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Operationalising ODEMM risk assessment for Integrated Ecosystem Assessment scoping: Complexity vs. manageability

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Integrated Ecosystem Assessments (IEA) require consideration of the full suite of pressures and impacts affecting ecosystems. However, capacity limitations often severely limit our ability to do everything that we want or 'should' do, outside of short-term fully-funded focused research projects. In order to make IEA a reality in many contexts, priority consideration has to be given to how to achieve such comprehensive assessments. Ecoregions and Large Marine Ecosystems (LMEs) have been identified as potential management units, however these large areas encompass diverse habitats, and multiple nations with diverse human communities and use of marine environments, and a multitude of different management strategies. In this context, how can we make IEA an operational tool that can be applied at such high-level in a comparable, yet regionally-relevant adaptable approach? This paper outlines the demonstration and adaptation of an established risk assessment approach (Options for Delivering Ecosystem-Based Marine Management: ODEMM) to a rapid risk scoping tool, and how this approach has been applied using open source common analytical tools to improve operationality in both the Mission Atlantic project and the International Council for the Exploration of the Seas (ICES) Integrated Ecosystem Assessment Working Groups. Furthermore, a hierarchical approach is detailed that allows the integration of different levels of detail into a common format. The resulting assessments are then ground-truthed with stakeholders to identify issues, omissions, potential conflicts, and key areas of interest for the next steps of the IEA process.

KEYWORDS

integrated ecosystem assessment, ecosystem based management, ecosystem, large marine ecosystems, scoping, stakeholders, risk assessment

1 Introduction

Human population, economic and industrial growth, and expansion of many activities from land to sea all contribute increasingly large and varied pressures on the marine environment (Millennium Ecosystem Assessment, 2005; Halpern et al., 2007; Halpern et al., 2008; OSPAR Commission, 2010; European Environment Agency, 2019; Jouffray et al., 2020). Environmental problems are often ubiquitous and 'wicked'; meaning they are persistent and complex, with multiple social, economic, ecological and political interdependencies (Jentoft and Chuenpagdee, 2009; O'Higgins et al., 2020). These difficulties are further exacerbated in the marine realm, where a lack of clear geographical/ecosystem boundaries combine with highly migratory species to exceed political and management boundaries, and where sampling and investigative research is challenging and expensive and thus often limited or unavailable, and fundamental understanding of ecosystem structure, functioning, and vulnerabilities to human impacts is often lacking (Christensen et al., 1996). Further contributing to the problem are a lack of cohesive management solutions and interdisciplinary approaches, with management tending to focus on siloed sectoral and even species-specific approaches.

Ecosystem-based management (EBM), or the ecosystems approach to management (EAM), is an environmental management approach that recognizes the full array of interactions within an ecosystem, including humans, and the need to incorporate systems thinking into natural resource management (Christensen et al., 1996; Halpern et al., 2007; Levin et al., 2009; Hilborn, 2011; Borja et al., 2016; O'Higgins et al., 2020). Operationally, EBM aims to achieve 'the comprehensive integrated management of human activities based on the best available scientific knowledge to achieve sustainable use of ecosystem goods and services and maintenance of ecosystem integrity" (OSPAR/HELCOM, 2003; ICES 2005; Enright and Boteler, 2020; Le Tissier, 2020). In practice, this has proven difficult to achieve, despite many high-level international commitments incorporating the ecosystems approach in their wording and objectives to varying degrees (e.g. the European Union (EU) Marine Strategy Framework Directive (MSFD: European Commission, 2008), Australia's Oceans Policy (Environment Australia, 1999), Canadian Oceans Act (Department of Fisheries and Oceans, 1996); Oceans Act of 2000 (US Congress, 2000), Norwegian Cross Sector Management Plans (Klima- og miljødepartementet, 2020), South African National Water Act (Government of the Republic of South Africa, 1998), etc.). Part of the implementation challenge lies in the many data, monitoring and modelling requirements of full EBM (Hilborn, 2011; Hobday et al., 2011; McQuatters-Gollop, 2012; Dickey-Collas, 2014; Borja et al., 2016; Harvey et al., 2017).

One common feature of EBM is the focus on sustainability; the recognition that our planetary resources are finite, and must be effectively managed to be maintained (Christensen et al., 1996). This recognition, coupled with the 'wicked' nature of environmental problems, necessitates the inclusion of stakeholders in order to understand their needs and priorities, identify trade-offs, and develop consensus (Jentoft and Chuenpagdee, 2009; O'Higgins et al., 2020). Effective tools and approaches are needed in order to address the identified technical, analytical and societal challenges to operationalising EBM, and to secure overall social and ecological sustainability.

Integrated Ecosystem Assessment (IEA) is one such approach for supporting EBM implementation. IEAs take a comprehensive multi-sectoral, multi-pressure, ecosystem view of the entire social-ecological system. They provide an incremental, iterative framework 'for organizing science in order to inform decisions in marine EBM at multiple scales and across sectors' (Levin et al., 2009). The IEA framework outlines 5 stages of IEA: scoping, indicator development, risk analysis, management strategy evaluation, and ecosystem assessment (Levin et al., 2009; Levin et al., 2014; Samhouri et al., 2014). The approaches used within each stage are dependent on the specific context, available data, knowledge, and tools, allowing for regionally-relevant and problem-specific solutions to meet management needs (Levin et al., 2014; Holsman et al., 2017; O'Higgins et al., 2020).

IEA has been adopted as a common approach by the United States National Oceanic and Atmospheric Administration (NOAA) and the International Council for the Exploration of the Sea (ICES, 2012). NOAA have been world leaders in developing and applying the approach and methodologies, particularly in the realm of socio-ecological systems (Levin et al., 2009; Fletcher et al., 2014; Levin et al., 2014; Samhouri et al., 2014; DePiper et al., 2017; Harvey et al., 2017; Gaichas et al., 2018; Muffley et al., 2020). A national strategy (the National Ocean Policy 2010-2018), an established IEA program, and governmental funding has helped to progress this work considerably, with five active regional programs (Alaska, California Current, West Hawaii, Northeast, and Gulf of Mexico). Across the Atlantic, ICES established an IEA Steering Group in 2013, with a series of working groups focusing on progressing ecoregional IEAs, and developing ecosystem advice products known as the Ecosystem Overviews. The development of IEA in the ICES context has faced a number of challenges (Clay et al., In Press). ICES expert groups members work on a voluntary basis. This means that progress is often slow as it is dependent on the availability of group members and their capacity. Secondly, few (if any) policies of ICES member countries currently fund a national IEA program. Thus, progress is generally made in aspects that relate to individual members' day jobs/research interests and funded research projects, with shifting foci frequently centred around fisheries (i.e. ecosystem-based fisheries management (EBFM)). This has resulted in elements of a (sectoral) IEA being carried out, but without completing all stages of the cycle outlined above, and, more critically, often without a specific goal/objective in mind (Clay et al., In Press). Finally, although guidelines exist for developing the ecosystem overviews (ICES, 2021a), a lack of common IEA guidelines or agreed upon tools has led to sometimes disparate approaches being applied across groups, limiting utility, uptake and comparability between regions. To tackle these issues, a series of ICES workshops to harmonise methodologies have been carried out over the last few years (ICES, 2018; ICES, 2019a; ICES, 2019b; ICES, 2022a).

The first stage of IEA, often referred to as the 'scoping' stage has been highlighted as one of the most critical yet potentially complicated steps in IEA (ICES, 2012). It is during this step that objectives, trade-offs, and scale (geographic, sectoral, disciplinary, etc.) are specified with stakeholders, and the boundaries of the assessment are set. To be comprehensive and holistic, all human activities/sectors, all the pressures they create, and all parts of the ecosystem should be taken into account. However, data are frequently a limiting factor, and we do not yet possess the capacity or tools to be able to process such wide-ranging information, nor their interactions. Furthermore, how can we expect any set of stakeholders to consider and prioritise entire ecosystems, their interactions, environmental influences, and the full range of anthropogenic pressures? As such, we need to take a type of 'triage' or ecological risk assessment (ERA) approach, whereby we assess all of the relevant elements at a high-level in order to flag areas of concern/highest risk for more in depth analyses (Holsman et al., 2017). Using such an approach, we can use qualitative data based on expert opinion to carry out a rapid first screening, which enables us to identify key areas for further quantitative analyses (Holsman et al., 2017).

Various approaches for ERAs exist and have potential use in the context of IEAs (e.g. Halpern et al., 2008; Halpern et al., 2012; Samhouri and Levin, 2012; Gray et al., 2013; Knights et al., 2013a; Samhouri et al., 2014; Korpinen and Andersen, 2016; Battista et al., 2017; Bryhn et al., 2020; Hammar et al., 2020). The ICES Workshop on Methods and Guidelines to Link Human Activities, Pressures and State of the Ecosystem in Ecosystem Overviews (WKTRANSPARENT: ICES, 2021b) reviewed eleven ERA methodologies on the basis of: scale of use, activity/pressures captured, ecosystem component/indicator assessed, type of measurement, measures of impact, recovery, combined effects, risk, uncertainty, socio-economic factors, and management scenario evaluation. Furthermore, pragmatic factors such as ease of use, adaptability/scalability, and ability to incorporate different levels of knowledge/data availability were considered critical to facilitate use and uptake across ICES expert groups. From these analyses, the ODEMM approach (from the European Commission 7th framework funded project 'Options for Delivering Ecosystem-Based Marine Management https://odemm.com/) was identified as the most suitable option due to its flexibility, adaptability, inclusivity, relative ease of use, lack of dependence on data, ability to include ecosystem services, and potential to be linked through to other tools such as conceptual/mental modelling approaches or other ERA approaches (e.g. Symphony tool, Hammar et al., 2020). Additionally, ODEMM has the benefit of using the DPSIR (Drivers, Pressures, State, Impacts, Response) type of approach, which while linear and unidirectional (i.e. oversimplified), has the benefit of being widely understood and well established (EEA, 1999; EEA, 1995; Borja et al., 2006; Atkins et al., 2011a; Atkins et al., 2011b.; Elliott et al., 2017).

This study answers calls for common methodologies with a pragmatic and practical approach to ensure operationality (O'Higgins et al., 2020). Mission Atlantic is a European Union Horizon 2020 funded project that is developing and progressing IEAs throughout the entire Atlantic Ocean to help decision-makers balance the need for protecting the ocean with the need to use ocean resources. Through seven regional case studies, along with a whole Atlantic assessment, Mission Atlantic is working to identify ways and means in which IEA can be progressed, using common methodologies that are iterative and adaptable to a wide range of data, knowledge, and management and policy scenarios. ICES is a member of the Mission Atlantic consortium, and numerous project members are also active in ICES IEA working groups. As such, Mission Atlantic is perfectly placed to test and validate the WKTRANSPARENT proposed approach across a diverse range of case studies. In parallel, adopting the ODEMM-based ICES approach in the Mission Atlantic project helps to ensure that project outputs are relevant and aligned with the ongoing efforts of an intergovernmental marine science organization providing evidence-based science and advice on the state and sustainable use of our seas and oceans.

This paper outlines the steps taken in reviewing, examining, and critically assessing the proposed risk assessment approach, and adapting it to provide a method that is comparable, transparent, and critically, useable by groups carrying out IEA work to provide advice. In this way, we aim to progress from theory to practice, and take steps towards making IEAs operational to support management and policy-maker decision-making. As a case study, we focus on the Celtic Sea ecosystem, a system assessed by both an ICES IEA working group and the Mission Atlantic project.

2 Methods

2.1 Study area

Mission Atlantic comprises seven case study (CS) regions. These are the Norwegian Sea, Celtic Sea, Canary Current, North Mid-Atlantic Ridge, South Mid-Atlantic Ridge, Benguela Current and the South Brazilian Shelf. The methods detailed below were applied in all case study areas, however here we present analyses from the Celtic Sea case study as an illustrative example. The Celtic Sea CS area takes in the Celtic Sea (south of Ireland) and the west of Ireland Atlantic shelf (Figure 1). Due to its location on the western most edge of Europe, it demonstrates a high connectance with other sub-ecoregions such as the Irish Sea, Eastern Atlantic Ocean, Bay of Biscay, and the Western English Channel. This makes it a highly dynamic area affected by a range of population centres and influenced by global marine currents.

2.2 Approach

The ODEMM approach consists of building a 'linkage framework' (Koss et al., 2011; Knights et al., 2013a; White et al., 2013), followed by a 'pressure assessment' (Robinson and Knights, 2011; Robinson et al., 2013; Knights et al., 2013b; Pedreschi et al., 2019). In the first step, all human activities/sectors, anthropogenic pressures, and ecological characteristics relevant to the study area are identified using predefined lists. Existing interactions between each element are then put in place to identify the 'pressure pathways', i.e. what sectors create which pressures, and which pressures pose a risk of impact to which ecosystem components, to create a series of sector-pressure-ecosystem component 'linkage chains'. From there, each individual linkage chain is scored for five attributes independently; spatial overlap, frequency of occurrence, degree of impact, resilience and persistence in the pressure assessment (Table 1). Scoring is carried out by expert panels based on their judgement and supported/informed by the best available knowledge (Robinson et al., 2013; Knights et al., 2013b). The size of the panels can vary from a core project team of <10 individuals supported by literature searches and reaching out to discipline specialists where knowledge is lacking, to many experts spread across disciplinary specific teams (e.g. by sectoral knowledge or ecosystem component specialists), depending on the case study. In most cases a few individuals assign the initial scores for the linkage chains (e.g. based on previous assessments), and these are then reviewed by a wider expert panel. This approach has proven to be the most successful for gathering input and engaging contributors with specific feedback in a limited time period. Where disagreements occur, consensus is sought. Where consensus was not possible, a precautionary approach was taken. Scores are applied with a business as usual view to assess current status rather than emergency risk planning (e.g. through floods/oil spills/climate change). Scores are applied with the emphasis on assemblage and ecosystem functioning rather than focusing on single species. Scores are also applied to document knowledge quality (e.g.; 1- expert knowledge, 2- literature support, 3- monitoring data/time series available).

Despite being chosen partially for its ease of use, initial efforts with this approach still presented obstacles. The assessment, while quicker and simpler than most other approaches, was still considered time-consuming. As such, application of the methods was investigated to identify the most appropriate modifications which would focus on the elements critical for IEA, while improving efficiency.

2.3 Analyses

The scorings were used to calculate Proportional Connectance, 'Impact Risk', 'Recovery Lag' and Total Risk (Table 2; Robinson et al., 2013; White et al., 2013: Knights et al., 2013b) estimates, with associated figures and tables, using R (Pedreschi et al., 2019, the code is publicly available at https://github.com/missionatlantic/MissionAtlantic-RISK-Analysis). Log transformation of the IR scores enabled a better visualisation of ranks (Figure S1). Both sum and mean scores were calculated for each element (i.e. the sum/mean of all linkages connected to each individual sector, pressure or ecosystem component) to identify which sectors and pressures contributed the most risk to the system, and which ecosystem components were most affected (rank ordering). Both the sum and the means were calculated to avoid the methodological bias possible through the use of only one metric. Both metrics provide different but complementary information, and while both are influenced by the number of linkage chains present, the sum is less sensitive.

In order to identify the most important linkage chains from a risk perspective, we calculated the Relative Contribution (RC) of each chain as the percentage of total risk contributed (Piet et al., 2015). We considered chains with RC of >1% to overall risk to be potential foci for action by decision-makers (Piet et al., 2015).

Initial results using the approach above appeared unintuitive to assessors and highly influenced by the RL scores. This issue

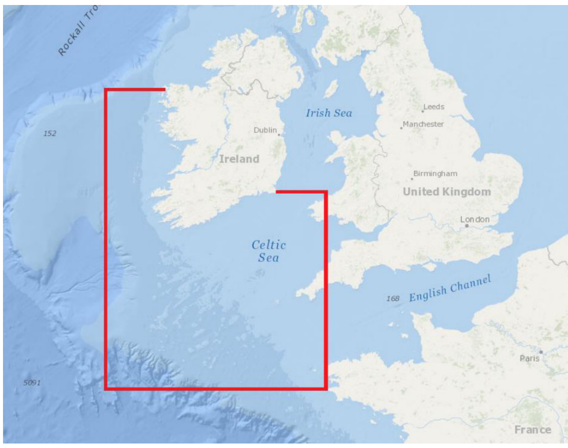

FIGURE 1
Celtic Sea Case Study region. Map from atlas.marine.ie.

TABLE 1 Scoring categories, definitions, criteria and numerical scores used in the assessment. Definitions for each category are provided under headings in grey boxes. Headings highlighted in green contribute to the Impact Risk score, those in white produce the Recovery Lag score. Note; the category 'Resilience: None' was not used in the assessment.

Spatial Overlap	Frequency	Degree of Impact	Resilience	Persistence
Spatial overlap of each activity-pressure combination with an ecosystem component	Temporal overlap of each activity-pressure combination with an ecosystem component	The severity (in terms of likely degree of impact) of any sector/pressure interaction with the ecological component	Resilience of the component given its status at the time of the assessment	Length of time that is needed for a pressure to disappear after an activity stops
No Overlap	*If there is no spatial overlap, the pressure is linkage chain is not considered further in the framework*			
0				
No overlap between Sector and Ecological Characteristic				
Exogenous	**Rare**	**Low**	**High**	**Low**
0.01	0.08	0.01	0.01	0.01
The activity occurs outside of the area occupied by the ecosystem component, but one or more of its pressures would reach the ecosystem	A pressure is introduced up to 1 months of the year	Never causes high levels of mortality or habitat loss/ never causes a noticeable effect for the ecosystem	The population will take between 0-2 years to recover	After cessation of the pressure, it continues to impact for between 0-2 years
Site	**Occasional**	**Chronic**	**Moderate**	**Moderate**
0.03	0.33	0.13	0.06	0.06
Sector overlaps an ecological component, but less than 5%	A pressure is introduced up to 4 months of the year	An impact that could have detrimental consequences if it occurs often enough or at high enough levels	The population will take between 2-10 years to recover	After cessation of the pressure, it continues to impact for between 2-10 years
Local	**Common**	**Acute**	**Low**	**High**
0.37	0.67	1	0.55	0.55
Sector overlaps an ecological component by more than 5% but less than 50%	A pressure is introduced up to 8 months of the year	A severe impact over a short duration. An interaction that kills a large proportion of individuals and causes an immediate change in the Ecological Characteristic	The population will take between 10-100 years to recover	After cessation of the pressure, it continues to impact for between 10-100 years
Widespread Patchy	**Persistent**		**None**	**Continuous**
0.67	1		1	1
Sector overlaps an ecological component by 50% or more with a patchy distribution	A pressure is introduced throughout the year		Population expected to go locally extinct or recovery expected to take over 100 years	After cessation of the pressure, it continues to impact for over 100 years
Widespread Even				
1				
Sector overlaps an ecological component by 50% or more with an even distribution				

was also highlighted by stakeholders during a previous analysis (Pedreschi et al., 2019). Whilst RL (the time required for ecosystem recovery) is important, we considered the RL index to provide complementary information, i.e. vulnerability assessment, to IR. As such, to meet the needs of IEA scoping (identifying areas of highest risk/concern for management action), and to minimise the workload issues and the time taken to carry out and produce an assessment, we carried out a second exercise examining IR scores only (i.e., not taking RL into account), to enable comparison with the full risk assessment based on TR (taking RL into account). We carried out a cross-project multi-case study comparative analyses to investigate the applicability and usefulness of an RL approach as a vulnerability assessment. This consisted of comparing Persistence and Resilience scores assigned for each of the seven Mission Atlantic case studies to assess degree of commonality.

TABLE 2 Metrics used for analyses and reporting. Scores allocated as detailed in Table 1.

Proportional Connectance	the proportion of all linkages that are connected to each element (i.e. how connected it is)
Impact Risk (IR)	product of Spatial Overlap, Frequency, Degree of Impact
Recovery Lag (RL)	product of Resilience and Persistence
Total Risk (TR)	Product of Impact Risk and Recovery Lag
Relative Contribution (RC)	the proportion of an assessment score that each individual element contributes

Previous discussions with stakeholders on the approach (ICES, 2017; ICES, 2020), coupled with expert group discussion within ICES (e.g. ICES, 2019c) revealed a level of dissatisfaction with the relative contribution approaches, as they were not felt to fully reflect the needs of the assessment, nor the understanding of stakeholders. As such, a hybrid methodology was developed. The hybrid method focuses on the IR, as the pressures highlighted using this approach were perceived to be more relevant to management questions, scales and timelines. Some of the pressures highlighted using the TR were felt to be intractable and/or beyond the control of managers. The hybrid approach combines both the ranking tables and the relative contribution (top linkages) approaches to produce a more informative output that details the top 5 sectors and pressures relevant to a given region. This number was selected as it was perceived to highlight the primary areas of concern to stakeholders and experts, whilst remaining manageable and tractable for further investigation/next steps.

2.4 Stakeholder consultation

In Mission Atlantic, assessments were produced by case study teams prior to presentation to stakeholders. The reason for carrying out initial assessments *before* meeting with the stakeholders were as follows; i) the initial assessments are time consuming, even for those familiar with the approach; ii) it is often easier to engage stakeholders through providing initial output to kick start discussions and feedback, thus maximising the use of their time and knowledge, and iii) due to the COVID-19 pandemic, longer in person meetings had to be replaced with shorter online meetings. The results were presented to stakeholders to 'ground-truth' the assessment, i.e. to gather their feedback, check consistency with their understanding, and identify any potentially missing elements. The first Celtic Sea stakeholder meeting was held online due to the COVID-19 pandemic on the 25th of June 2021 and was attended by 27 stakeholders spanning marine and environmental management, the fisheries industry (including angling), and environmental non-governmental organisations from Ireland, the United Kingdom and France. The elements included in the assessment were presented and discussed to identify any missing elements. Initial results were presented to identify how they related to stakeholder understanding of primary issues and concerns.

3 Results

3.1 Risk assessment

Seventeen Sectors, 20 pressures and 26 ecological components were assessed in the Celtic Sea case study, with a potential of 8,840 interactions. Of these 1,592 (18%) were found to occur. Summary boxplots can be seen in Figure S1. The Celtic Sea case study was adapted and updated by the case study leads (DP & DR) from an existing assessment of the Irish EEZ (see Pedreschi et al., 2019) to which over 43 experts had contributed.

Comparison between the various assessment elements using the full approach (TR) or only using the IR are presented below (Tables 3–5). The difference between TR and IR is due to the inclusion of RL. There is a high degree of agreement between the primary contributing sectors no matter the metric used (Table 3), recognising fishing, land-based industry, shipping and waste-water management among the top 5 contributing sectors. However, while TR includes also coastal infrastructure, IR includes tourism/recreation (sumIR) or harvesting/collecting (avgIR).

Differences between the approaches are more pronounced for the Pressures, resulting in a substantially different top 5 pressures depending on the assessment and metric used. Full assessment scores using TR as the key metric were highly influenced by RL scores, driving top pressures towards those with a long persistence (e.g. contaminants, litter) when compared to those based purely on IR, including pressures such as bycatch, incidental loss and abrasion (Table 4).

Similarly, substantial differences are observed for the Ecological Components depending on the assessment and metric used. Full assessment scores using TR as the key metric were highly influenced by RL scores, placing the highest risk of impact on large and/or slow growing species (i.e. marine mammals and elasmobranchs) and habitats with long turnover/recovery times (e.g. deep sea). In contrast, the sum IR scores indicate highest risk of impact to the shallow habitats

TABLE 3 Ranks for each sector and ranking index used.

Sector	AvgIR	SumIR	AvgTR	SumTR
Fishing	1	1	2	1
Land-based Industry	3	2	1	2
Shipping	5	4	4	3
Waste Water	2	3	3	4
Coastal Infrastructure	6	6	5	5
Tourism/Recreation	8	5	7	6
Aquaculture	7	7	8	7
Agriculture	9	11	6	8
Non-renewable (oil & gas)	12	12	9	9
Telecommunications	14	13	10	10
Renewable Energy	15	14	11	11
Navigational Dredging	10	10	14	12
Research	11	9	16	13
Harvesting/Collecting	4	8	12	14
Military	16	16	15	15
Nuclear	17	17	13	16
Aggregates	13	15	17	17

Sectors listed in order of SUMTR. AVGIR: mean Impact Risk, SUMIR: sum Impact Risk, AVGTR mean Total Risk, SUMTR sum Total Risk. Top 5 highlighted in grey.

in which the majority of our marine activities take place (Table 5).

The Relative Contribution (RC) scores reflect the above rankings, but provide greater insight into the linkages between the top sectors and pressures. Using the RC on the TR outputs, six sectors and only three pressures, creating just 20 linkage chains are identified as contributing more than 1% TR to the assessment (Table 6). In total, these 20 linkage chains are responsible for 56.3% of the TR score.

Using the RC on the IR outputs, only one Sector (Fishing) is responsible for all 37 of the linkage chains contributing more than 1% to the assessment (Table 7), cumulatively contributing 57.6% of the Impact Risk of the system. Fishing mortality factors (selective extraction and bycatch) contribute much greater risk scores than abrasion and other physical disturbance impacts of fishing practices. This is due to the fact that both selective extraction and bycatch affect both pelagic and benthic habitats, whereas physical seabed impacts occur only in benthic habitats. This illustrates the importance of understanding the assessment mechanism when interpreting results and communicating them to stakeholders.

The hybrid approach combining both the ranking tables and the IR relative contribution approach details the top 5 sectors (Fishing, Land-based Industry, Waste Water, Shipping, and Tourism/Recreation) and top 5 pressures (Bycatch, Species Extraction, Incidental Loss, Litter, and Abrasion) relevant to the Celtic Sea region (Table 8). In total these top sectors and pressures contribute between 81% (by pressures) and 92% (by sectors) of the risk present in the system. The greatest individual impact chains arise from Fishing, and these account for 57.6% of the risk affecting the system. However, overall, Fishing contributes 77.5% of the risk in the assessment.

3.2 Stakeholder consultation

These results, along with the wider assessment were then presented to stakeholders. After in-depth discussions on the definitions and included elements, the Celtic Sea stakeholders were satisfied and supportive of the presented assessment, and no Sectors or Pressures were identified as missing. An anonymous poll asking 'Are you happy with the results presented so far (do they reflect your understanding)?' received a 100% Yes response (12 respondents). Subjectivity of the assessment was discussed, and how scores are assessed and supported. Scale was also discussed; some stakeholders expected pressures like Agriculture to feature more highly on the list, however, due to the coastal restriction of associated impacts, the spatial footprint over the entire assessment areas was proportionally smaller. As such, the group understood that a coastally focused assessment would

TABLE 4 Ranks for each Pressure and ranking index used.

Pressure	AvgIR	SumIR	AvgTR	SumTR
Litter	7	4	1	1
Contaminating Compounds	8	6	3	2
Wave Exposure	5	10	2	3
Sealing	6	8	4	4
Species Extraction	2	2	6	5
Bycatch	1	1	5	6
Incidental Loss	3	3	7	7
Siltation/Smothering	10	7	10	8
Abrasion	4	5	9	9
Invasive Species	20	19	12	10
Organic Matter	9	9	13	11
Radionuclides	18	17	11	12
Noise	16	11	16	13
Barriers	17	20	8	14
Current Changes	15	14	14	15
Non-living Resources	11	13	15	16
Salinity Regime	13	12	18	17
pH Changes	14	15	19	18
EMF	19	18	20	19
Thermal Regime	12	16	17	20

Pressures listed in order of SUMTR. AVGIR: mean Impact Risk, SUMIR: sum Impact Risk, AVGTR mean Total Risk, SUMTR sum Total Risk. Top 5 highlighted in grey.

potentially present a different picture, and the site and scale chosen can strongly influence the results. Sectors such as offshore renewable energy and deep-sea mining were flagged as emerging issues, and regulation (i.e. governance) was discussed as a potential pressure. Finally, emergency situations such as oil spills, which present a high impact, but a low frequency occurrence are not included under this assessment which focuses on 'business as usual'. These were acknowledged as different types of risk, which are managed differently, but that are also important to be taken into consideration. Questions were raised around climate change, interactive, foodweb, and cumulative effects, all of which will be addressed in the next stages of IEA (modelling and scenarios).

3.3 Vulnerability assessment

Through experience of using the ODEMM approach we hypothesised that the Recovery Lag approach is not fine scale or nuanced enough to be able to capture regional differences in these aspects of vulnerability. To assess regional variation in vulnerability, the scores for Persistence and Resilience were compared across the 7 Mission Atlantic case studies. This showed an 87.8% agreement for Resilience scores, and 94.5% agreement across Persistence scores, indicating strong support for the hypothesis. Conversely, it could also indicate consistency and hence a high degree of transferability of knowledge on persistence and resilience between systems at this coarse level of categorisation.

3.4 Hierarchical Approach

In order to improve operationality, the above approach must meet the needs of both regional studies/managers/stakeholders, and the ecoregional work of ICES. In order to address these needs we suggest a hierarchical approach, where finer resolved elements are consistently nested within coarser resolved elements (Table 9), through which groups can carry out detailed assessments as appropriate to their region or sub-region, but then summarise them to meet the higher-level reporting needs.

TABLE 5 Ranks for each Ecological Component and ranking index used.

Ecological Component	AvgIR	SumIR	AvgTR	SumTR
Demersal Elasmobranch	9	8	6	1
Deep Sea Rock & Reef	21	23	1	2
Deep Sea Sediment	21	23	1	2
Pelagic Elasmobranch	5	13	5	4
Toothed Whales	23	22	4	5
Baleen Whales	25	25	3	6
Littoral Sediment	20	14	9	7
Littoral Rock & Reef	17	11	10	8
Shallow Mud	12	3	13	9
Shallow Sediment	6	1	15	10
Shallow Rock & Reef	7	2	16	11
Shelf Sediment	3	5	11	12
Shelf Rock & Reef	4	6	12	13
Seals	18	16	14	14
Deep Sea Fish	15	19	7	15
Deep Sea Elasmobranch	15	19	7	15
Slope Rock & Reef	1	4	18	17
Slope Sediment	2	7	17	18
Seabirds	24	21	20	19
Demersal Fish	9	8	22	20
Pelagic Fish	8	12	21	21
Reptiles	26	26	19	22
Cephalopods	11	10	23	23
Coastal Pelagic	19	15	26	24
Shelf Pelagic	14	17	24	25
Oceanic Pelagic	13	18	25	26

Ecological Components listed in order of SUMTR. AVGIR: mean Impact Risk, SUMIR: sum Impact Risk, AVGTR mean Total Risk, SUMTR sum Total Risk. Top 5 highlighted in grey.

4 Discussion

In the context of a multidisciplinary, international, collaborative efforts, methods need to be accessible, clearly documented, reactive, adaptable, efficient and effective. O'Higgins et al. (2020) advocate for the '*standardisation of EBM approaches*', provision of '*a clear set of logical steps, which can be conducted in a flexible fashion*', and '*structured and documented methods for incorporating specific aspects of EBM into practice*', which can meet the requirements of '*co-design of the EBM process with stakeholders and the development of problem-specific solutions*'. Here we outline an attempt to address these issues, whilst building upon existing knowledge in order to maximize impact whilst minimizing redundancy in effort. We argue that the hybrid assessment, based on both IR and relative contributions, provides a risk assessment that meets the scoping needs of IEA by providing a high level and comprehensive approach, enabling the assessment of all relevant sectors and pressures, and identification of those that present the most urgent foci for management action. Furthermore, this presents a common approach to enable comparisons between ecoregions and/or case study areas. Critically for ICES IEA groups, it provides a documented method through which they can carry out a more detailed scoping exercise for IEA, and summarizes those assessment elements to the level of detail required for the Ecosystem

TABLE 6 The Sectors, Pressures and Ecological Components present in the top linkage chains as identified from the Relative Contribution (RC) to Total Risk Scores.

Sector	Sum of TR RC (%)	Pressure	Sum of TR RC (%)	Ecological Component	Sum of TR RC (%)
Fishing (6)	25.0	Litter (16)	49.1	Deep Sea Rock & Reef (3)	9.8
Land-based Industry (6)	14.3	Wave Exposure (2)	4.3	Deep Sea Sediment (3)	9.8
Shipping (3)	6.0	Contaminating Compounds (2)	2.8	Demersal Elasmobranch (3)	9.8
Waste Water (2)	5.2			Toothed Whales (4)	7.7
Coastal Infrastructure (2)	4.3			Baleen Whales (3)	7.5
Agriculture (1)	1.4			Pelagic Elasmobranch (2)	7.3
				Littoral Rock & Reef (1)	2.2
				Littoral Sediment (1)	2.2
Grand Total	56.3		56.3		56.3

Number of linkages in brackets.

Overviews *via* a hierarchical approach. In this way, the exercise can serve two purposes, thus saving on group time and energy.

The hybrid approach retains the potential of the original approach, being able to link through to ecosystem services (Böhnke-Henrichs et al., 2013; Hussain et al., 2013; DeWitt et al., 2020), or specific objectives such as the MSFD descriptors and criteria (Breen et al., 2012; White et al., 2013; Pedreschi et al., 2019). Furthermore, there is potential for linking through

TABLE 7 Top linkage chains as identified from the Relative Contribution (RC) to Impact Risk Scores.

Sector	Sum of IR RC (%)	Pressure	Sum of IR RC (%)	Ecological Component	Sum of IR RC (%)
Fishing (37)	57.6	Bycatch	23.1	Shelf Sediment (4)	6.3
		Species Extraction	18.9	Slope Sediment (4)	6.3
		Abrasion	7.9	Cephalopods (3)	4.7
		Incidental Loss	7.9	Demersal Elasmo (3)	4.7
				Demersal Fish (3)	4.7
				Shallow Rock & Reef (3)	4.7
				Shallow Sediment (3)	4.7
				Slope Rock & Reef (3)	4.7
				Pelagic Elasmo (2)	3.1
				Pelagic Fish (2)	3.1
				Shallow Mud (2)	3.1
				Coastal Pelagic (1)	1.6
				Oceanic Pelagic (1)	1.6
				Shelf Pelagic (1)	1.6
				Shelf Rock & Reef (1)	1.6
				Seals (1)	1.1
Grand Total	57.6		57.6		57.6

Number of linkages in brackets.

TABLE 8 Relative contribution scores for both the top linkages and the entire assessment.

	Sectors			Pressures	
	% relative contribution			% relative contribution	
	Top linkages	Entire Assessment		Top linkages	Entire Assessment
Fishing	57.6	77.5	Bycatch	23.1	24.1
Land-based Industry		4.4	Species Extraction	18.9	20.1
Waste Water		4.3	Incidental Loss	7.9	14.0
Shipping		3.3	Litter		12.9
Tourism/Recreation		2.7	Abrasion	7.9	9.7
Grand Total	58	92	Grand Total	58	81

to more quantitative and cumulative effects assessments (e.g. Hammar et al., 2020; ICES, 2022b), and socio-economic systems through conceptual modelling (Levin et al., 2016; DePiper et al., 2017; Piet et al., 2020) and/or indicator frameworks (Gaichas et al., 2018). This flexibility and adaptability enable the scoping exercise to act as a keystone IEA module, focusing efforts on key ecosystem risks for the next stages, whilst connecting to other approaches to advance complex systems understanding. The approach also ensures the explicit consideration of sectors beyond fishing. Even when fishing emerges as the overwhelming top pressure as it did in the Celtic Sea case study, the assessment provides context on other relevant sectors and possible interacting pressures.

Our comparative exercise indicated that the 'Recovery Lag' scores represent a vulnerability assessment that is not fit for comparative purposes, and of limited use for IEA. When RL and IR are coupled together, they can provide a longer-term view which is important to communicate with managers. However, through experience of using the approach we hypothesised that the approach is not currently fine scale or nuanced enough to be able to capture regional differences. A narrower categorisation of the Resilience and Persistence scores may lead to higher regional differentiation. The Mission Atlantic case studies showed an 87.8% agreement for Resilience, and 94.5% agreement across Persistence values, strongly supporting the hypothesis. This indicates that the metrics are highly transferable between regions, and as such the RL method is not useful for capturing regional specificities, instead describing a generic ecosystem. Where differences between regions are known to be important, or when vulnerable habitats are known to occur (e.g. mangroves, sponge habitats, coral reefs, etc.), we recommend that different vulnerability methods are used. Attempting to capture vulnerability at the coarse scale of the ecosystem components described here is likely inappropriate. Vulnerability tends to differ greatly at a species level, or depending on community characteristics, and so we propose looking more deeply at vulnerability in the next stages of the IEA, where we incorporate warnings signals, trends and indicators, along with more fine scale and species-specific information. Recovery/vulnerability elements are likely to be extremely important and relevant to managers and other integrated advice recipients, and thus, the assessment approach and the elements included should depend on the research objectives and management needs.

Coupling the proposed methodology with the IEA framework plays to the strengths of DPSIR approaches whilst helping to overcome many of its criticisms (Gari et al., 2015). For example, using it for scoping enables practitioners to continue beyond the identification of the Sectors, Pressures, Ecosystem Components and their linkages, through to the next steps of IEA where relevant indicators and trends are identified and incorporated into modelling frameworks where cause-and-effect relations, interactions among pressures, and complex socio-ecological dynamics can be investigated. This avoids the potential pitfalls of a static view, unidirectional causal chains, and poor understanding of dynamics and interactions that have previously been flagged as issues when using the DPSIR approach on its own (Gari et al., 2015). Ground-truthing the outcomes of the assessment with stakeholders, and working together to co-develop relevant scenarios, can also help to incorporate local and indigenous knowledge and address and minimize the power imbalance potential between the developers and the stakeholders.

The proposed amendments are not a panacea. Issues remain such as in interpretation and consistency of scoring. In both the Mission Atlantic and ICES assessments definitions and assisted guidance on their use are provided. Scores are applied with the emphasis on species assemblages and functional groups and hence ecosystem functioning, rather than focused on single species. This results in an averaging effect, which may miss important detail and nuance, and frequently makes

TABLE 9 Example hierarchy for carrying out detailed analyses and summarising to the coarse categories required for the ICES Ecosystem Overviews.

SPECIES GROUPS CONSIDERED INDEPENDENTLY OF BENTHIC HABITATS			
ICES EO Core Elements	More detail (example)	Fine detail (example)	Details
Fish	Fish	Demersal Fish	
		Pelagic Fish	
	Elasmobranchs	Demersal Elasmobranchs	
		Pelagic Elasmobranchs	
Cephalopods	Cephalopods	Cephalopods	
Reptiles	Reptiles	Reptiles	
Marine Birds	Marine Birds	Marine Birds	
Marine Mammals	Cetaceans	Cetaceans	
	Seals	Seals	
HABITATS BELOW ARE CONSIDERED INCLUDING ALL FAUNA NOT SPECIFICALLY LISTED SEPARATELY ABOVE, e.g. Include all associated benthos (macro, micro, epifauna, infauna, etc), algae, bacteria, etc.			
Benthic habitat (and associated biota)		Variable Salinity Waters	coastal wetlands, lagoons, estuaries etc
	Coastal Pelagic	Coastal Pelagic	include plankton, jellyfish, algae, bacteria, etc
	Shelf Pelagic	Shelf Pelagic	
	Oceanic Pelagic	Oceanic Pelagic	
	Ice habitats	Ice habitats	
	Littoral Rock & biogenic Reef	Littoral Rock & biogenic Reef	Tidal region up to high water mark
	Littoral Sediment	Littoral Sediment	
	Shallow sublittoral rock & biogenic reef	Shallow sublittoral rock & biogenic reef	up to 50m depth
	Shallow sublittoral sediment	Shallow sublittoral coarse sediment	
		Shallow sublittoral sand	
		Shallow sublittoral mud	
		Shallow sublittoral mixed sediment	
	Shelf rock & biogenic reef	Shelf rock & biogenic reef	50-200m
	Shelf sublittoral sediment	Shelf sublittoral coarse sediment	
		Shelf sublittoral sand	
		Shelf sublittoral mud	
		Shelf sublittoral mixed sediment	
	Slope Rock & biogenic Reef	Slope rock & biogenic reef	200-800m
	Slope Sediment	Slope sublittoral coarse sediment	
		Slope sublittoral sand	
		Slope sublittoral mud	
		Slope sublittoral mixed sediment	
	Deep Sea Rock and Reef	Upper bathyal rock & biogenic reef	Bathyal to 2700m, Abyssal beyond
		Upper bathyal sediment	

(Continued)

TABLE 9 Continued

SPECIES GROUPS CONSIDERED INDEPENDENTLY OF BENTHIC HABITATS			
ICES EO Core Elements	More detail (example)	Fine detail (example)	Details
		Lower bathyal rock & biogenic reef	
	Deep Sea Sediment	Lower bathyal sediment	
		Abyssal rock & biogenic reef	
		Abyssal sediment	

participants uncomfortable. Additionally, the assessment is criticized for being subjective through its expert judgement scoring approach. While this criticism is valid, it is the only way to carry out such a comprehensive assessment. Scores are informed by the best available scientific evidence, data and quantitative results where it is available, and expert judgement where it is not (De Lange et al., 2010; Knights et al., 2013b; Holsman et al., 2017). Scores are also assigned to indicate knowledge quality, although these are not used to weight the overall scoring, but instead to highlight areas of high risk and low knowledge (i.e. gap analysis) where more research is required. The alternative would be to omit data-poor elements or regions completely, which would highly bias the assessment to those things and regions we already study and/or think are important. Finally, the stakeholder ground-truthing mitigates against the omission of critical elements, and aligns the expert assessment with the consensus understanding of the system.

An additional issue that regularly arose with stakeholders is in relation to the exclusion of climate change from this analysis. It is acknowledged that climate change is *the* major over-riding issue and concern in each of the case studies examined to date, however the assessment presented herein does not capture climate change in a useful and tractable way. Indeed, climate change can be expected to interact in complex ways with all elements of the framework. When working with participants, both of the above concerns have been overcome by reiterating that this is the first scoping stage of the IEA, the focus is ensuring inclusiveness (i.e. all anthropogenic pressures), and more detail and data can be provided at the next steps, including climate change projections at different time steps of interest, and the cumulative and/or interactive effects of climate change and the high risk current pressures and/or emergent issues identified herein. If relevant, a future-focused/emergent issue view could be taken to repeat the same approach and compare between the current status and future expectations. Additionally, it is possible to carry out an analysis with an ‘emergency planning’ view that takes into account rare events such as oil spills and extreme weather events.

The next steps within the Mission Atlantic case studies will be somewhat dependent on the resources available within the study region, but may range from building conceptual models with stakeholders (Levin et al., 2016; DePiper et al., 2017; ICES, 2022c) through to minimally-realistic models, models of intermediate complexity (MICE), full end-to-end models and even ensemble and multi-model approaches (Fulton et al., 2003; Plagányi et al., 2013; Collie et al., 2016; Thorson et al., 2019; Geary et al., 2020). No matter the level of complexity however, time should be taken with relevant stakeholder groups to define questions relevant to the region and management, and within the scope of the models used.

5 Conclusion

IEA enables a structured decision-making approach where problems and objectives are identified, and potential alternatives, consequences and trade-offs are investigated through scenarios and management strategy evaluation to inform decision-making (Gregory et al., 2012; Muffley et al., 2020). IEA itself has been selected as a core tool in the efforts to progress EBM from theory to practice (e.g. NOAA, ICES). The key objective here was to advance this goal by taking an established risk assessment approach, and amending it to make it as streamlined, operational, and fit-for-purpose as possible. The limited resources and time challenges experienced by ICES groups are often also experienced by public bodies, research agencies, and management institutions. These challenges may explain why previous project-based outputs have not been taken up as actively as one might have expected, and progress towards EBM remains slow.

There exists between science and management a tension and trade-off between doing the best, and doing *something;* i.e. what can be achieved now based on the best available science and evidence. As discipline specialists work towards making assessments more comprehensive (see evolution of Pressure-State-Response (PSR) to DAPSI(W)R(M); Gari et al., 2015; Elliott et al., 2017 and references therein) this also leads them to becoming more complicated and less operational. We must not let ‘perfection be the enemy of progress’; the increasing pressures affecting our marine environments cannot wait. In the race to achieve EBM, perhaps less is more.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

DP, SN, DR, MS-M contributed to conception and design of the study, and coordinated across Mission Atlantic case studies and work packages. DP performed the analyses, led on the Celtic Sea case study work, ran the case study training, co-chaired the WKTRANSAPRENT workshop, and wrote the first draft of the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2022.1037878/full#supplementary-material

SUPPLEMENTARY FIGURE 1
Proportional Connectance, Impact Risk, Impact Rank and Recovery Lag Boxplots. Each component assessed is listed in order of its summed Total Risk. 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.

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