University of Plymouth

PEARL https://pearl.plymouth.ac.uk

01 University of Plymouth Research Outputs University of Plymouth Research Outputs

2019-01

Integrated ecosystem analysis in Irish waters; Providing the context for ecosystem-based sheries management

Pedreschi, D

http://hdl.handle.net/10026.1/12454

10.1016/j.fishres.2018.09.023
Fisheries Research
Elsevier

All content in PEARL is protected by copyright law. Author manuscripts are made available in accordance with publisher policies. Please cite only the published version using the details provided on the item record or document. In the absence of an open licence (e.g. Creative Commons), permissions for further reuse of content should be sought from the publisher or author.

Integrated Ecosystem Analysis in Irish waters; Providing the Context for Ecosystem-based Fisheries Management

Pedreschi, Debbi*[a], Bouch, Paul[a], Moriarty, Meadhbh [a,1], Nixon, Eugene[a], Knights, Antony M.[c] & Reid, David G[a].

[a]Marine Institute, Rinville, Oranmore, Co. Galway, Ireland.

[c]School of Biological & Marine Sciences, Plymouth University, Plymouth, Devon, United Kingdom.

[1]Present Address: Environmental Sciences Research Institute, Ulster University, Cromore Road, Coleraine, Co. Londonderry, BT52 1SA, United Kingdom.

*Debbi.Pedreschi@Marine.ie

Paul.Bouch@Marine.ie

Moriarty-M3@ulster.ac.uk

ernixon1@gmail.com

antony.knights@plymouth.ac.uk

David.Reid@Marine.ie

Abstract:

Fishing has long been considered the most impactful human activity on the marine ecosystem. To adopt ecosystem-based fisheries management (EBFM) requires consideration of all human impacts, not just those of fishing. The ODEMM (Options for Delivering Ecosystem-based Marine Management) approach provides an integrated ecosystem assessment that is a flexible, cost-efficient and expert-based. The framework traces the sectors affecting the marine environment, the pressures they create, and the ecological characteristics affected. This research presents the first application of the ODEMM framework outside of the ODEMM project, completed for Ireland's marine waters. The assessment places fishing in the context of other anthropogenic pressures and highlights areas of threat to Marine Strategy Framework Directive (MSFD) descriptors. From 1,874~~9~~

impact chains, just 59~~60~~ (44~~5~~ of which were attributed to the fishing sector) account for 64% of the Total Risk score, highlighting areas for management action with a high risk-reduction return. Of the sectors, The analysis showed *Waste Water* to have the highest average risk of all sectors, followed by *Land-based Industry, Fishing* and then *Shipping.* In terms of total risk, *Fishing* was the most important sector, due to its high connectance to many ecosystem components and widespread influence, even though many of the impacts are relatively low and the components impacted show a high degree of recoverability. Litter was ~~found to be the highest risk~~identified as the pressure with the highest total risk scores (average and summed) due to its persistence, and widespread reach. Among the ecological characteristics, ~~D~~deep water habitats that have low resilience to pressures showed the highest average total risk, yet the highest impact risks were for ecological characteristics that were closer to land and were impacted more frequently. These conclusions highlight the importance of context and interpretation in the analysis. The impact chains were further linked through to the MSFD environmental status descriptors, indicating *Biological Diversity* and *Food Webs* as the descriptors most at risk, followed by *Sea-floor Integrity*. As the first independent application of the method, issues arose with interpretation of some categories and definitions, and some modifications are discussed.

Overall, this has proven a valuable exercise for helping to identify management priorities. The analysis presented provides useful context for EBFM and a basis for decision making and trade-off analysis for Ireland. The ODEMM framework employed offers a comprehensive, adaptable, globally-applicable tool to guide ecosystem management and the decision-making process, by highlighting risk areas and priorities for management action and research.

KEYWORDS: ecosystem-based fisheries management, integrated ecosystem assessment, risk assessment, ODEMM, MSFD.

1. INTRODUCTION:

Today's ecosystems are widely recognized as being highly impacted and extensively modified by human activities (Firth et al., 2016; Halpern et al., 2008, 2007; Millennium Ecosystem Assessment, 2005; OSPAR Commission, 2010). We struggle to balance our aspirational goals of sustainable management (e.g. Sustainable Development Goal 14: "Conserve and sustainably use the oceans, seas and marine resources" (United Nations, 2015)) with an increasingly developed world and rising population levels (Meadows et al., 2005). Improved knowledge and recognition of the multitude of anthropogenic pressures affecting natural ecosystems has resulted in broad acceptance that ecosystem-based management is essential for the effective conservation and management required to maintain ecosystem services (European Environment Agency, 2006; Halpern et al., 2008; Levin et al., 2009; OSPAR Commission, 2010; Pikitch, 2004). Ecosystem-based management requires consideration of the whole suite of anthropogenic pressures affecting entire ecosystems, rather than focusing on individual components (Borja et al., 2016; Halpern et al., 2007; Harvey et al., 2017; Hilborn, 2011; Levin et al., 2009). In recent years, legislation and policy have also moved in this direction, increasingly requiring scientists and managers to be holistic in their work, advice, and decision-making, rather than looking at single or few elements in isolation (e.g. Marine Strategy Framework Directive (MSFD; European Union, 2008), Common Fisheries Policy (CFP; European Union, 2013), Maritime Spatial Planning Directive (MSPD; European Union, 2014), Magnuson–Stevens Fishery Conservation and Management Act (MSA: *Magnuson-Stevens Fishery Conservation and Management Act.*, 1996), Australia's Oceans Policy (Environment Australia, 1999), Canadian Oceans Act (Department of Fisheries and Oceans, 1996); Oceans Act of 2000 (US Congress, 2000), South African National Water Act (Government of the Republic of South Africa, 1998), etc.). Within Europe, the MSFD specifically enshrines the ecosystem approach in a legislative framework to manage European seas in a sustainable, holistic manner, through establishing (by 2020) and maintaining 'good environmental status' (GES) of the marine ecosystem (European Union, 2008). The current CFP specifically aims to deliver economically, environmentally and socially sustainable fisheries. The CFP also acknowledges that the impacts of human activities on all components of the ecosystem are not fully understood, and makes specific references to multi-annual ecosystem-based management plans (European Commission, 2018; European Union, 2013). The MSPD requires us to manage our waters more coherently by ensuring cross-sectoral human activities at sea take place in an efficient, safe and sustainable way (European Union, 2014). Taken together, these Directives require us to look at fisheries in the context of the suite of other human induced pressures affecting our marine ecosystems.

Efforts to implement ecosystem approaches to fisheries management (EAFM) and ecosystem-based fisheries management (EBFM), as well as the necessary research to underpin them have increased dramatically in recent years (Borja et al., 2016; Korpinen and Andersen, 2016; Pitcher et al., 2009; Trochta et al., 2018), partly in response to legislation. However, actual practical tactical implementation of EBFM in the real world has been much rarer (Borja et al., 2011; Skern-Mauritzen et al., 2016). Efforts have ranged in scale and ambition, from simply incorporating some 'ecosystem knowledge' into single species assessment models at one extreme, to building complex ecosystem models that incorporate the suite of **D**rivers, **A**ctivities, **P**ressures, **S**tate, **I**mpacts (human **W**elfare), management **R**esponses (as **M**easures); (*sensu* DAPSI(W)R(M) after Borja et al., 2016). Ecosystems approaches by definition should include all sectors (Borja et al., 2016; Dickey-Collas, 2014; Fitzpatrick et al., 2010), yet they rarely do (but see Knights et al., 2015). It is perhaps the daunting complexity of what can and/or should be included in EBFM that has led to the rarity of 'real-world' implementation, yet in order to advance EBFM, fisheries (and its pressures) must be placed within the context of the wide range of others sectors and the pressures they create if measures are to be in anyway effective.

Common perception often assumes that fishing is the sector creating the most pressures, affecting the widest range of ecosystem components, and with the greatest impact. However, is this really the case? And if so, does it apply everywhere equally? What pressures beyond 'extraction of species' and ‘sea floor degradation’ does it create, and which ones should we be most concerned about? And importantly, is focusing on fisheries the most efficient way to reduce risk and pressure on the marine environment? Many questions remain, and thus much is to be gained by placing fisheries within the wider context of the ecosystem.

To deliver holistic ecosystems-based marine management, managers must know the causal drivers of impact if they are to be managed (Knights et al., 2014). Integrated ecosystem assessments (IEA’s) have been proposed as a framework to facilitate ecosystem-based management, and to steer management efforts to achieve multiple objectives (Dickey-Collas, 2014; Harvey et al., 2017; Levin et al., 2014, 2009). IEA takes a birds-eye view to assess the suite of pressures that co-exist, identify the sectors that cause them, and the ecosystem components affected by them, thus providing the context in which the sectors and pressures operate. Conceptually, IEA is both simple and sensible, yet implementation is more difficult (Dickey-Collas, 2014; Walther and Möllmann, 2014). The data, monitoring and modelling requirements of full ecosystem based management are many and daunting (Borja et al., 2016; Harvey et al., 2017; Hilborn, 2011; Hobday et al., 2011; McQuatters-Gollop, 2012). Inevitably an extensive list of pressures and threatened ecological components results from such an IEA, and resources are rarely, if ever, sufficient to address them all (Halpern et al., 2007). Therefore tough decisions must be made, and priorities specified. IEA can play a central role in the decision-making process by providing holistic information that is based on best available understanding and knowledge, which then allows comparisons and judgements to be made (i.e. identification of trade-offs) and the most appropriate objectives for management to be determined (Walther and Möllmann, 2014).

There are many tools and stages in the IEA toolbox that are applicable at a range of scales (Harvey et al., 2017; Levin et al., 2014, 2009). One key element, however, is risk assessment (Battista et al., 2017; DePiper et al., 2017; Fletcher, 2015; Hilborn, 2011; Hobday et al., 2011; Holsman et al., 2017; Korpinen and Andersen, 2016; Slater et al., 2017). In broad terms, risk assessment comprises identification (scoping) of relevant pressure elements to include in your assessment (in consultation with stakeholders),~~ and~~ an analysis of the 'susceptibility' of ecosystem components, and their ability to recover ('resilience') post-impact (Levin et al., 2009). Assessments may be quantitative (i.e. indicator-based, see review in Borja et al., 2016), qualitative (e.g. ODEMM, Robinson et al., 2014), or a mixture of the two (e.g. Bayesian Network Analysis, Fletcher et al., 2014); indeed a wide range of methodologies for applying such risk assessments exist (see Korpinen and Andersen, 2016). Quantitative and qualitative assessments are not mutually exclusive, in fact they are often complimentary, each filling the gaps left by the other and can be used together in a series of steps.

In 2014, the ODEMM project (Options for Delivering Ecosystem-based Marine Management, FP7, http://odemm.com/; Robinson et al., 2014) developed a flexible, adaptable and relatively quick and cost-efficient tool that can be tailored to requirements in order to allow the identification and assessment of risk. ODEMM grew out of the OSPAR Quality Status Report methodology (OSPAR Commission, 2010; Walther and Möllmann, 2014), building upon it, while refining the process and developing outputs. The framework traces the causal links of impact (i.e. pressure mechanisms or 'impact chains', sensu Knights et al., 2015) between multiple sectors and the marine environment, 'to provide the structure within which management options can be explored' (Robinson et al., 2014). Scores which detail the spatial extent/overlap, frequency of occurrence, degree of impact, persistence and resilience for each pressure pathway, based on pre-determined categorical thresholds are then assigned by an expert panel informed by data and supported by a cross-check methodology. Through the process, all available information can be incorporated, along with tacit knowledge and expert judgement where data gaps exist. From this assessment, products that are easily interpreted and understood can be created that facilitate the communication of complex messages in a relatively simple format to non-scientists such as policy-makers and stakeholders. This simplicity is critical for enabling the entire suite of ecosystem threats to be observed and understood (Borja et al., 2016). It places each sector and pressure in context of wider human activity, facilitating decision-making and prioritization exercises. Here, we present a risk assessment framework, based on the ODEMM approach, for Ireland's marine waters to inform ecosystem management within the context of the MSFD, CFP and MSPD, and to place fisheries within the context of wider anthropogenic pressures.

2. MATERIALS & METHODS:

The study area was taken as all of Ireland's marine waters (Irish EEZ), encompassing parts of the Irish and Celtic Seas, and the Atlantic Ocean. The ODEMM approach (Robinson et al., 2014) was adopted as the best available means of rapidly and efficiently assimilating expert input into an integrated assessment for the purposes of determining the key pressures acting on the Irish ecosystems and their components. The Irish EEZ expert panel assessment was first attempted in 2012, with the intention to inform Ireland's MSFD Initial Assessment. Only Irish sectors affecting Irish waters were considered, as the aim was to produce a tool to aid in national decision-making. The expert panel were volunteers, and consisted of 43 scientists, advisors and policy-makers from national state agencies and scientific institutions. Details as to the institutes and areas of expertise can be found in Appendix A, Table A.1. Participants were assigned to one of four groups based on their expertise; Group 1 - Predominant Seabed Habitats; Group 2 – Predominant Pelagic Habitats, Fish, Cephalopods; Group 3 – Contaminants; and Group 4 –Mammals, Birds, and Reptiles. Each group had a chair to ensure smooth running and adherence to the protocol. Participants were provided with a 'pilot assessment' carried out by the assessment team and informed by publically available maps and monitoring data (e.g. http://data.marine.ie/). Participants contributed expert opinion and institutionally held data to assign the categorical evaluations (outlined below) to the preliminarily identified pressure-pathways, and to add/remove pathways as they saw fit.

Scores were applied with a 'current status' and 'standard practice' view (i.e. business as usual rather than potential risk assessment). Majority assessment was applied to the scoring of broad ecological components; i.e. where habitats were assessed, emphasis was on assemblage and ecosystem functioning rather than focused on single species. Consensus was sought from the panels; best evidence/majority rules applied where consensus was not immediately forthcoming.

The Irish waters categories differed from the original ODEMM categories, as some sectors and pressures were not applicable in Irish waters, i.e. the removal of sectors and pressures, such as *nuclear energy*, and *introduction of radionuclides* (see Appendix A, 'Comparison' Tab for full comparison). The pressure *introduction of microbial pathogens* was removed due to limited knowledge/expertise of this pressure and its potential impacts. The list of ecosystem components used was increased from 11 to 28 groups in order to provide greater resolution of impacts on regionally important, species groups, pelagic habitats, and benthic habitats, structured by depth and relevant to the MSFD initial assessment (see Figures 1 & 2). Finally, as our area of interest is primarily on the impacts of fishing, and its placing in context with of all other marine pressures, we included the pressure of *bycatch*, to distinguish from *targeted species extraction* and *incidental loss of species/death or injury by collision.*

A 'linkage framework' (White et al., 2013) and 'pressure assessment' (Robinson et al., 2013) were produced as outputs from the assessments. The linkage framework was built by identifying 'links' between elements of the framework, e.g. between a sector and a pressure, and between a pressure and an ecological characteristic. 'Linkage chains' consist of pathways between multiple elements of the framework (i.e. tracing a potential impact from a sector and the pressure it creates to the ecological characteristic affected). Each one of these linkage chains was assessed by the expert panels to assign broad qualitative categories (see Table B1 in Appendix B) to each of 5 assessment criteria; overlap (spatial), frequency of occurrence, degree of impact, persistence (of the pressure), and resilience (of the ecological characteristic) (Robinson et al., 2014) based on the best available knowledge. These qualitative scores were then converted into numerical scores for further analysis (Table B1 in Appendix B).

At the time of the original implementation (2012), the ODEMM project was still ongoing and thus the rules and the guidelines were yet to be finalized. As a result, issues arose with this implementation, particularly around consistency and interpretation of the non-finalized rules and definitions. Therefore, an assessment review was carried out in 2015/2016, using the updated ODEMM guidelines (Robinson et al., 2014; and references therein), and in consultation with one of the original ODEMM team (Dr. Antony Knights). This review and crosscheck process, a common and essential feature of such assessments (Robinson et al., 2013) flagged inconsistencies in particular areas, such as benthic habitats and in relation to the 'contaminants' pressures (i.e. 'synthetic compounds', 'non-synthetic compounds', and 'organic inputs'). As such, expert panels in these fields were re-convened to review and adjust the previous assessment. The benthic panel consisted of seven of the original Group 1, and the Contaminants Panel consisted of five of the original Group 3. ~~D. Pedreschi & M. Moriarty joined as the chairs and facilitators of the re-assessments.~~

Following the guidelines provided in the ODEMM guidance documents and published papers (for full methodological details see: Knights et al., 2015, 2013; Robinson et al., 2014, 2013; White et al., 2013) 'Proportional Connectance', 'Impact Risk' (product of the 'overlap', 'frequency' and 'degree of impact' scores) and 'Recovery Lag' (product of 'resilience' and 'persistence' scores) boxplots and estimates were produced in R. The code used to produce these estimates is publically available for use at (http://github.com/PaulBouch/ODEMM_Celtic_Sea). The Impact Risk scores were log transformed to allow better visual comparison between the scores and their ranks. Both the sum and the means were used in the ranking process to avoid the methodological influence and bias that can be introduced through the use of only one method– both methods of aggregation are influenced by the number of impact chains present although 'summation' is less sensitive to such fluctuations. Bias was further mitigated by selecting the highest impacting *individual* linkage chains to recommend foci for action to decision-makers. These highest risk chains were identified by ranking the risk scores (Total Risk, Impact Risk and Recovery Lag) as outlined in Piet et al. (2015).

The Irish assessment was further related to the MSFD descriptors (categories of environmental status for which GES must be achieved in European marine waters by 2020: European Union, 2008), however this was approached in an alternative manner to the original ODEMM project. Instead of using a combination of existing assessments and expert knowledge to assess which descriptors were most at risk of departure from GES (Breen et al., 2012; Knights et al., 2011a; Robinson et al., 2014), we directly mapped our linkage framework (which does not require expert input) through to the MSFD descriptors in a more comprehensive manner than employed in the original ODEMM (White et al., 2013). Pressures and ecosystem components linked to a MSFD descriptor were identified (following White et al., 2013), and the number of sectors causing each pressure were listed, to enable the counting of the number of linkages (proportional connectance) of the MSFD descriptors (see Appendix C, 'MSFD detailed' Tab). In this way, risk to GES (informed by the number of linkages only, but no 'risk' scoring mechanism included) is emergent from the assessment process.

Pressure pathways were also traced through to ecosystem services, by linking the ecological characteristics to ecosystem services using the ODEMM typology (Böhnke-Henrichs et al., 2013; Hussain et al., 2013) to provide a high level overview of what services may be at risk from the existing pressures, and to provide a context for consideration of trade-offs in decision-making.

Finally, the results from the Irish assessment were then compared with the North East Atlantic assessment carried out by the ODEMM project (Knights et al., 2011b) to identify key ways in which they differ. The overview comparison was necessarily limited to the highlights published in Robinson et al. (2014, section 4.3.1).

3. Results:

3.1 Irish Assessment Results

3.1.1 Sectors

The highest risk sector changes depending on the descriptive statistic used (Table 1). When looking at the average Total Risk score, *Waste Water* is the highest risk, whereas using the sum of the Total

Risk places *Fishing* as the highest risk sector. *Waste Water* tops the average list due to the combination of high median Impact Risk scores coupled with a relatively long Recovery Lag (median ~60 years; Figure 3). *Fishing* has a higher Impact Risk score, but generally a much shorter Recovery Lag; within 10 years for most impact chains. Comparison of the proportional connectance plots (Figure 3) helps to further explain the differences, with *Fishing* demonstrating a proportional connectance double that of *Waste Water*, reflecting the wide range of habitats and species that interact with fishing activities. Individual *Fishing* chains span the entire range of possible Impact Risk values, while *Waste Water* has a more restricted range. Irrespective of the method used, the top five highest risk sectors remain the same, albeit with changes in the order (i.e. *Waste Water, Land-based Industry, Fishing, Shipping,* and *Tourism/Recreation*).

Overall Impact Risk scores are low (Fig 3a), with few exceptions. Nearly two thirds (62.5%) of the impacts from sectors are expected to recover within 10 years (4 within 2 years). Only impacts from *Telecommunications, Military, Renewable Energy, Coastal Infrastructure, Shipping* and *Waste Water* have median recovery values above 50 years. Despite this, nearly all sectors cause at least some pressures that will have impacts for which recovery is not expected within a century.

3.1.2. Pressures

Litter tops the list as the highest ranked pressure according to the both the averaged and summed Total Risk scores (Table B2 in Supplementary Information), due to its widespread nature (high proportional connectance), constant occurrence and high persistence rates in the environment. Litter Impact Risk scores (Figure 3) are variable due to variations in the frequency and overlap of littering from the activities of various sectors. Whilst resilience to litter varies, its persistence in the environment dictates that the recovery lag will never be less than 100 years.

Similar to the results for Sectors, the top 5 pressures are the same for both the averaged and summed Total Risk Scores, only the order differs (*Litter, Bycatch, Selective Species Extraction, Synthetic* and *Non-Synthetic Compounds*).

Again, overall Impact Risk scores are low (Fig 3b), with the lowest and least variable scores being assigned for *Barriers to Species Movement* and *Invasive Species*, whilst there was a higher risk score for *Electromagnetic Fields*, it was equally invariable. *Smothering* has the highest median value but occurs less frequently (see proportional connectance) than many other pressures. The primarily *Fishing*-related pressures of *bycatch, incidental loss of species* and *selective extraction of species* would appear to have the largest spread in Impact Risk values illustrating a wide range in risk scores (from the lowest to highest of the assigned scores) depending on the ecological characteristic affected.

In general, most ecosystem components have relatively fast recovery times (<10 years) with notable exceptions for ecosystem components subject to pressures related to hard structures in marine environments (e.g. *Barriers, Emergence Regime Changes, Wave Exposure*) and those related to *Litter* (plastics) and *Invasive Species* whose Recovery Lag are all >=100 years.

3.1.3. Ecological Characteristics

Deep-sea habitats (>=750m) and long-lived species (cetaceans and elasmobranchs) had the highest averaged and summed Total Risk scores, with shallow sublittoral habitats being higher ranked according to summed Total Risk, whereas deep-sea species and reptiles were higher ranked using average Total Risk (Table B3 in Supplementary Information). Comparison of Total Risk ranking vs. Impact Risk ranking is most interesting for the ecological characteristics (see Figure 3: ecological components are ordered in Total Risk ranking order, and median Impact Risk scores are visible on the ranking panel). Total Risk (which includes the recovery lag) identified deep offshore habitats and long-lived species at greatest risk, whereas ranking by median Impact Risk scores shows almost the direct opposite; the highest scores are assigned to those habitats and species closest to land, and thus to centres of anthropogenic pressure (i.e. the coast). This is also reflected in the higher proportional connectance values of near shore habitats and species. Overall, this highlights the need for information to be shown in context and with a thorough methodological understanding ~~(Piet et al., 2017)~~.

Recovery Lag scores were split into two distinct groupings depending on aggregation method; those with long-lived species and deep-water species and habitats with long Recovery Lag estimates, and those species with higher impact risk median scores (i.e. those that are closer to/more accessible to humans) have been assigned faster recovery time scales. Of note is that every ecological characteristic assessed, at least one pressure was predicted to persist for >100 years.

3.2 Prioritization

The highest risk chains were determined as those that contributed over 1% of the risk scores (Impact Risk and Total Risk) to the assessment. These 59~~60~~ chains accounted for 6~~1.5~~2% of the Impact Risk score, and 64% of the Total Risk score. Forty-four of these identified chains related to *Fishing*, via the pressures *Abrasion, Litter, Bycatch, Incidental Loss* and *Selective Species Extraction*. The remaining sectors (*Land-based Industry, Waste Water* and *Shipping*) all related to the pressure of *Litter* on deep-sea habitats, marine mammals, and elasmobranchs.

3.3 Marine Strategy Framework Directive

Connecting the Linkage Framework though to the MSFD descriptors provides us with an overview of which of the high-level descriptors are most at risk of not achieving GES by 2020. *Biological Diversity* and *Food Webs* come out as the highest risk of not achieving GES (100% connectance; Table 2). This is due the fact that all pressures affecting any ecological characteristic have the potential to affect GES for Biological Diversity and Food webs. The next most important descriptor was *Sea-floor Integrity* (55% connectance; Table 2). Similarly it should be highlighted that the Descriptors themselves vary in their specificity, some being extremely limited in scope (e.g. D9 - *Contaminants in Seafood*: Contaminants in fish and other seafood for human consumption do not exceed levels established by community legislation or other relevant standards) whereas others, such as *Biological Diversity* are extremely broad (D1 - *Biological diversity is maintained*: The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic and climate conditions).

3.4 Comparison to North East Atlantic (NEA) assessment

The majority of impact chains in the Irish waters assessment exist at site or local scales (see Table B1 for scoring criteria), with only 272 chains (15%) considered as 'widespread', matching the findings of the ODEMM NEA assessment ~~(Robinson et al., 2014)~~. Similarly, 'rare' and 'occasional' were the most commonly assigned frequencies (58%); however, our assessment classified many more pressures as being 'persistent' (36%) compared to the NEA assessment (3%). The majority of pressures were assessed as having a 'low' degree of impact (66%), with the remaining as 'chronic' (18%) and 'acute' (16%). This again contrasts with the NEA assessment which assessed about 80% of the pressures as being 'chronic'. The 'persistence' of the pressures in the environment were classified as 52% 'low' (<2 years), 15% 'medium' (2-10 years), 14% 'high' (10-100 years) and 20% were continuous (> 100 years). Similar to the NEA assessment, the 'continuous' category was predominantly used for pressures that were unlikely to be removed, such as for structures related to *coastal infrastructure, telecoms, renewable* and *non-renewable energies* and *aquaculture* as appropriate.

The majority of ecological characteristics were considered to be moderately resilient (2-10 years; 62%); only 7% of ecological characteristics were assigned high resilience (recovery within 2 years). Deep-sea habitats and species, and long-lived mammals and elasmobranchs, were considered 'low' resilience (10-100 years) accounting for 31%, however a special case was also used in relation to the pressure of *Invasive Species*. It was felt that all species and habitats that could be affected by *Invasive Species* demonstrate 'low' resilience when the threat occurs (i.e. when an invasive species establishes). For instance, *Coastal Pelagic* environments are generally assessed as 'high' resilience to most pressures. However, if an *Invasive Species* managed to establish, it was felt they would have 'low' resilience as returning to pre-impact conditions (eradication) is highly unlikely. As such, all *Invasive Species* linkages were assigned 'low' resilience (7%).

4. Discussion

4.1 The Irish EEZ Assessment

4.1.1 Pressures and Risks in the Irish EEZ

We began with the hypothesis that *Fishing* is the top impacting sector affecting the marine environment. Depending on the method of assessment, this was both true and false. *Fishing* is pervasive, impacting on many ecological components inaccessible to other sectors and creating a wide range of pressures; thus, the associated risks are high. However, the expected recovery times assigned during the assessment are generally within ten years. Our analysis indicated that *Fishing* is the most 'connected' sector, i.e. it introduces the greatest number of pressures that act on the greatest number of ecological characteristics. When sectors were assessed using 'average' risk, *Waste Water* and *Land-based Industry* were considered of greater risk to the Celtic Sea ecosystem than *Fishing*. In contrast, summation of risk scores (Total Risk) led to *Fishing* being assessed as the sector posing the greatest risk (Figures 1-3). It should be highlighted that the large number of impact chains (many with low risk scores; 58% have a low 'Degree of Impact'), affect the average Total Risk value in relation to those sectors with fewer impact chains as there is a larger number of impact chains to divide the summed Risk Score by.

Fishing was found to produce~~s~~ a wide range of pressures beyond simply extracting target commercial species, as illustrated in Figure 1. Filtering through the most impactful chains (Figure 2) highlights the importance of *Fishing* as a source of pressures, as 44~~5~~ of the top ~~6~~59~~0~~ impact chains belong to this sector, suggesting that summation may be the more appropriate descriptive statistic. The Total Risk score for *Bycatch* (ranked second), surpasses that of *Selective Species Extraction* (ranked third), as *Bycatch* affects far more species than those targeted for commercial exploitation (Burgess et al., 2018). This highlights how identification of the relevant categories for your assessment can provide interesting insights. From the results of this assessment, it is indeed appropriate to focus on fisheries for ecosystem-based management, as the largest individual impact chain risk scores are stemming from this sector. However, fisheries do not act in isolation and it is important to place it in the context of all its activities, and those of other sectors, with their potentially cumulative effects (Jennings and Kaiser, 1998). Similar to Halpern et al. (2007), some of

Formatted: Font: Calibri

our top ranked threats (e.g. *Waste Water, Land-based Industry*) are land-based highlighting that effective management of the marine ecosystem requires management of terrestrial and freshwater threats synergistically.

4.1.2 Comparison of Irish waters to North East Atlantic

High-level comparison between the Irish and the ~~North East Atlantic (~~NEA~~)~~ assessments highlighted both contrasts and commonalities. Considering the extremely large size of the NEA area, stretching from the Canary Islands in the south to Scandinavia in the north, assessed by ODEMM, in comparison to the island of Ireland and its surrounding waters, coupled with the changes in categories outlined above (see Section 2, and Appendix C), and different expert panels, it is not surprising to see differences in assessment scores. For instance, the overlap and frequency scores will vary dramatically depending on what scale you carry out the assessment; e.g. an activity that is considered 'site' at the scale of the whole NEA (<5% overlap with an ecological component: see Table B1) may be an extremely important sector at a different resolution and thus have a larger overlap. In some cases however, there may also be variation in interpretations of the categories depending on the panel assembled. For instance, a large difference in the proportional assignment of the 'persistent' frequency (37% Irish, 3% NEA) was observed. Based on the ODEMM guidelines (Robinson et al., 2013; Robinson and Knights, 2011) the Irish assessment considered 'persistent' to mean occurs in every month of the year. However Robinson et al. (2014) further elaborated that they interpreted it to mean that 'ecological components were thought to be exposed to the sector/pressure at all times where interactions occurred in space'. This subtle difference may account for the substantial variation in this category between the two assessments and further highlights the importance of documenting the interpretation of the terms used.

4.1.3 Risk Assessment and Management through the Implementation of ODEMM

Through our implementation of the ODEMM approach, we progressed from the scoping exercise producing a horrendogram with 1,874~~9~~ identified links (Figure 1), and no indication of risk scores, through to being able to identify the impact chains that are responsible for the majority of the identified risk (Figure 2). This process highlights just ~~60~~ 59 sector-pressure-ecological characteristic pathways that are responsible for 64% of the Total Risk. This reduced number of impact chains provides a feasible set of pathways for targeted management objectives that are most likely to provide the greatest 'return on investment'. Potential management actions could include: spatial or temporal controls to reduce/remove the spatio-temporal footprint of the identified sector and/or its pressure; input or output controls to reduce the degree of impact (and together reduce the Impact Risk score); and/or remediation/restoration efforts to improve the current state of the ecological characteristic affected and thus reduce the Recovery Lag (Piet et al., 2015). Furthermore, co-benefits may be realized through targeting these high risk chains, where implementing measures to mitigate or remediate the highest identified risks may bring about improvements in risk scores across a range of other impact chains, MSFD descriptors, and ecosystem services through synergistic effects (Robinson et al., 2014). For example, action taken to reduce inputs of litter into the marine environment (or equally to remove it from marine waters) would not only benefit seabirds, but a plethora of other organisms (all other ecological characteristics in our framework; see Appendix C). Similarly, spatio-temporal management of fisheries (e.g. real-time incentives fishery management; Kraak et al., 2015) may provide benefits not only in reduction of some of the top highlighted *Fishing*-related risks (*Abrasion, Litter, Bycatch, Incidental Loss* and *Selective Species Extraction*) but would also reduce other impacts caused by *Fishing* (e.g. *Smothering* and *Noise*). Further, examination of the linkage framework (Appendix C) shows that reduction in these pressures would reduce the risk related to 6 of the 11 MSFD descriptors (*Biological Diversity, Commercial Fishing, Food Webs, Sea-floor Integrity, Litter* and *Noise*) and 20 of the 21 identified ecosystem services (excluding *Sea Water*). Finally, if the top risks emergent from the system are assessed as outside of the management remit within the assessment area (e.g. due to insufficient information or conflicting institutional priorities), the assessment can be revised in light of this information. As Hobday at al. (2011) note, employing a precautionary approach that requires the inclusion of all possible linkages means it is possible to include false positives during the assessment process, but these can be screened out when data is available to eliminate them. Once appropriate areas of action are identified, the ODEMM approach can help to identify the relative costs and benefits of implementation of specified measures in terms of ecosystem services and possibly even economics (Hussain et al., 2013).

4.2 Using ODEMM

4.2.1 Definitions and interpretations of terminology

Although (to our knowledge) this is the first application of the methodology outside of the ODEMM project, it was important to use an established methodology that provides an open access common tool that can facilitate direct comparisons between different regions. In this same spirit, our adaptation of the published methodology has been outlined here (see Section 2 and Appendix C,), and the code developed for producing the outputs provided freely on GitHub (Section 2). During our implementation of the approach we encountered a few issues. Almost exclusively these related to the application of definitions and interpretations. Panelists (and even workshop leaders) were occasionally uncomfortable with some of the definitions and rules that apply to the pressure assessment. It would appear that this is not an issue limited to the Irish experience as the ODEMM project revised and updated its guidelines throughout the project (Robinson et al., 2013; Robinson and Knights, 2011), nor is it limited to the ODEMM project (see Halpern et al., 2007). In particular issues related to the definition of 'resilience' and 'persistence' (outlined above), were raised. According to the scoring rules, 'resilience' is based on generation times and the time taken (following impact and cessation of the pressure) to recover to its current status, but "resilience", as defined in an ODEMM evaluation, should be independent of all other assessment criteria and thus does not vary between sectors or pressures. The reason for this is to avoid conflating the *degree of impact* with *resilience.* For instance, this means that the resilience of a sublittoral habitat to *abrasion* from *navigational dredging* should be the same as its resilience to *noise* from *tourism/recreation*:

resilience is an inherent property of the ecological characteristic of interest. This proved to be distinctly uncomfortable, and frustrating, for many participants, even resulting in the generation of an 'exception' during our assessment, as outlined above for *Invasive Species* (Section 3.~~1~~4). The expert panel felt that within the framework of a 'current status' assessment, that the appropriate 'degree of impact' score for *Invasive Species* was low, reflecting a belief that overall there is a low risk of establishment of a given invasive species. However, in cases where an invasive species manages to establish, then the 'resilience' of the system/species affected is 'low'. This interpretation is breaking the rules by somewhat conflating the 'degree of impact' and 'resilience', particularly as a 'low degree of impact' by definition 'never causes a noticeable effect for the ecological component of interest in the area of interaction' – which *Invasive Species* clearly can. However, the panel felt that neither 'chronic' nor 'acute' adequately captured the *current* risk for this category. As the assessment scores were assigned by an expert panel, we have honored their scoring, but note it as a special case, whilst highlighting it as a 'quirk' associated with working with panels. We suggest that perhaps a change in terminology, such as renaming 'resilience' to something more akin to 'average turnover time' might make participants more comfortable, as within our experience, the term resilience encourages individuals to relate scoring to the specific impact under consideration. We encourage those that may employ this methodology in the future to carry out the 'resilience' scoring as one of your first exercises, as it need only be done once for each ecological characteristic, as clarified in ~~(~~Robinson et al.~~,~~ (2013).

The second difficulty encountered was in the omission of an 'intensity' factor, to indicate how severe the pressure is, or what proportion of a component is affected - more than a simple overlap of spatial footprints (e.g. similar to 'resistance' and 'functional impact' as per Halpern et al., (2007)). For instance, a small proportion of species encompassed by an ecological component category (e.g. demersal fish) may be highly susceptible (beyond recovery) to a given pressure. However, other species may be very robust to the same pressure, and overall ecosystem functioning is maintained, thus the risk score may be low, despite being acute for certain elements of that ecological characteristic. Related to this is the acknowledgement by Robinson et al., (2014) that there is no specified point for when a 'chronic' becomes a problem, due to a lack of knowledge of where these thresholds exist for many pressures. Throughout the guidance documents 'degree of impact' is referred to as an indication of severity, however, given the lack of a threshold for when 'chronic' may become 'acute' the distinction seems more a description of mechanism than an indication of severity, and a description as such can tempt panelists to interpret them as 'high', 'medium' and 'low' categories, which they are not.

4.2.2 Work load

Robinson et al. (2014) caution about the time-consuming nature of carrying out an ODEMM assessment. In our experience we believe this to be variable as the flexible nature of the approach allows groups to apply components of it within their resource limitations. The assessment can be carried out in stages, and once a familiarity with the methodology has been achieved by the assessment leaders, reviews can be carried out relatively quickly, and the analysis is extremely rapid, particularly since the development of an R script. The most time-consuming aspect is in compiling data to serve as a basis for assessment to inform the expert panels, however using publicly available resources such as mapping tools that are becoming ever more available and using national experts for your panels that can themselves bring data and/or reports to the table can drastically cut down on the preparation and panel time. We are also developing a data support tool that underpins the data linkages specified by the panels to help to provide the paper trail that is often missing (and often criticized) from expert opinion assessments (Halpern et al., 2007). Furthermore, as outlined in the methods, we have used the Linkage Framework to inform our MSFD descriptor risks rather than relying on expert assessment. This may further help to reduce the time required for such an assessment, however it provides only proportional connectance and not risk values. Linking the risk assessment through in this way provides another option for prioritization, as the risks contributing most to each MSFD descriptor can be identified, and the highest risk impact chains for each descriptor highlighted for action. This could prove to be particularly useful for filtering out the appropriate information of interest where different departments or agencies are responsible for different aspects of MSFD reporting, monitoring and actions.

4.2.3 Further Recommendations

Following from the above, we found that splitting participants into specific groups facilitates efficiency; however, the time allowed for the workshop of just two days was overly ambitious – even with a pilot assessment to work from. Further, although the chairs had been briefed in the methodology and goals of the workshop, there were differences in interpretations of criteria and how they were applied (in the 2012 assessment). This subsequently necessitated the re-running of some sub-groups to eliminate such inconsistency. Strong leadership with a thorough understanding of the methodology, and the capability to explain it simply, is required to lead such an exercise. Knowledge and employment of tools such as the ‘parking lot’ (acknowledging and parking ideas not relevant to the current discussion to be addressed later) are extremely useful to keep things on track. Furthermore, it is recommended that the chair act as a facilitator rather than a participant, to facilitate discussion, ensure consensus, or note dissention, and maintain progress. We suggest it may be better to run a series of workshops on different dates, but with the same chair/facilitator, to ensure the same rules are followed and applied in a consistent manner across all groups. This also means that individuals with expertise relevant to more than one group can participate in multiple panels. Finally, be aware that these workshops, whilst important, are often tedious for participants; ensure regular breaks.

4.3 The experience of applying the ODEMM approach

Through our experience working with ODEMM we maintain that it is a flexible framework that can be adapted as required. Scoping and qualitative risk assessment, whilst just one part of the IEA cycle is a critical first step on the way to the goal of informed ecosystem-based management (Knights et al., 2014; Levin et al., 2009; Walther and Möllmann, 2014). The risk assessment presented here can be adjusted to answer specific questions for management strategy evaluation (MSE) – the next necessary stage of the IEA cycle (Harvey et al., 2017; Levin et al., 2014, 2009; Piet et al., 2015), or used to highlight specific areas of interest that may require finer examination or require quantitative data streams. MSE as developed by ODEMM thus far only allows for relative comparisons, assuming management options are 100% effective and operate on 100% of the activity (either in time or space; Piet et al., 2015). True MSE would require more underlying data and modelling tools to be used in concert with high-level tools such as ODEMM for specific management options and scenario-testing. ODEMM frameworks can be linked to, and further informed by, analyses such as integrated trend analyses (Kenny et al., 2009) and food web models (e.g. Ecopath with Ecosim; Heymans et al., 2016) to inform missing parameters, answer specific trade-offs questions, and to model identified management options (Borja et al., 2016; Levin et al., 2009)

The assessment presented herewith is a living tool, consistent with the idea that the IEA framework is a an iterative process necessary for adaptive management (Dickey-Collas, 2014; Harvey et al., 2017; Levin et al., 2014, 2009). It should be consistently reviewed, to evolve for each new purpose, and when new data becomes available (OSPAR Commission, 2010; Pikitch, 2004). As such data becomes more available, knowledge and understanding improve and precautionary limits can be eased in deference to true understanding (Pikitch, 2004). In reality for such a process to work requires not one person or team, but a synergistic group effort. The authors, along with international colleagues have made steps in this direction (and will continue to do so), making our assessment results available to the International Council for the Exploration of the Seas (ICES) to provide data and understanding that underpins the ICES ecosystem overviews (ICES, 2016a, 2016b).

4.3.1 Future implementation and ongoing work

The potential future avenues of this research are many, including downsizing to help address specific management issues, such as marine spatial planning conflicts where single sector development plans dominate, often resulting in unsustainable use (Böhnke-Henrichs et al., 2013), or delving deeper into particular sectors and/or pressures identified as areas of interest in this assessment.

Management actions rarely act directly on the ecosystem, but instead upon people and their actions through legislative instruments. As such, ecosystem-based management needs to take account of the 'human dimension' (Hilborn, 2011). We believe carrying out expert panel reviews with wider stakeholder groups than scientists and managers (e.g. industry and eNGOs) would facilitate the inclusion of relevant local knowledge and new perspectives. Furthermore, efforts should be made to improve gender and age representation. Although discussion is likely to be longer and consensus more difficult to attain in more diverse groups, such perspectives are extremely valuable and help minimize bias associated with more monolithic groups. Understanding motivations and potential responses of stakeholders as individuals and groups by including them directly in the assessment will greatly aid in building more effective policies and voluntary management actions through direct engagement of the organizations and individuals affected by management changes.

Further investigation of the threats to meeting GES would require information on the current status and/or trends of identified indicators (Breen et al., 2012; Knights et al., 2011a), as well as drilling down to the level of "criteria" and indicators within each Descriptor (Borja et al., 2013). While the data sources identified by the original ODEMM project provide a valuable resource, data from, and specific to, the Irish EEZ (e.g. from the initial assessment) will add to the value of this national assessment by providing a level of detail that is generally not possible in the broader regional assessments.

Although further analysis of ecosystem services is possible within the ODEMM framework, it has not been carried out here due to limited resources. The full ecosystem service assessment requires an assessment of the relative contribution of each ecological characteristic to the identified ecosystem services (Robinson et al., 2014). This is a proposed area of future development.

5 CONCLUSIONS

As Dickey-Collas (2014) said IEA 'does not lead to one answer, but provides the information and knowledge to facilitate exploring the space for decision-making and policy development.' This work presents such an assessment, relevant for guiding and facilitating integrated marine ecosystem assessment and decision-making processes. The outputs can be used to help enlighten stakeholders and enable policy-makers to make informed decisions, particularly when coupled with complimentary methods such as integrated trend analysis and ecosystem modelling. In light of the complex landscape of ecosystem-based management and the MSFD, these tools have a real benefit as they are easy to understand. Expert panel risk assessments are a smart way to get the ball rolling with limited resources, and can be used to flag where risk areas lie and thus priorities, not just for management, but also for future research (gaps analysis), indicator development and monitoring. Statutory obligations and binding international treaties require scientists to provide advice now, despite not having all the answers yet. The process outlined herewith serves to provide a cost-effective triage approach, similar to Hobday et al.'s (2011) levels (but with a wider sectoral context), where issues are highlighted for further investigation, quantitative assessment and monitoring.

FIGURES:

Figure 1. Horrendogram of the Irish EEZ linkage framework. Sectors are linked to the pressures they cause, pressures are linked to the ecological characteristics they affect (cumulatively, a 'linkage chain'). Ecological characteristics are aggregated under MSFD GES descriptors. For illustrative purposes, black lines are used to indicate the impact chains associated with fishing, allowing visualisation of *Fishing* in the context of all other sectors under consideration.

Figure 2. Horrendogram of the top identified risks by Impact Risk (black) and Total Risk (Red) scores.

Figure 3: Proportional Connectance, Impact Risk, Impact Rank and Recovery Lag Boxplots. Each component assessed is listed in order of its average Total Risk Rank. The thick black vertical lines on the boxplots indicate the median values, with the box lengths representing the 25% quartiles and the whiskers representing 1.5 times the interquartile range. Outliers are shown as black dots. The

small Impact Risk scores have been log-transformed ('Impact Rank') to allow visual comparison between the assessed components.

TABLES:

Table 1: Ranking of the Irish sectors according to averaged and summed Total Risk scores. See Appendix B for pressure and ecological characteristic comparisons.

Table 2. Proportional connectance of the MSFD Descriptors. Descriptors are in descending order of their overall proportional connectance values (final column). Interpretation of columns is explained below using examples. Entries in grey are those that appear in Part II of the 2017 European Commission Decision.

SUPPLEMENTARY INFORMATION:

Appendix A. Workshop Details. List of participating institutes and expertise included in the Irish ODEMM assessment workshops.

Appendix B. Assessment Criteria and Scores, Rankings and Total Risk Scores. Assessment Criteria and Scores, Ranking values, average and summed Total Risk scores for the assessed Pressures and Ecological Characteristics.

Appendix C. Irish EEZ Linkage Framework. This file shows the comparison between the categories used in the original ODEMM project, and those used in this adaptation, and the linkage framework showing heat maps of interactions between the various components (Sectors, Pressures, Ecological Characteristics, Ecosystem Services and Marine Strategy Framework Directive Descriptors).

ACKNOWLEDGEMENTS:

The authors would like to acknowledge the many individuals that contributed to these assessments and workshops over the years. Without their knowledge, this assessment would not be possible. We would also like to acknowledge the ODEMM project group who developed the methodologies implemented in this study. This analysis was funded under the Beaufort Ecosystem Approach to Fisheries Management award, as part of the Irish Government's National Development Plan (NDP), the Beaufort Marine Research Award is grant aided by the Department of Communications, Energy & Natural Resources (DCENR) & the Department of Agriculture, Fisheries & Food (DAFF) under the Strategy for Science Technology & Innovation (SSTI) & the Sea Change Strategy.

CONTRIBUTORS:

D.P. carried out the review of the original 2012 assessment, led the expert-panel reviews, compiled and led the data analysis and led the writing of the paper. M.M. and P.B. contributed to the in-house reviews, the data analysis, production of the R code, and editing/writing of the paper. A.M.K., E.N. and D.G.R. led the original 2012 assessment. A.M.K. was consulted in 2015 for guidance during the review process and reviewed and edited the manuscript. D.R. oversaw the project, provided guidance, contributed to the in-house reviews, and editing, writing of the paper. All authors have approved the final article. Declarations of interest: none.

REFERENCES

Battista, W., Karr, K., Sarto, N., Fujita, R., 2017. Comprehensive Assessment of Risk to Ecosystems (CARE): A cumulative ecosystem risk assessment tool. Fish. Res. 185, 115–129. https://doi.org/10.1016/j.fishres.2016.09.017

Böhnke-Henrichs, A., Baulcomb, C., Koss, R., Hussain, S.S., de Groot, R.S., 2013. Typology and indicators of ecosystem services for marine spatial planning and management. J. Environ. Manage. 130, 135–145. https://doi.org/10.1016/j.jenvman.2013.08.027

Borja, A., Elliott, M., Andersen, J.H., Berg, T., Carstensen, J., Halpern, B.S., Heiskanen, A.-S., Korpinen, S., Lowndes, J.S.S., Martin, G., Rodriguez-Ezpeleta, N., 2016. Overview of Integrative Assessment of Marine Systems: The Ecosystem Approach in Practice. Front. Mar. Sci. 3. https://doi.org/10.3389/fmars.2016.00020

Borja, A., Elliott, M., Andersen, J.H., Cardoso, A.C., Carstensen, J., Ferreira, J.G., Heiskanen, A.-S., Marques, J.C., Neto, J.M., Teixeira, H., Uusitalo, L., Uyarra, M.C., Zampoukas, N., 2013. Good Environmental Status of marine ecosystems: What is it and how do we know when we have attained it? Mar. Pollut. Bull. 76, 16–27. https://doi.org/10.1016/j.marpolbul.2013.08.042

Borja, Á., Galparsoro, I., Irigoien, X., Iriondo, A., Menchaca, I., Muxika, I., Pascual, M., Quincoces, I., Revilla, M., Germán Rodríguez, J., Santurtún, M., Solaun, O., Uriarte, A., Valencia, V., Zorita, I., 2011. Implementation of the European Marine Strategy Framework Directive: A methodological approach for the assessment of environmental status, from the Basque Country (Bay of Biscay). Mar. Pollut. Bull. 62, 889–904. https://doi.org/10.1016/j.marpolbul.2011.03.031

Breen, P., Robinson, L.A., Rogers, S.I., Knights, A.M., Piet, G., Churilova, T., Margonski, P., Papadopoulou, N., Akoglu, E., Eriksson, A., Finenko, Z., Fleming-Lehtinen, V., Galil, B., Goodsir, F., Goren, M., Kryvenko, O., Leppanen, J.M., Markantonatou, V., Moncheva, S., Oguz, T., Paltriguera, L., Stefanova, K., Timofte, F., Thomsen, F., 2012. An environmental assessment of risk in achieving good environmental status to support regional prioritisation of management in Europe. Mar. Policy 36, 1033–1043. https://doi.org/10.1016/j.marpol.2012.02.003

Burgess, M.G., McDermott, G.R., Owashi, B., Peavey Reeves, L.E., Clavelle, T., Ovando, D., Wallace, B.P., Lewison, R.L., Gaines, S.D., Costello, C., 2018. Protecting marine mammals, turtles, and birds by rebuilding global fisheries. Science 359, 1255–1258. https://doi.org/10.1126/science.aao4248

Department of Fisheries and Oceans, 1996. An act respecting the oceans of Canada.

DePiper, G.S., Gaichas, S.K., Lucey, S.M., Pinto da Silva, P., Anderson, M.R., Breeze, H., Bundy, A., Clay, P.M., Fay, G., Gamble, R.J., Gregory, R.S., Fratantoni, P.S., Johnson, C.L., Koen-Alonso, M., Kleisner, K.M., Olson, J., Perretti, C.T., Pepin, P., Phelan, F., Saba, V.S., Smith, L.A., Tam, J.C., Templeman, N.D., Wildermuth, R.P., 2017. Operationalizing integrated ecosystem assessments within a multidisciplinary team: lessons learned from a worked example. ICES J. Mar. Sci. https://doi.org/10.1093/icesjms/fsx038

Dickey-Collas, M., 2014. Why the complex nature of integrated ecosystem assessments requires a flexible and adaptive approach. ICES J. Mar. Sci. 71, 1174–1182. https://doi.org/10.1093/icesjms/fsu027

Environment Australia, 1999. Australia's oceans policy: caring, understanding, using wisely. Bd. 1: ... Environment Australia, Canberra.

European Commission, 2018. Reforming the Common Fisheries Policy (CFP): Building a brighter future for fish and fishermen.

European Environment Agency (Ed.), 2006. The changing faces of Europe's coastal areas, EEA report. European Environment Agency ; Office for Official Publications of the European Communities, Copenhagen, Denmark : Luxembourg.

Formatted: Bibliography, Widow/Orphan control, Adjust space between Latin and Asian text, Adjust space between Asian text and numbers

European Union, 2014. DirectiveE 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for maritime spatial planning. Off. J. Eur. Union 257.

European Union, 2013. Regulation(EU) No 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy, amending Council Regulations (EC) No 1954/2003 and (EC) No 1224/2009 and repealing Council Regulations (EC) No 2371/2002 and (EC) No 639/2004 and Council Decision 2004/585/EC. Off. J. Eur. Union 354.

European Union, 2008. Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). Off. J. Eur. Union 164, 19–40.

Firth, L., Knights, A.M., Thompson, R., Mieszkowska, N., Bridger, D., Evans, A., Moore, P., O'Connor, N., Sheehan, E., Hawkins, S., 2016. Ocean sprawl: challenges and opportunities for biodiversity management in a changing world., in: Oceanography and Marine Biology: An Annual Review. pp. 189–262.

Fitzpatrick, M., Graham, N., Rihan, D., Reid, D.G., Sutton, G., MacMullen, P., 2010. Reversing the burden of proof in fisheries management in the context of an integrated ecosystem approach ICES CM 2010/P:13.

Fletcher, P.J., Kelble, C.R., Nuttle, W.K., Kiker, G.A., 2014. Using the integrated ecosystem assessment framework to build consensus and transfer information to managers. Ecol. Indic. 44, 11–25. https://doi.org/10.1016/j.ecolind.2014.03.024

Fletcher, W. (Rick) J., 2015. Review and refinement of an existing qualitative risk assessment method for application within an ecosystem-based management framework. ICES J. Mar. Sci. 72, 1043–1056. https://doi.org/10.1093/icesjms/fsu142

Government of the Republic of South Africa, 1998. National Water Act. An Act to provide for fundamental reform of the law relating to water resources; to repeal certain laws; and to provide for matters connected therewith.

Halpern, B.S., Selkoe, K.A., Micheli, F., Kappel, C.V., 2007. Evaluating and Ranking the Vulnerability of Global Marine Ecosystems to Anthropogenic Threats. Conserv. Biol. 21, 1301–1315. https://doi.org/10.1111/j.1523-1739.2007.00752.x

Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C., Bruno, J.F., Casey, K.S., Ebert, C., Fox, H.E., Fujita, R., Heinemann, D., Lenihan, H.S., Madin, E.M.P., Perry, M.T., Selig, E.R., Spalding, M., Steneck, R., Watson, R., 2008. A Global Map of Human Impact on Marine Ecosystems. Science 319, 948–952. https://doi.org/10.1126/science.1149345

Harvey, C.J., Kelble, C.R., Schwing, F.B., 2017. Implementing "the IEA": using integrated ecosystem assessment frameworks, programs, and applications in support of operationalizing ecosystem-based management. ICES J. Mar. Sci. https://doi.org/10.1093/icesjms/fsw201

Heymans, J.J., Coll, M., Link, J.S., Mackinson, S., Steenbeek, J., Walters, C., Christensen, V., 2016. Best practice in Ecopath with Ecosim food-web models for ecosystem-based management. Ecol. Model. 331, 173–184. https://doi.org/10.1016/j.ecolmodel.2015.12.007

Hilborn, R., 2011. Future directions in ecosystem based fisheries management: A personal perspective. Fish. Res. 108, 235–239. https://doi.org/10.1016/j.fishres.2010.12.030

Hobday, A.J., Smith, A.D.M., Stobutzki, I.C., Bulman, C., Daley, R., Dambacher, J.M., Deng, R.A., Dowdney, J., Fuller, M., Furlani, D., Griffiths, S.P., Johnson, D., Kenyon, R., Knuckey, I.A., Ling, S.D., Pitcher, R., Sainsbury, K.J., Sporcic, M., Smith, T., Turnbull, C., Walker, T.I., Wayte, S.E., Webb, H., Williams, A., Wise, B.S., Zhou, S., 2011. Ecological risk assessment for the effects of fishing. Fish. Res. 108, 372–384. https://doi.org/10.1016/j.fishres.2011.01.013

Holsman, K., Samhouri, J., Cook, G., Hazen, E., Olsen, E., Dillard, M., Kasperski, S., Gaichas, S., Kelble, C.R., Fogarty, M., Andrews, K., 2017. An ecosystem-based approach to marine risk assessment. Ecosyst. Health Sustain. 3, e01256. https://doi.org/10.1002/ehs2.1256

Hussain, S., Baulcomb, C., Bloomfield, H., Böhnke-Henrichs, A., Culhane, F., Fofana, A., Frid, C., de Groot, R., Koss, R., Robinson, L.A., 2013. The ODEMM Approach to Analysing the Costs &

Benefits of Marine Management. Deliverable 12, EC FP7 ‘Options for Delivering Ecosystem-based Marine Management’.

ICES, 2016a. Final Report of the Working Group on Ecosystem Assessment of Western European shelf Seas (WGEAWESS) (No. ICES CM 2016/SSGIEA:02).

ICES, 2016b. ICES Ecosystem Overviews: Celtic Seas Ecoregion.

Jennings, S., Kaiser, M.J., 1998. The effects of fishing on marine ecosystems. Adv. Mar. Biol. 34, 201–352.

Kenny, A.J., Skjoldal, H.R., Engelhard, G.H., Kershaw, P.J., Reid, J.B., 2009. An integrated approach for assessing the relative significance of human pressures and environmental forcing on the status of Large Marine Ecosystems. Prog. Oceanogr. 81, 132–148. https://doi.org/10.1016/j.pocean.2009.04.007

Knights, A.M., Culhane, F., Hussain, S.S., Papadopoulou, K.N., Piet, G.J., Raakær, J., Rogers, S.I., Robinson, L.A., 2014. A step-wise process of decision-making under uncertainty when implementing environmental policy. Environ. Sci. Policy 39, 56–64. https://doi.org/10.1016/j.envsci.2014.02.010

Knights, A.M., Koss, R.S., Papadopoulou, N., Cooper, P., Robinson, L.A., 2011a. Sustainable use of European regional seas and the role of the Marine Strategy Framework Directive. Deliverable 1, EC FP7 Project (244273) ‘Options for Delivering Ecosystem-based Marine Management’. University of Liverpool, UK.

Knights, A.M., Koss, R.S., Robinson, L.A., 2013. Identifying common pressure pathways from a complex network of human activities to support ecosystem-based management. Ecol. Appl. 23, 755–765.

Knights, A.M., Piet, G.J., Breen, P., Goodsir, F., Leonie A., 2011b. The North East Atlantic: Additional information on status of threatened ecological characteristics relevant to the Marine Strategy Framework Directive. FP7 Options for Delivering Ecosystem-Based Marine Management’ (ODEMM, Theme ENV.2009.2.2.1.1).

Knights, A.M., Piet, G.J., Jongbloed, R.H., Tamis, J.E., White, L., Akoglu, E., Boicenco, L., Churilova, T., Kryvenko, O., Fleming-Lehtinen, V., Leppanen, J.-M., Galil, B.S., Goodsir, F., Goren, M., Margonski, P., Moncheva, S., Oguz, T., Papadopoulou, K.N., Setälä, O., Smith, C.J., Stefanova, K., Timofte, F., Robinson, L.A., 2015. An exposure-effect approach for evaluating ecosystem-wide risks from human activities. ICES J. Mar. Sci. 72, 1105–1115. https://doi.org/10.1093/icesjms/fsu245

Korpinen, S., Andersen, J.H., 2016. A Global Review of Cumulative Pressure and Impact Assessments in Marine Environments. Front. Mar. Sci. 3. https://doi.org/10.3389/fmars.2016.00153

Kraak, S.B.M., Reid, D.G., Bal, G., Barkai, A., Codling, E.A., Kelly, C.J., Rogan, E., 2015. RTI (“Real-Time Incentives”) outperforms traditional management in a simulated mixed fishery and cases incorporating protection of vulnerable species and areas. Fish. Res. 172, 209–224. https://doi.org/10.1016/j.fishres.2015.07.014

Levin, P.S., Fogarty, M.J., Murawski, S.A., Fluharty, D., 2009. Integrated Ecosystem Assessments: Developing the Scientific Basis for Ecosystem-Based Management of the Ocean. PLoS Biol. 7, e1000014. https://doi.org/10.1371/journal.pbio.1000014

Levin, P.S., Kelble, C.R., Shuford, R.L., Ainsworth, C., deReynier, Y., Dunsmore, R., Fogarty, M.J., Holsman, K., Howell, E.A., Monaco, M.E., Oakes, S.A., Werner, F., 2014. Guidance for implementation of integrated ecosystem assessments: a US perspective. ICES J. Mar. Sci. 71, 1198–1204. https://doi.org/10.1093/icesjms/fst112

Magnuson-Stevens Fishery Conservation and Management Act., 1996.

McQuatters-Gollop, A., 2012. Challenges for implementing the Marine Strategy Framework Directive in a climate of macroecological change. Philos. Trans. R. Soc. Math. Phys. Eng. Sci. 370, 5636–5655. https://doi.org/10.1098/rsta.2012.0401

Meadows, D.H., Randers, J., Meadows, D.L., 2005. The limits to growth the 30-year update. Earthscan, London.

Millennium Ecosystem Assessment (Ed.), 2005. Ecosystems and human well-being: synthesis. Island Press, Washington, DC.

OSPAR Commission (Ed.), 2010. Quality status report 2010. London.

Piet, G.J., Jongbloed, R.H., Knights, A.M., Tamis, J.E., Paijmans, A.J., van der Sluis, M.T., de Vries, P., Robinson, L.A., 2015. Evaluation of ecosystem-based marine management strategies based on risk assessment. Biol. Conserv. 186, 158–166. https://doi.org/10.1016/j.biocon.2015.03.011

Pikitch, E.K., 2004. Ecosystem-Based Fishery Management. Science 305, 346–347. https://doi.org/10.1126/science.1098222

Pitcher, T.J., Kalikoski, D., Short, K., Varkey, D., Pramod, G., 2009. An evaluation of progress in implementing ecosystem-based management of fisheries in 33 countries. Mar. Policy 33, 223–232. https://doi.org/10.1016/j.marpol.2008.06.002

Robinson, L.A., Culhane, F.E., Baulcomb, C., Bloomfield, H., Boehnke-Henrichs, H., Breen, P., Goodsir, F., Hussain, S.S., Knights, A.M., Raakjær, J., van Tatenhove, J., Frid, C.L.J., 2014. Towards delivering ecosystem-based marine management: The ODEMM Approach. Deliverable 17, EC FP7 Project (244273) 'Options for Delivering Ecosystem-based Marine Management.

Robinson, L.A., Knights, A.M., 2011. ODEMM Pressure Assessment Userguide. ODEMM Guidance Document Series No.2. EC FP7 project (244273) 'Options for Delivering Ecosystem-based Marine Management.'

Robinson, L.A., White, L.J., Culhane, F.E., Knights, A.M., 2013. ODEMM Pressure Assessment Userguide V.2.. ODEMM Guidance Document Series No.2. EC FP7 project (244273) 'Options for Delivering Ecosystem-based Marine Management.'

Skern-Mauritzen, M., Ottersen, G., Handegard, N.O., Huse, G., Dingsør, G.E., Stenseth, N.C., Kjesbu, O.S., 2016. Ecosystem processes are rarely included in tactical fisheries management. Fish Fish. 17, 165–175. https://doi.org/10.1111/faf.12111

Slater, W.L., DePiper, G., Gove, J.., Harvey, C.J., Hazen, E.L., Lucey, S.M., Karnauskas, M., Regan, S.D., Siddon, E.C., Yasumiishi, E.M., Zador, S.G., Brady, M.M., Ford, M.D., Griffis, R.B., Shuford, R., Townsend, H.M., O'Brien, T.D., Peterson, J.O., Osgood, K.E., Link, J.S., 2017. Challenges, Opportunities and Future Directions to Advance NOAA Fisheries Ecosystem Status Reports (ESRs): Report of the National ESR Workshop. (No. 66). NOAA.

Trochta, J.T., Pons, M., Rudd, M.B., Krigbaum, M., Tanz, A., Hilborn, R., 2018. Ecosystem-based fisheries management: Perception on definitions, implementations, and aspirations. PLOS ONE 13, e0190467. https://doi.org/10.1371/journal.pone.0190467

United Nations, 2015. Transforming Our World: The 2030 Agenda For Sustainable Development (No. A/RES/70/1).

US Congress, 2000. Oceans Act of 2000.

Walther, Y.M., Möllmann, C., 2014. Bringing integrated ecosystem assessments to real life: a scientific framework for ICES. ICES J. Mar. Sci. 71, 1183–1186. https://doi.org/10.1093/icesjms/fst161

White, L.J., Koss, R.S., Knights, A.M., Eriksson, A., Robinson, L.A., 2013. ODEMM Linkage Framework Userguide (Version 2). ODEMM Guidance Document Series No.3. EC FP7 project (244273) 'Options for Delivering Ecosystem-based Marine Management. University of Liverpool.