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The need, opportunities, and challenges for creating a standardized framework for marine restoration monitoring and reporting

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Abstract

Marine ecosystems have been used, impacted by, and managed by human populations for millennia. As ecosystem degradation has been a common outcome of these activities, marine management increasingly considers ecosystem restoration. Currently, there is no coherent data recording format or framework for marine restoration projects. As a result, data are inconsistently recorded and it is difficult to universally track progress, assess restoration's global effectiveness, reduce reporting bias, collect a holistic suite of metrics, and share information. Barriers to developing a unified system for reporting marine restoration outcomes include: reaching agreement on a framework that meets the needs of all users, funding its development and maintenance, balancing the need for 'ease of use' and detail, and demonstrating the value of using the framework. However, there are opportunities to leverage arising from the United Nation Decades of Ecosystem Restoration and Science for Sustainable Development and with existing processes already developed by restoration groups (e.g. Global Mangrove Alliance, Society for Ecological Restoration). Here we provide guidelines and a roadmap for how such a framework could be developed and the potential benefits of such an endeavor. We call on practitioners to collaborate to develop such a framework and on governing bodies to commit to making detailed reporting a requirement for restoration project funding. Using a standardized marine restoration monitoring framework would enable the application of adaptive management when projects are not progressing as expected, advance our understanding of the state of worldwide marine restoration, and generate knowledge to advance restoration methodologies.

Keywords: Marine; Ecosystem restoration; Monitoring; Conservation evidence; Reporting

Highlights:

- The field of marine ecosystem restoration is growing rapidly.
- Currently projects are failing to systematically record the outcomes of restoration.
- This gap hinders the field and prevents knowledge sharing and refined methods.
- Developing a restoration reporting framework will help address this issue.
- We present a roadmap for creating a restoration reporting framework.

1. Global state of marine ecosystem restoration

Humans have undertaken restoration-like actions, including hydrologic modification, transplanting, and weeding in coastal and marine ecosystems to maintain and enhance culturally important natural resources for millennia (Saunders et al., 2020). However, modern ecosystem restoration, i.e. "the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed" (SER, 2004), was only conceptualized by Aldo Leopold in the 1930s. Ecosystem restoration has since evolved into a robust body of research and practice and has expanded from terrestrial into freshwater and marine systems. Restoration is now recognized as vital to support the recovery of the abundance, structure, and function of marine life due to catastrophic declines in marine species, habitats, and ecosystems (Appendix 1 - "Awareness" Duarte et al., 2020).

While there is evidence from the 18th century of ecosystem restoration of oyster reefs and the 20th century in coral reef, kelp forest, seagrass meadow, mangrove, and saltmarsh ecosystems, the field remains relatively small compared to terrestrial restoration and grew slowly over the 20th century (Saunders et al., 2020). This lag is thought in part due to marine ecosystems being 'invisible' to much of the population (Crowder and Norse, 2008), but also due to the large spatial scales of impacts, the decentralized ownership of marine ecosystems, and a perception that passive conservation approaches such as marine reserves could reverse habitat and biodiversity losses (Elliott et al., 2007; Hawkins et al., 2002). Despite these challenges, new approaches, a greater awareness of the degraded state of marine ecosystems (Lotze et al., 2006), and a growing appreciation of the services provided by marine ecosystems has meant that marine restoration has increased since 1990s (Saunders et al., 2020). Indeed, scientists, governments, industries, aboriginal governments, and non-profit groups worldwide are interested in marine ecosystem restoration (Basconi et al., 2020; Bersoza Hernández et al., 2018; Saunders et al., 2020; Zhang et al., 2018) to restore biodiversity, enhance ecosystem services, offset development, answer scientific questions, or improve society (Hagger et al., 2017). There are now more new marine restoration projects than ever before, and as we move into the United Nations Decade on Ecosystem Restoration (2021–2030) and the UN Decade of Ocean Science for Sustainable Development, there is an impetus to scale up marine and coastal restoration to restore critical ecosystem services such as food production, climate control, and coastal protection (Appendix 1 – "Partnerships").

A major challenge that scientists, practitioners, and policy makers face is to fully determine the biophysical, political, and socio-economic drivers influencing restoration success and track progress towards global restoration and conservation targets. Further, while the scientific community has produced considerable research on marine and coastal restoration, there has been limited success in translating this science into information that can be used by policy makers and practitioners. While ecosystem restoration is a human endeavor and project success is determined by more than the ecological attributes of a system, a recent review of marine restoration projects found that projects most often used only ecosystem attributes such as growth/productivity and survivorship to measure success, while failing to record ecosystem functions and associated socio-economic benefits (Bayraktarov et al., 2020). Monitoring and reporting of restoration outcomes against objectives should enable more reliable assessments of restoration success (Hagger et al., 2017; Seddon et al., 2020), and improve restoration strategies for the future (Suding, 2011).

Here we propose an approach to address some of the challenges facing marine ecosystem restoration, namely outlining a roadmap for the development of a restoration monitoring and reporting framework (Appendix 1). Such a framework would provide a mechanism to measure the progress of a restoration project, stimulate adaptive management, capture its success level, and measure restoration impact. This information will then inform more effective decision making for future marine restoration projects and will assist further development in the field of ecosystem restoration, particularly given its growing societal importance and need.

2. Why is a standardized marine restoration framework needed?

We suggest that a restoration reporting framework (RRF) is needed so that we can learn from past and present restoration projects in an efficient way to inform better evidence-based decision making for future marine restoration (Fig. 1). The proposed RRF is achievable in the short- term and we argue that its creation should be prioritized before the number and magnitude of restoration projects accelerates further. A RFF will enable the standardization of reporting, so that restoration outcomes from projects applying different methodologies become comparable. We define a RRF as a cohesive set of tools (a structured set of activities, guidelines, and standards) for the planning and management of reporting success and failures for restoration projects or programs. Therefore, it is important that an RRF includes a standardized set of information, i.e., 'metrics', that are recorded for all restoration projects. This standardization would encompass the metrics that are recorded (e. g., duration, actors, extent, costs), their units (e.g., days, m^2, or specific categories), as well as a standardized protocol for storing and accessing the information. This framework could encompass all coastal, habitat forming ecosystems because they share several key characteristics (i.e., biotic marine environments in the photic zone) and monitoring requirements. We believe it is beneficial to encompass all marine ecosystems as lessons learned in one system may be applied to another and because many marine ecosystems are in fact mosaics and are not independent in the seascape (Gillis et al., 2014; Saunders et al. 2014; Nagelkerken et al., 2015).

The proposed RFF would provide a number of advantages over currently uncoordinated and disparate efforts, including to: 1) consolidate the metrics being recorded 2) facilitate progress tracking and project synthesis to advance our quantitative understanding of restoration success 3) ensure collation of wider set of metrics to ensure socio-economic and cultural aspects are taken into consideration 4) reduce reporting bias, and 5) facilitate greater information sharing between projects. Below we expand on each of these concepts.

2.1. Project tracking and synthesis

Understanding the drivers of restoration project success is a complex process that currently involves hundreds of disparately collected metrics. When standard data (i.e., the same metrics collected across many projects) are available, large scale meta-analyses allow us to identify the overall impact of restorative actions and the factors driving the impact (Benayas et al., 2009). However, Bayraktarov et al. (2020) found that in 275 publications on marine restoration, of the 465 different metrics recorded, only the survival of the restored organism was universally recorded. As a result, syntheses often have data gaps with only partial information recorded by all projects (Bayraktarov et al., 2016; Eger et al., 2020a) or incompatible formatting that results in their exclusion from a larger analysis altogether. The wide array of metrics used and the lack of standardization and comparability hampers our ability to draw conclusions about restoration success across multiple projects using different methodologies. Having a RRF that standardizes the data collected will greatly increase the statistical rigor of analyses. Cumulatively, these improvements should allow for better predictions of what drives restoration success, better project planning, and ultimately, more successful restoration projects (Christie et al., 2020).

Multiple national or international organizations have restoration targets or goals. For instance, the Global Mangrove Alliance has a target of 20% of mangrove areas restored by 2030 (Waltham et al.,

2020) and the European Union has a goal of restoring 'significant areas' by 2030 (European Commission, 2020). Yet, it remains difficult to track restoration progress towards these goals. The RRF would help increase data reporting and comparability across projects, such that we are comparing like-to-like and produce a comprehensive understanding of the national, regional and global state of restoration (i.e., quantification of the area that has been restored or how much progress has been made towards restoration targets and the delivery of ecosystem services, Greiner et al., 2013; Zu Ermgassen et al., 2020). Consistent and accurate monitoring of these restoration targets will be essential for meeting governmental goals as well as for potential industries such as blue carbon credits (Wylie et al., 2016).

2.2. Capturing multiple dimensions of restoration

Ecosystem restoration is a human construct, accordingly societal preferences and motivations dictate the future of restored and unrestored ecosystems (Bayraktarov et al., 2020). While ecosystem restoration has traditionally focused on its namesake, ecology, resulting in the collection of biological metrics, there is increasing recognition of the need to incorporate social, cultural and economic indicators when making restoration decisions (Cohen-Shacham et al., 2016; Fischer et al., 2020). Recording and reporting these metrics can help determine whether marine ecosystem restoration is meeting its true potential as a 'triple bottom line' activity that supports the environment, society, and the economy (Halpern et al., 2013).

To date there has been less attention paid to the social than to the ecological outcomes of restoration projects. For instance, information to understand the socio-economic benefits (e.g. jobs, recreational opportunities, cultural value, wellbeing) generated by the project are often unrecorded. Without recording these metrics, we cannot determine how the restoration action is impacting people. This human dimension is outlined in the SDGs and UN decade guidelines (Claudet et al., 2020) and will become increasingly visible as ecosystems are managed to include and not exclude human activity (Mace, 2014). There is a particular need to ensure that communities that rely on these ecosystems (e.g. Indigenous persons) are not marginalized or disenfranchised from restoration activity.

Through considered design, a RRF will help define what social, economic and governance metrics can be measured and reported. Additionally, the RRF can be supported by guidance on the best approaches and outline best-practice methods for measuring these metrics. While not all project teams will be able to complete the entire RRF, it is envisaged that by outlining the full suite of factors that could be considered when reporting on a restoration project, future project design processes will be stimulated to include a greater breadth of the metrics in the planning process. As such, a RRF will help to evaluate whether projects are achieving social outcomes and indeed benefiting local and global communities.

The ecosystem services generated or enhanced through restoration are also underreported (Bayraktarov et al., 2016), yet recognition and enhancement of these benefits are vital to advancing the field. The quantification of the full set of benefits from restoration is a key component of the total economic value of restoration (Spurgeon, 1999). Decision makers and restoration practitioners need to be able to identify the benefits of restoration so that they can understand the real return on the investment (ROI). The field currently tends to focus on the habitat restored and presumes that benefits will flow from there. However, without adequate documentation of the benefits of restoration there will be less incentive to allocate the high level of resources needed for large scale restoration. A RFF can help to overcome this problem by capturing the metrics needed to parameterize and validate models estimating the ecosystem service benefits (both monetary and non-monetary values) from restoration. These ecosystem service models can then be applied to any restoration projects as long as standard metrics are recorded. As data become more readily available, a greater understanding of the benefits and value of restoration will further motivate additional restoration projects, in particular by enabling ROI estimates and benefit-cost analyses (BCA) to support the case for the expansion of restoration in a growing range of ecosystems and situations (Knoche et al., 2020).

Project financing is a major element of marine restoration (Eger et al., 2020b) that currently receives little focus. Both the cost and cost efficacy of projects influence the likelihood that a project will be attempted or completed. At present there are major inconsistencies in reporting project costs or the breakdown of these costs (Bayraktarov et al., 2016). A lack of cost reporting makes it difficult for future projects to formulate accurate budgets or understand the cost-benefit trade-offs of certain actions when undertaking ecosystem restoration (Iacona et al., 2018). As actors are often motivated to make decisions based on the premise of a net economic gain (Brent, 2006), the absence of accurate cost estimates may inhibit or even prevent investment in restoration projects. Further, as funding for restoration projects is limited (Evans et al., 2012) restoration practitioners need to make efficient use of the funds available to them. A RFF will standardize how costs are monitored and reported across projects and help generate an improved understanding of the costs of restoration and encourage the sharing of this kind of data. In turn, better restoration accounting will facilitate planning and cost-effectiveness analyses. Combining the costs with the benefits will also enable the development of BCA models and allow for more nuanced restoration planning decisions to be made (Duke et al., 2013).

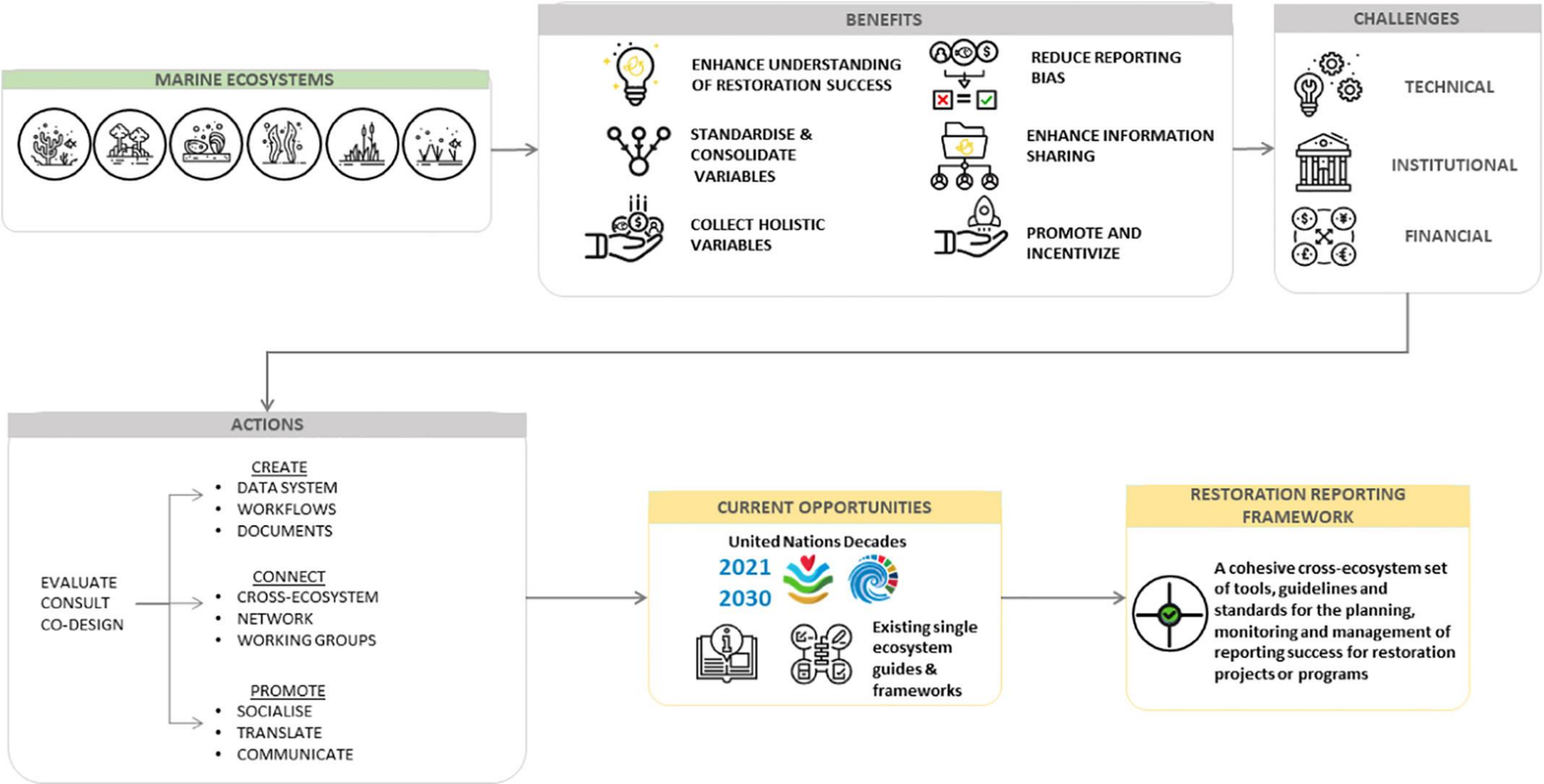

Figure 1. Overview of the opportunities, actions, benefits, and challenges for creating a standardized marine restoration reporting framework. Ecosystem icons represent all major marine ecosystems targeted for restoration icons (from left to right): corals, mangroves, shellfish reefs, kelp forests, tidal marsh and seagrasses.

2.3. Reporting bias

Reporting bias is the selective presentation of successful results. It limits our understanding of the causes of project failures, which are often not recorded and/or not reported (Catalano et al., 2019). This bias can be driven by many factors, including a tendency to only publish the information perceived to be most attractive to scientific journals, the desire to avoid admitting project failure, the desire to meet statutory or organizational environmental management targets, or other unknown factors (Cooke et al., 2019). Regardless of the underlying reasons, it is likely that failures in ecosystem restoration are underreported. Although these “failed” projects may not have succeeded in restoring an ecosystem, they can still provide essential information on what prevented success, as understanding and addressing the causes of failure is a key process in improving ecological restoration practices. Instituting a RFF from the beginning of a project will help guarantee that all the relevant information is recorded, not just the most positive or desired results. Projects could commit to using the RRF before starting and thus ensure that all available information will be used to determine the efficacy of the methodologies used.

Restoration projects are also often funded for limited durations (Bayraktarov et al., 2016; Eger et al., 2021), typically shorter than the ecological succession periods of marine ecosystems. A RFF could help establish recommended monitoring periods for observing the impact of a restoration activity and allow monitoring responsibilities to be easily shared between project partners, by clearly identifying what is being measured, when, how and by whom. Committing to recommended monitoring periods prior to a project's onset, will ensure that projects are adequately budgeted and improve recording of relevant information over a meaningful timeframe

2.4. Enhanced information sharing

Successful restoration projects are being conducted by many different actors across the world. Unfortunately, they are often undertaken in isolation and lessons are rarely shared between projects. Such an absence of knowledge transfer hinders new projects which might have benefited from the experience gained by previous projects. A RFF could adopt a FAIR (Findable, Accessible, Interoperable and Reusable) approach to data dissemination (Wilkinson et al., 2016). Such an approach would allow information to be easily communicated across regions, disciplines, and languages, enabling the RRF to enhance the dissemination of information, accelerate the uptake of valuable lessons learned, and work to build a stronger global restoration community. Making the RRF available in multiple languages and contextually applicable across cultures is a major challenge which could be turned into a significant opportunity to access and share knowledge with restoration practitioners around the globe. Translation or iterative coproduction of an RRF can help reduce some of the barriers associated with publishing biodiversity data (Amano and Sutherland, 2013) while also creating a more inclusive global restoration community for non-English speaking countries which are currently underrepresented in restoration (Bayraktarov et al., 2020). Similarly, a well-designed RRF would help create a common language between actors in differing fields and disciplines (e.g. practitioners, researchers, and policy makers).

3. What are the challenges to the framework?

Despite the benefits arising from a standard framework for marine restoration monitoring and reporting, there are inevitable challenges to the development and the eventual uptake of a RFF. These challenges can be divided into technical, institutional, and financial barriers and will require consideration as the framework is developed to ensure its application meets user expectations and leads to the desired outcomes.

3.1. Metrics to be included

Creating a universal standardized framework, that is robust enough to present useful ecological and socioeconomic information across all marine environments, yet simple enough to be applied by non-technical users and local communities is a major challenge. There are many different metrics that can be, and have been, recorded in marine restoration projects, which reflects the complexity of marine systems as well the multiple needs of different marine user groups. Deciding which of these metrics are essential and which are auxiliary will require careful consideration and require buy-in and collaboration from groups working in specific ecosystems and across some or all ecosystem types. An RRF will require a fine balance of including enough information to ensure the records are comprehensive and not recording too much information so that it becomes burdensome and creates an aversion to using the framework.

3.2. RRF platform and repository

After the RRF is developed, the data recorded will need to be collected, stored, and readily accessible (Wilkinson et al., 2016). These elements require an online home for the documentation describing the framework, a data portal for uploading data, and a reliable server to store and display the information (Ranjan et al., 2018; Siddiqa et al., 2017). While these elements are not exceptionally complex, they require due consideration, funding, and long-term support.

3.3. User uptake

Institutional challenges to a RFF relate to user uptake and support. As there are many elements to restoration, there are also many different projects being led by a wide variety of actors in different countries (Ounanian et al., 2018). For instance, many governments already have reporting frameworks established for service providers and funding recipients under governmental restoration programs, and there may be a lack of administrative flexibility to adopt new frameworks. The first challenge to uptake will be connecting the RRF to project practitioners, whether they are scientists, government groups, Indigenous peoples, businesses, non-profits, or other actors.

Adoption of the framework will likely require a shift away from existing practices towards one that involves a greater degree of transparency. Existing ecological monitoring protocols have evolved to meet user needs and such a change could be perceived as a risk (Harries and Penning-Rowsell, 2011) which could lead to resistance to its uptake. These risks could relate to the explicit recording of restoration failure, which may threaten the legal (e.g. development consent) or social license of an organization (Niner and Randalls, 2021). Data ownership and sharing is also acknowledged as a contentious issue and a barrier to adoption. Issues of commercial interest may lead to further resistance to uptake or 'trust' in a new system. A short publication embargo period may help to address some of these concerns but, some projects or aspects of certain projects will never be publicly reported due to data privacy concerns (e.g. development projects).

3.4. Funding

The last barrier to a restoration reporting framework is funding. Creating a RFF will require significant resources to review existing frameworks, consult users on the development of a new framework, and promote and disseminate the finished product. Because this framework aims to span multiple ecosystems, it may be difficult to entice any one group to fund it in its entirety. For instance, if a country has no coral reefs, they may lack the incentive to fund a project that partially aims to monitor coral reef restoration. Funding will also need to be continuous as the framework will need to be adjusted for changing future conditions, improved based on user feedback, and hosted in a permanent location to ensure sustained access. If funding were to fail, the framework would fail to be useful for future projects and any data hosted alongside the framework might become inaccessible.

4. How do we make it happen?

The success of a marine RRF will be dependent on funding, collaborative and participatory development, and uptake by the global restoration community. These requirements are not trivial, but we believe they are surmountable given the existing and emerging marine restoration landscape, in particular the growth and diversification of a marine restoration constituency.

4.1. Identify existing initiatives and end users

Given the increasing interest in ecosystem restoration (Basconi et al., 2020), nature-based solutions (Cohen-Shacham et al., 2016), payment for ecosystem services (Meyers et al., 2020), restoration standards and methodologies (Gann et al., 2019), and the growth in active participation from groups with substantial resources (e.g. national and international governments, businesses, and philanthropists), there are feasible funding streams to finance the necessary steps (UNEP-WCMC et al., 2020). For instance, the European Union's second environmental target is to “maintain and restore ecosystems” and requires millions of euros in contributions from member states (European Commission, 2020). Further recognition of nature-based solutions for climate change and sustainability will provide additional funding avenues, either through party contributions (European Commission, 2021) or from industries offsetting carbon emissions (Vanderklift et al., 2018) or meeting environmental sustainability targets (Barko et al., 2021).

Much of the required work will be logistical and first requires the identification of existing resources to avoid unnecessary duplication of effort (Appendix 1 – “Synthesize knowledge”). After the state of the field in each ecosystem is established, efforts will be needed to generate a list of potential end users across the different sectors for each ecosystem (Appendix 1 – “Partnerships”). Ideally a key contact person(s) working in each ecosystem and/or region would make these connections. It will be important to ensure that representative end users are included in this step, local persons have a wealth of knowledge about their local ecosystems and can help identify the most important metrics to consider.

4.2. Pilot project(s)

A pilot project focusing on one or two ecosystems in select jurisdictions would help minimize the initial complexity and provide a proof of concept to help incentivize further partnership and uptake (Appendix 1 – “Pilot projects”). Mapping the state of marine restoration (section 4.1) will identify which groups have made the most progress in creating a community of practice and developing reporting standards (e.g. the Global Mangrove Alliance), and which jurisdictions (e.g. countries or states) would be amendable to running a pilot project using those standards.

Once the confines of the pilot study are specified, and the users are identified they can then be engaged on how they monitor, evaluate, report on, and inform restoration projects in their respective ecosystems (Worthington et al., 2020). Minimizing complexity, regardless of the ecosystem, will be key to the success of any RRF – if the framework is too complex, users are unlikely to use it consistently and accurately. This consultation process could consist of multiple rounds, each going back to the end users for feedback (Appendix 1 – "Improved workflows"). Such work could be conducted virtually and in multiple language to encourage wide participation across geographies, although if funding and opportunity are available, the processes could be conducted, at least partially, through in-person workshops or field trials in the specified regions.

Following this pilot project, the process could be repeated across other geographies and ecosystems, each time using the lessons learned from the collective marine restoration community.

4.3. Hosting infrastructure

After the RRF structure is agreed upon, the supporting infrastructure will need to be developed (Appendix 1 – "Hosting"). Specifically, it will need to be hosted online, with a simple data entry portal for users to submit new information. A recent example of such a system designed for coral reefs is MERMAID (Marine Ecological Research Management AID), which is an open-source data platform that aims to accelerate the transformation of data into decisions to save coral reefs. The development of infrastructure to support the RRF will require the development of data templates, user guides linked to best practice, a web page to access these materials, a data portal for entering new information, and a queryable database or data warehouse with an interface to visualize the information (Appendix 1 - "Improved Workflows"). As data are collected, it will be important that they are subject to quality control, either from QA/QC steps built into the data entry, a centralized team or from a peer-review process. After the data are uploaded, they should be freely available and downloadable to maximize their use in restoration practice and research. These are not technologically complex steps but will require adequate funding and resources to ensure their development.

4.4. Release and publicization

Once the RRF has been developed, the next task will be to publicize and ensure uptake (Appendix 1 – "Publicity"). The aforementioned UN Decades can both be leveraged to advertise the framework and encourage its usage. In particular, the UN Decade on Ecosystem Restoration or the Society for Ecosystem Restoration could be potential homes for the completed framework. Alternatively, the framework could be hosted across a range of ecosystem specific restoration groups and alliances, or a new group could be formed to host and promote the framework. Although subsequent discussions will be needed, it is important that these steps be considered and ideally a host confirmed, prior to the development of the actual framework. Therefore, once the framework is complete, there will be no delay in hosting and making it available.

Regardless of the project's home, a well-publicized project launch and promotional materials will help increase uptake of the platform (Appendix 1 – "Launch"). Within this launch, it would be helpful to develop training materials on how to use the framework and the platform (Appendix 1 – "Capacity Building"). It will also be helpful to select one or a few key events to use as launch points for the RRF and provide demos to potential users such as the World Conservation Congress (iucn. org). Uptake can also be motivated by demonstrating the usefulness of the RRF. If users see that using the RRF has benefits such as improved analysis, consolidated project tracking, and readily available data for improved adaptive management, they will be more willing to adopt the new framework.

4.5. Multiple languages

A key step to ensuring uptake and success of the RRF will be to ensure that it meets user needs, globally across all restoration contexts (Appendix 1 – "Partnerships"). This requires that it be available in multiple languages and that its development is ideally co-produced with members representative of the global restoration community. There are many logistical constraints to achieve this, and substantial investment will be required to support the development and maintenance of a multi-lingual platform. Recognizing the current funding constraints within the marine restoration field (Bos et al., 2014) it is unlikely to be achieved from the outset and a reliance on English language for the first iteration will likely be necessary with an aim to translate to multiple languages as funding is made available. To support an equitable approach to this the English iteration should be produced in close collaboration with users of many contexts and languages to ensure representation and inclusion. This engagement will not only ensure that the RRF is inclusive in its application across the restoration community but also that appropriate terminology is applied that can translate across varying global restoration contexts.

4.6. Incentives and requirements for use

If high level partnerships are established, the framework could become a mandatory requirement for restoration projects published in academic journal or those funded by and associated with certain bodies. For instance, as is increasingly common, scientific journals require that data be open access and uploaded alongside publications or environmental data-sharing could become a stipulated condition of biodiversity offsetting resulting from human development and the RRF could be the specified standard. Similarly, project grants and funding could be contingent on a mandated level of restoration reporting as well as the release of data. A common theme for uptake and success is the decentralization of the framework and the buy-in of numerous partners, small and large, from different sectors around the world. Ultimately the success of the framework will rely primarily not on technology, but on societal buy-in.

5. What current opportunities can be leveraged?

Given the global expansion of ecological restoration and its increasing recognition as a global priority we believe that there will be growing opportunities to develop a RFF. There are two ongoing United Nations led initiatives: the "UN Decade for Ecosystem Restoration – UNDER" (Waltham et al., 2020) and the "UN Decade of Ocean Science for Sustainable Development – UNDOSSD" (Claudet et al., 2020). Further, national commitments to restoration are increasing (European Commission, 2021; Prime Minister of Australia, 2021) and countries have standing commitments to reducing CO2 levels (Paris Agreement, 2015) and are increasingly considering restoration as a tool to achieve these goals (Herr et al., 2017). Indeed, the success of these initiatives hinges on the ability to accurately track and monitor restoration projects, and with so much activity, a standardized approach is required. Creating a RFF and enhancing restoration efforts works to meet these goals and are thus valuable contributions to the decade.

There are several promising existing frameworks that can provide valuable lessons learned and/or potentially be incorporated into the development of a comprehensive marine RRF. Chief among these is the Society for Ecological Restoration (SER) framework "International Principles and Standards for the Practice of Ecological Restoration" (Gann et al., 2019). This comprehensive document details the principles for successful restoration projects, including the goals set, as well as the project planning and design stage. Within this framework is a 5-point star system that details how managers can evaluate the success of their restoration project. This framework relies on broad categorical goals such as "soils and waters repaired", "cultures conserved", or "science drawn upon". Any new RRF could be specifically designed to inform these categories and further improve best practices in restoration. Some of the categories within the SER framework are focused on terrestrial systems (e.g. "soils and water repaired") and will need to be modified for the marine and coastal environment. Importantly, SER is an internationally recognized body in ecosystem restoration and could help develop and-or promote the uptake of the RRF ensuring integration between marine, freshwater, and terrestrial ecosystem restoration. Therefore, a partnership with the SER would be beneficial for creating and promoting the RRF.

There are several ecosystem-specific marine restoration guides which could be leveraged to develop a marine RRF. There are currently guides for restoration in coral reef ecosystems (Edwards and Gomez, 2007; Goergen et al., 2020), shellfish reefs (Fitzsimons et al., 2020), seagrasses (Fonseca, 1998), mangroves (Global Mangrove Alliance, 2019), and a guide is in development for kelp forests (Eger et al., 2021). These guides provide some information on which metrics should be recorded (e.g., habitat cover, area extent, project dates) but none contain a comprehensive list across ecological, economic, and social metrics. Furthermore, the guides have not been developed with the intent of sharing information across ecosystems or even necessarily projects. Nevertheless, they can all support a strong knowledge base on which to develop a cohesive RRF.

6. Conclusion

Restoring marine ecosystems at a scale relevant to reversing ecological degradation and to meeting societal goals such as food security, water filtration, biodiversity conservation, and climate adaptation and mitigation, is necessary. This challenge will require iterative research, critical analysis of success and failures, informed decision making, and societal buy-in. A standardized restoration reporting framework will systematically advance the field and ultimately lead to increased efficiencies which can substantially increase the extent of restored marine habitats. The field is currently primed for such a framework with heightened interest, restoration activity, habitat specific restoration and monitoring standards to work from across marine systems, and increased recognition of the importance of ecosystem restoration. Nevertheless, there are logistical and societal hurdles that challenge the framework's development or hinder its adoption. These challenges can be overcome by developing relationships among end users, funding bodies, and regulatory groups. Funding could be a notable barrier, but ecosystem restoration is an increasingly fundable field that has demonstrated economic returns to society (De Groot et al., 2013; Edwards et al., 2013; Knoche et al., 2020). As we consider the need, opportunity, challenges, and steps for developing a framework, it appears that such an endeavor is feasible and will be a significant asset for the global marine restoration community and ocean users worldwide.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi. org/10.1016/j.biocon.2021.109429.

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References

Amano, T., Sutherland, W.J., 2013. Four barriers to the global understanding of biodiversity conservation: wealth, language, geographical location and security. Proc. R. Soc. B Biol. Sci. 280, 20122649.

Barko, T., Cremers, M., Renneboog, L., 2021. Shareholder engagement on environmental, social, and governance performance. J. Bus. Ethics 1–36.

Basconi, L., Cadier, C., Guerrero-Lim ́on, G., 2020. Challenges in marine restoration ecology: how techniques, assessment metrics, and ecosystem valuation can lead to improved restoration success. In: YOUMARES 9-The Oceans: Our Research, Our Future. Springer, Oldenburg, Germany, pp. 83–99.

Bayraktarov, E., Saunders, M.I., Abdullah, S., Mills, M., Beher, J., Possingham, H.P., Mumby, P.J., Lovelock, C.E., 2016. The cost and feasibility of marine coastal restoration. Ecol. Appl. 26, 1055–1074.

Bayraktarov, E., Brisbane, S., Hagger, V., Smith, C.S., Wilson, K.A., Lovelock, C.E., Gillies, C., Steven, A.D.L., Saunders, M.I., 2020. Priorities and motivations of marine coastal restoration research. Front. Mar. Sci. 7, 484.

Benayas, J.M.R., Newton, A.C., Diaz, A., Bullock, J.M., 2009. Enhancement of biodiversity and ecosystem services by ecological restoration: a meta-analysis. Science 325, 1121–1124.

Bersoza Hernández, A., Brumbaugh, R.D., Frederick, P., Grizzle, R., Luckenbach, M.W., Peterson, C.H., Angelini, C., 2018. Restoring the eastern oyster: how much progress has been made in 53 years? Front. Ecol. Environ. 16, 463–471.

Bos, M., Pressey, R.L., Stoeckl, N., 2014. Effective marine offsets for the great barrier reef world heritage area. Environ. Sci. Policy 42, 1–15.

Brent, R.J., 2006. Applied Cost-Benefit Analysis. Edward Elgar Publishing.

Catalano, A.S., Lyons-White, J., Mills, M.M., Knight, A.T., 2019. Learning from published project failures in conservation. Biol. Conserv. 238, 108223.

Christie, A.P., Amano, T., Martin, P.A., Petrovan, S.O., Shackelford, G.E., Simmons, B.I., Smith, R.K., Williams, D.R., Wordley, C.F.R., Sutherland, W.J., 2020. The challenge of biased evidence in conservation. Conserv. Biol. 35 (1), 249–262.

Claudet, J., Bopp, L., Cheung, W.W.L., Devillers, R., Escobar-Briones, E., Haugan, P., Heymans, J.J., Masson-Delmotte, V., Matz-Lück, N., Miloslavich, P., 2020. A roadmap for using the UN Decade of

Ocean Science for sustainable development in support of science, policy, and action. One Earth 2, 34–42.

Cohen-Shacham, E., Walters, G., Janzen, C., Maginnis, S., 2016. In: Nature-based Solutions to Address Global Societal Challenges. IUCN Gland, Switz, p. 97.

Cooke, S.J., Bennett, J.R., Jones, H.P., 2019. We have a long way to go if we want to realize the promise of the "Decade on Ecosystem Restoration". Conserv. Sci. Pract. 1, e129.

Crowder, L., Norse, E., 2008. Essential ecological insights for marine ecosystem-based management and marine spatial planning. Mar. Policy 32, 772–778.

De Groot, R.S., Blignaut, J., Van Der Ploeg, S., Aronson, J., Elmqvist, T., Farley, J., 2013. Benefits of investing in ecosystem restoration. Conserv. Biol. 27, 1286–1293.

Duarte, C.M., Agusti, S., Barbier, E., Britten, G.L., Castilla, J.C., Gattuso, J.-P., Fulweiler, R.W., Hughes, T.P., Knowlton, N., Lovelock, C.E., 2020. Rebuilding marine life. Nature 580, 39–51.

Duke, J.M., Dundas, S.J., Messer, K.D., 2013. Cost-effective conservation planning: lessons from economics. J. Environ. Manag. 125, 126–133.

Edwards, A.J., Gomez, E.D., 2007. Reef Restoration Concepts and Guidelines: Making Sensible Management Choices in the Face of Uncertainty.

Edwards, P.E.T., Sutton-Grier, A.E., Coyle, G.E., 2013. Investing in nature: restoring coastal habitat blue infrastructure and green job creation. Mar. Policy 38, 65–71.

Eger, A.M., Marzinelli, E., Steinberg, P., Verǵes, A., 2020a. Worldwide Synthesis of Kelp Forest Reforestation [WWW Document]. Open Sci. Framew. https://osf.io/5bgtw/.

Eger, A.M., Verǵes, A., Choi, C.G., Christie, H.C., Coleman, M.A., Fagerli, C.W., Fujita, D., Hasegawa, M., Kim, J.H., Mayer-Pinto, M., Reed, D.C., Steinberg, P.D., Marzinelli, E. M., 2020b. Financial and institutional support are important for large-scale kelp forest restoration. Front. Mar. Sci. 7 https://doi.org/10.3389/fmars.2020.535277.

Eger, A., Marzinelli, E., Christie, H., Fujita, D., Hong, S., Kim, J.H., Liee, L.C., McHugh, T., Nishihara, G.N., Vasquez, A.P.G., 2021. Global Kelp Forest Restoration: Past Lessons, Status, and Future Goals.

Elliott, M., Burdon, D., Hemingway, K.L., Apitz, S.E., 2007. Estuarine, coastal and marine ecosystem restoration: confusing management and science–a revision of concepts. Estuar. Coast. Shelf Sci. 74, 349–366.

European Commission, 2020. Our life insurance, our natural capital: an EU biodiversity strategy to 2020 [WWW Document]. URL. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0244&from=EN (accessed 1.21.21).

European Commission, 2021. Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions EU biodiversity strategy for 2030 bringing nature back into our lives Com/2020/380 final. https://eur-lex.europa.eu/legal-content/EN/TXT/? uri=CELEX:52020DC0380.

Evans, D.M., Barnard, P., Koh, L.P., Chapman, C.A., Altwegg, R., Garner, T.W.J., Gompper, M.E., Gordon, I.J., Katzner, T.E., Pettorelli, N., 2012. Funding Nature Conservation: Who Pays?.

Fischer, J., Riechers, M., Loos, J., Martin-Lopez, B., Temperton, V.M., 2020. Making the UN decade on ecosystem restoration a social-ecological endeavour. Trends Ecol. Evol. 36 (1), 20–28.

Fitzsimons, J.A., Branigan, S., Gillies, C.L., Brumbaugh, R.D., Cheng, J., DeAngelis, B.M., Geselbracht, L., Hancock, B., Jeffs, A., McDonald, T., 2020. Restoring shellfish reefs: global guidelines for practitioners and scientists. Conserv. Sci. Pract. 2 (6), e198.

Fonseca, M.S., 1998. Guidelines for the Conservation and Restoration of Seagrasses in the United States and Adjacent Waters. US Department of Commerce, National Oceanic and Atmospheric Administration.

Gann, G.D., McDonald, T., Walder, B., Aronson, J., Nelson, C.R., Jonson, J., Hallett, J.G., Eisenberg, C., Guariguata, M.R., Liu, J., 2019. International principles and standards for the practice of ecological restoration. Restor. Ecol. 27, S3–S46.

Gillis, L.G., Bouma, T.J., Jones, C.G., Van Katwijk, M.M., Nagelkerken, I., Jeuken, C.J.L., Ziegler, A.D., 2014. Potential for landscape-scale positive interactions among tropical marine ecosystems. Mar. Ecol. Prog. Ser. 503, 289–303.

Global Mangrove Alliance, 2019. Taking Action to Increase Global Mangrove Habitat by 20 Percent by 2030. The Global Mangrove Alliance.

Goergen, E.A., Schopmeyer, S., Moulding, A.L., Moura, A., Kramer, P., Viehman, T.S., 2020. Coral reef restoration monitoring guide: methods to evaluate restoration success from local to ecosystem scales. In: NOAA Technical Memorandum NOS NCCOS, 279. https://doi.org/10.25923/xndz-h538.

Greiner, J.T., McGlathery, K.J., Gunnell, J., McKee, B.A., 2013. Seagrass restoration enhances "blue carbon" sequestration in coastal waters. PLoS One 8, e72469.

Hagger, V., Dwyer, J., Wilson, K., 2017. What motivates ecological restoration? Restor. Ecol. 25, 832–843.

Halpern, B.S., Klein, C.J., Brown, C.J., Beger, M., Grantham, H.S., Mangubhai, S., Ruckelshaus, M., Tulloch, V.J., Watts, M., White, C., 2013. Achieving the triple bottom line in the face of inherent trade-offs among social equity, economic return, and conservation. Proc. Natl. Acad. Sci. 110, 6229–6234.

Harries, T., Penning-Rowsell, E., 2011. Victim pressure, institutional inertia and climate change adaptation: the case of flood risk. Glob. Environ. Chang. 21, 188–197. Hawkins, S.J., Allen, J.R., Ross, P.M., Genner, M.J., 2002. Marine and coastal ecosystems. In: Handb. Ecol. Restor, 2, pp. 121–148.

Herr, D., von Unger, M., Laffoley, D., McGivern, A., 2017. Pathways for implementation of blue carbon initiatives. Aquat. Conserv. Mar. Freshw. Ecosyst. 27, 116–129.

Iacona, G.D., Sutherland, W.J., Mappin, B., Adams, V.M., Armsworth, P.R., Coleshaw, T., Cook, C., Craigie, I., Dicks, L.V., Fitzsimons, J.A., 2018. Standardized reporting of the costs of management interventions for biodiversity conservation. Conserv. Biol. 32, 979–988.

Knoche, S., Ihde, T.F., Samonte, G., Townsend, H.M., Lipton, D., Lewis, K.A., Steinback, S., 2020. Estimating Ecological Benefits and Socio-economic Impacts From Oyster Reef Restoration in the Choptank River Complex, Chesapeake Bay.

Lotze, H.K., Lenihan, H.S., Bourque, B.J., Bradbury, R.H., Cooke, R.G., Kay, M.C., Kidwell, S.M., Kirby, M.X., Peterson, C.H., Jackson, J.B.C., 2006. Depletion, degradation, and recovery potential of estuaries and coastal seas. Science 312, 1806–1809.

Mace, G.M., 2014. Whose conservation? Science 345, 1558–1560.

Meyers, D., Bohorquez, J., Cumming, T., Emerton, L., Heuvel, O.v.d., Riva, M., Victurine, R., 2020. Conservation Finance: A Framework. Conservation Finance Alliance.

Nagelkerken, I., Sheaves, M., Baker, R., Connolly, R.M., 2015. The seascape nursery: a novel spatial approach to identify and manage nurseries for coastal marine fauna. Fish Fish. 16, 362–371.

Niner, H.J., Randalls, S., 2021. Good enough for governance? Audit and marine biodiversity offsetting in Australia. Geoforum 120, 38–45.

Ounanian, K., Carballo-C ́ardenas, E., van Tatenhove, J.P.M., Delaney, A., Papadopoulou, K.N., Smith, C.J., 2018. Governing marine ecosystem restoration: the role of discourses and uncertainties. Mar. Policy 96, 136–144. Paris Agreement, 2015. Paris agreement. In: Report of the Conference of the Parties to the United Nations Framework Convention on Climate Change (21st Session, 2015: Paris), p. 2017. Retrieved December. HeinOnline.

Prime Minister of Australia, 2021. Australia announces $100 million initiative to protect our oceans [WWW Document]. URL. https://www.pm.gov.au/media/austra lia-announces-100-million-initiative-protect-our-oceans.

Ranjan, R., Rana, O., Nepal, S., Yousif, M., James, P., Wen, Z., Barr, S., Watson, P., Jayaraman, P.P., Georgakopoulos, D., 2018. The next grand challenges: integrating the Internet of Things and data science. IEEE Cloud Comput. 5, 12–26.

Saunders, M.I., Leon, J.X., Callaghan, D.P., Roelfsema, C.M., Hamylton, S., Brown, C.J., Mumby, P.J., 2014. Interdependency of tropical marine ecosystems in response to climate change. Nat. Clim. Change 4 (8), 724–729.

Saunders, M.I., Doropoulos, C., Babcock, R.C., Bayraktarov, E., Bustamante, R.H., Eger, A.M., Gilles, C., Gorman, D., Steven, A., Vanderklift, M.A., Vozzo, M., Silliman, B.R., 2020. Bright spots in the emerging field of coastal marine ecosystem restoration. Curr. Biol. 30.

Seddon, N., Daniels, E., Davis, R., Chausson, A., Harris, R., Hou-Jones, X., Huq, S., Kapos, V., Mace, G.M., Rizvi, A.R., 2020. Global recognition of the importance of nature-based solutions to the impacts of climate change. Glob. Sustain. 3.

SER, 2004. The SER Primer on Ecological Restoration. Tucson, AZ.

Siddiqa, A., Karim, A., Gani, A., 2017. Big data storage technologies: a survey. Front. Inf. Technol. Electron. Eng. 18, 1040–1070.

Spurgeon, J., 1999. The socio-economic costs and benefits of coastal habitat rehabilitation and creation. Mar. Pollut. Bull. 37, 373–382.

Suding, K.N., 2011. Toward an era of restoration in ecology: successes, failures, and opportunities ahead. Annu. Rev. Ecol. Evol. Syst. 42, 465–487. https://doi.org/ 10.1146/annurev-ecolsys-102710-145115. UNEP-WCMC, FFI, ELP, 2020. Funding Ecosystem Restoration in Europe.

Vanderklift, M., Steven, A., Marcos-Martinez, R., Gorman, D., 2018. Achieving carbon offsets through blue carbon: a review of needs and opportunities relevant to the Australian seafood industry. In: Fish. Res. Dev. Corp. CSIRO Ocean. Atmos. FRDC Proj. 2018, 60, p. R126.

Waltham, N.J., Elliott, M., Lee, S.Y., Lovelock, C., Duarte, C.M., Buelow, C., Simenstad, C., Nagelkerken, I., Claassens, L., Wen, C.K.C., 2020. UN decade on ecosystem restoration 2021–2030—what chance for success in restoring coastal ecosystems? Front. Mar. Sci. 7, 71.

Wilkinson, M.D., Dumontier, M., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.-W., da Silva Santos, L.B., Bourne, P.E., Aalbersberg, Ij.J., 2016. The FAIR guiding principles for scientific data management and stewardship. Sci. Data 3, 1–9.

Worthington, T.A., Andradi-Brown, D.A., Bhargava, R., Buelow, C., Bunting, P., Duncan, C., Fatoyinbo, L., Friess, D.A., Goldberg, L., Hilarides, L., 2020. Harnessing big data to support the conservation and rehabilitation of mangrove forests globally. One Earth 2, 429–443.

Wylie, L., Sutton-Grier, A.E., Moore, A., 2016. Keys to successful blue carbon projects: lessons learned from global case studies. Mar. Policy 65, 76–84.

Zhang, Y.S., Cioffi, W.R., Cope, R., Daleo, P., Heywood, E., Hoyt, C., Smith, C.S., Silliman, B.R., 2018. A global synthesis reveals gaps in coastal habitat restoration research. Sustainability 10, 1040.

Zu Ermgassen, P.S.E., Thurstan, R.H., Corrales, J., Alleway, H., Carranza, A., Dankers, N., DeAngelis, B., Hancock, B., Kent, F., McLeod, I., 2020. The benefits of bivalve reef restoration: a global synthesis of underrepresented species. Aquat. Conserv. Mar. Freshw. Ecosyst. 30, 2050–2065. A.M. Eger et al.