, 1960)

**Photophobic:** avoiding light; growing best in the absence of light. (Farlax, 2013)

**Planorbeilla:** is a genus of freshwater air-breathing snails, aquatic pulmonate gastropod mollusks in the family Planorbidae, the ram's horn snails, or planorbids, which all have sinistral, or left-coiling, shells. (Farlax, 2013)

**Polydactyly:** More than the normal number of metatarsal bones are present with or without a complete set of phalanges. (Meteyer et al., 2000)

**Polymelia:** More than two forelimbs or more than two rear limbs are present. The extra limb needs to have identifiable major segments (e.g. femur and tibiafibula) to be classified as a multiple limb. (Meteyer et al., 2000)

**Polymorphonuclear:** Having nuclei of varied forms; denoting a variety of leukocyte. (Biology-
**Ranid:** any of a large family (Ranidae) of long-legged frogs distinguished by extensively webbed hind feet, horizontal pupils, and a bony sternum (Merriam-Webster, 2013)

**Rediae:** A kind of larva, or nurse, which is produced within the sporocyst of certain trematodes by asexual generation. It in turn produces, in the same way, either another generation of rediae, or else cercariae within its own body. Called also proscolex, and nurse. (Biology-online.org, 2013)

**Retinoic acid (RA or all-trans-retinoic-acid):** the aldehyde (retinal) has long been known to be involved in photoreception, but retinoic acid has other roles. There are cytoplasmic retinoic acid binding proteins and retinoic acid response elements that regulate gene transcription. Retinoic acid is thought to be a morphogen in chick limb bud development and in early development of the chick that probably accounts for its potent teratogenic action. (Biology-online.org, 2013)

**S-methoprene:** an insecticide C_{19}H_{34}O_{3} that arrests growth at the larval stage of development (Merriam-Webster, 2013)

**Seminiferous tubule:** any of many threadlike structures, located in the testes, that are the specialized areas of sperm production. (wiktionary.org, 2013)

**Skin web (cutaneous fusions):** a band of skin crossing a joint and restricting motion of that limb. (Meteyer et al., 2000)

**Spectrometry:** the measurement of the wavelength of electromagnetic radiation, especially any of several techniques used to analyze the structure of molecules; the measurement of spectra of things other than radiation, such as the masses of molecules and their breakdown products. (wiktionary.org, 2013)

**Spongiform:** like a sponge, porous, full of holes. (wiktionary.org, 2013)

**Sporocyst:** a cyst that develops from a sporoblast and from which sporozoites develop; a larval stage in many trematode worms (wiktionary.org, 2013)

**Tarsus:** Posterior part of the foot. This term is used to describe the bones that make up the posterior part of the foot. (AmphibiaWeb.org, 2013)

**Teratogenesis:** the development of congenital malformations. (wiktionary.org, 2013)

**Teratogens:** any agent or substance which can cause malformation of an embryo or birth defects. (wiktionary.org, 2013)

**Thiosemicarbazide:** An analogue of a semicarbazide that contains a sulfur atom in place of the oxygen atom. (wiktionary.org, 2013)

**Tibia:** The bone on the medial side of the lower leg, in line with the first digit. (AmphibiaWeb.org, 2013)

**Tibiafibula (bony triangles)**
**Trematode**: any of several parasitic flatworms, of the class *Trematoda*, that have external suckers (wiktionary.org, 2013)

**Zone of polarizing activity**: region of mesenchymal connective tissue that carries instructions which direct the developing limb bud to form along the anterior-posterior axis. (wiktionary.org, 2013)
Bibliography


Metamorphosis and Behaviour in *Bufo bufo* Tadpoles. *Aquatic Toxicology*, vol. 91, no. 2, 135–142.


Darwin, E. (1825) Botanic Garden, a Poem, in Two Parts; Containing the Economy of Vegetation and The Loves of Plants, with Philosophical Notes. London: Jones and Company.


Dubois, A. (2012) Interview with Alain Dubois [personal communication] with Ballengée, B. [12 November].


Duménil, A. (1867) ‘Description de diverses monstruosités observées à la Ménagerie des Reptiles du
Muséum d'Histoire Naturelle sur les batraciens urodèles a extréries dits axolotls'.


Garber, EAE, Erb, JL, Magnier, and Larsen G 2002, ‘Low Levels of Sodium and Potassium in the Water from Wetlands in Minnesota that Contained Malformed Frogs Affect the Rate of *Xenopus* Development’, *Environmental Monitoring and Assessment*, vol. 90, no. 1–3, 45–64.


Johnson, P. T. J. and Carpenter, S. R. (2008) ‘Influence of Eutrophication on Disease in Aquatic...


Disease: How Interactions between Infection and Environment Affect Predation Risk’. 

Trematode Genus Ribeiroia (Psilostomidae): Ecology, Life History, and Pathogenesis, with 
Special Emphasis on the Amphibian Malformation Problem’. Advances in Parasitology, vol. 
57, 191–253.

Johnson, PTJ, Townsend, AR, McKenzie, VJ, Howarth, R, Rejmankova, E and Glibert, P 
2010, ‘Linking environmental nutrient enrichment and disease emergence in humans and 


Mellon University and the STUDIO for Creative Inquiry.


Transcript Verlag.

Management, 63(3), 269–279.


Island Press.

BC: Islands Institute of Interdisciplinary Studies.

Amphibian Sensitivity to Environmental Contaminants: Are Amphibians Poor Canaries?’ 


no. 2, 192–201.


Multiple Stressor Effects. Pensacola: SETAC Press.


Transdisciplinariedad, 11 September 2005, Espiritu Santo, Brazil.


Toxicology 66:171–182.


Socientize Consortium [online].


Steinberg, L. (1986). ‘Art and Science: Do They Need to be Yoked?’ Daedalus, 1–16.


Appendix Materials

Results of Public Bio-Art Laboratory Questionnaires
1. 2008 Public Bio-Art laboratory questionnaire results (Yorkshire Sculpture Park, Wakefield, England)
2. Examples of public responses to 2008 Public Bio-Art laboratory questionnaires
3. 2009 Public Bio-Art laboratory questionnaire results (SAT, Montréal, Quebec)
4. Examples of public responses to 2009 Public Bio-Art laboratory French questionnaires
5. Examples of public responses to 2009 Public Bio-Art laboratory English questionnaires

Participatory Biology Observation Forms
1. 2008 UK field and laboratory blank observation forms
2. 2009 Canada field and laboratory blank observation forms
3. 2010-onwards International field and laboratory blank observation forms

Complete Figures and Tables
1. Complete Figures
2. Complete Tables

Correspondences with artists
1. Interview with Helen and Newton Harrison (2009)
2. Blank questionnaire to artists (2011)
3. Response from Patricia Johanson (2011)
4. Response from Hans Haacke (2011)
5. Response from Oron Catts (2012)

Correspondences with curators and organizers
1. Blank questionnaire to curators and organizers (2013)
2. Responses from 38 curators and organizers (2013/14)

Correspondences with scientists
1. Blank questionnaire to scientists (August 2011)
2. Response from Franco Andreone, Curator Of Zoology, Museo Regionale Di Scienze Naturali, Torino, Italy
3. Response from David Green, Professor, Redpath Museum, McGill University, Montréal, Canada
4. Response from Kerry Kriger, Executive Director, SAVE THE FROGS, Santa Cruz, California, USA
5. Response from John W. Wilkinson, Research and Monitoring Officer, Amphibian and Reptile Conservation, Bournemouth, England
7. Response from Pierre Raymond Warny, New York State Museum, Albany, New York, USA

Curricula Vitae
1. Art Curriculum Vitae
2. Science Curriculum Vitae
3. Teaching Curriculum Vitae

Select Art Portfolio
1. PDF of select bodies of work (1996-2012)
2. Video work *Un Requiem pour Flocons de neige Blessés* (2009/11)

Select Monographs
1. *From Scales to Feathers: Brandon Ballengée*. Texts by KuyDelair, Peter Boyd, Joanne Cooper, Robert Mattison, James Secord. (Eds.) Michiko Okaya, Adrian Plant. Published by Lafayette College, Easton, (USA); Shrewsbury Museum, Shropshire, (UK); Verbeke Gallery, Antwerp (BE). forthcoming

Select Public Presentations
2. University of New Mexico’s Museum of the Southwestern Biology, Albuquerque, New Mexico, USA, “Malamp: The Occurrence of Deformed Amphibians”, 24 February 2012
4. Redpath Museum, McGill University, Montreal, Canada, “Temporal and spatial analysis of deformed amphibians at selected localities in Southern Quebec: What role do Odonate predators play in inducing anuran limb abnormalities?”, 2 November 2010
5. Joint Meeting of the American Society for Ichthyologists and Herpetologists, Providence, Rhode Island, USA “Predation induced limb-deformities in Southern Quebec anurans”, 11 July 2010
7. Concordia University, Montréal, Canada, “Malamp: The Occurrence of Deformed Amphibians”, 28 March 2010
9. Yale University, School of Forestry & Environmental Studies, New Haven, Ct., “Ecological Art that generates Primary Research Biology”, 25 April 2006

Select Science Articles


Select Transdisciplinary Articles

Transfer Paper (2009)
2. Transfer paper appendix materials

Video Documents
2. PAV Eco-Action documentary by PAV, Torino, Italy (2010)
3. Quebec Citizen Science Volunteer interviews, by Brandon Ballengée, SAT, Montréal, Canada (2009)

Ethical Approvals for Research
1. Ethical Approvals from Hartwick College (2008)
2. Ethical Approvals from McGill University (2009)
3. Ethical Approvals from Plymouth University (2009)
Brandon Ballengée Curriculum Vitae

Scientific Publications:


Art Publications:


**Invited Presentations and Participation in Conferences:**


Ballengée, B. (2006) ‘Ecological Art That Generates Primary Research Biology’, paper presented 25 April, Yale University, School of Forestry and Environmental Studies, New Haven, CT (USA).


Solo Exhibitions:

**Malamp: The Occurrence of Deformities in Amphibians**


2010 Parco Arte Vivente, Centro d’Arte Contemporanea, Torino, Italy. ‘Praeter naturam’, 7 July–10 October.


2007 Peabody Museum of Natural History, Yale University, New Haven, CT (USA). ‘Early Life’, 1 May–15 September


Group Exhibitions:

**Malamp: The Occurrence of Deformities in Amphibians**


Exit Art/The First World, New York, NY (USA). ‘Every Exit is an Entrance’, 24 March–19 May.

2010 Museo Della Scienza e Della Tecnologia, Milano, Italy. ‘STEP 09 Art Fair’, 26 November–28 November.
Koning Boudewijngebouw, Brussels, Belgium. ‘Sustainable Philanthropist’.


Ars Electronica Center, Museum of the Future, Linz, Austria. ‘Ars Electronica Festival’, 4 September–9 September.
National Centre for Contemporary Art, Kaliningrad Branch, Russia. ‘Evolution Haute Couture: Art and Science in the Post-Biological Age’, 8 August–28 August.
Z33, Hasselt, Belgium. ‘1% Water’, 29 June–28 September.

Centro Andaluz de Arte Contemporanea, Seville, Spain. ‘BIOS 4’, 3 May–2 September.
Centre d’Art Santa Mònica, Barcelona, Spain. ‘Dios de Bioart 07’, 16 March–10 June.
