

2019-01

Integrated ecosystem analysis in Irish waters; Providing the context for ecosystem-based fisheries 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.

1 Integrated Ecosystem Analysis in Irish 2 waters; Providing the Context for 3 Ecosystem-based Fisheries Management 4

5 **Pedreschi, Debbi^{*a}, Bouch, Paul^b, Moriarty, Meadhbh^{a,1}, Nixon, Eugene^a, Knights, Antony M.^c &
6 Reid, David G^a.**

7 ^aMarine Institute, Rinville, Oranmore, Co. Galway, Ireland.

8 ^cSchool of Biological & Marine Sciences, Plymouth University, Plymouth, Devon, United Kingdom.

9
10 ¹Present Address: Environmental Sciences Research Institute, Ulster University, Cromore Road,
11 Coleraine, Co. Londonderry, BT52 1SA, United Kingdom.

12
13 [*Debbi.Pedreschi@Marine.ie](mailto:Debbi.Pedreschi@Marine.ie)

14 Paul.Bouch@Marine.ie

15 Moriarty-M3@ulster.ac.uk

16 ernixon1@gmail.com

17 antony.knights@plymouth.ac.uk

18 David.Reid@Marine.ie

20 **ABSTRACT:**

21 Fishing has long been considered the most impactful human activity on the marine ecosystem. To
22 adopt ecosystem-based fisheries management (EBFM) requires consideration of all human impacts,
23 not just those of fishing. The ODEMM (Options for Delivering Ecosystem-based Marine
24 Management) approach provides an integrated ecosystem assessment that is a flexible, cost-
25 efficient and expert-based. The framework traces the sectors affecting the marine environment, the
26 pressures they create, and the ecological characteristics affected. This research presents the first
27 application of the ODEMM framework outside of the ODEMM project, completed for Ireland's
28 marine waters. The assessment places fishing in the context of other anthropogenic pressures and
29 highlights areas of threat to Marine Strategy Framework Directive (MSFD) descriptors. From 1,8749

30 impact chains, just ~~5960~~ (445 of which were attributed to the fishing sector) account for 64% of the
31 Total Risk score, highlighting areas for management action with a high risk-reduction return. Of the
32 sectors, The analysis showed *Waste Water* to have the highest average risk of all sectors, followed
33 by *Land-based Industry*, *Fishing* and then *Shipping*. In terms of total risk, *Fishing* was the most
34 important sector, due to its high connectance to many ecosystem components and widespread
35 influence, even though many of the impacts are relatively low and the components impacted show a
36 high degree of recoverability. Litter was ~~found to be the highest risk~~ identified as the pressure with
37 the highest total risk scores (average and summed) due to its persistence, and widespread reach.
38 Among the ecological characteristics, ~~D~~deep water habitats that have low resilience to pressures
39 showed the highest average total risk, yet the highest impact risks were for ecological characteristics
40 that were closer to land and were impacted more frequently. These conclusions highlight the
41 importance of context and interpretation in the analysis. The impact chains were further linked
42 through to the MSFD environmental status descriptors, indicating *Biological Diversity* and *Food Webs*
43 as the descriptors most at risk, followed by *Sea-floor Integrity*. As the first independent application
44 of the method, issues arose with interpretation of some categories and definitions, and some
45 modifications are discussed.

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

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

53

54 **1. INTRODUCTION:**

55 Today's ecosystems are widely recognized as being highly impacted and extensively modified by
56 human activities (Firth et al., 2016; Halpern et al., 2008, 2007; Millennium Ecosystem Assessment,
57 2005; OSPAR Commission, 2010). We struggle to balance our aspirational goals of sustainable
58 management (e.g. Sustainable Development Goal 14: "Conserve and sustainably use the oceans,
59 seas and marine resources" (United Nations, 2015)) with an increasingly developed world and rising
60 population levels (Meadows et al., 2005). Improved knowledge and recognition of the multitude of
61 anthropogenic pressures affecting natural ecosystems has resulted in broad acceptance that
62 ecosystem-based management is essential for the effective conservation and management required
63 to maintain ecosystem services (European Environment Agency, 2006; Halpern et al., 2008; Levin et
64 al., 2009; OSPAR Commission, 2010; Pikitch, 2004). Ecosystem-based management requires
65 consideration of the whole suite of anthropogenic pressures affecting entire ecosystems, rather than
66 focusing on individual components (Borja et al., 2016; Halpern et al., 2007; Harvey et al., 2017;
67 Hilborn, 2011; Levin et al., 2009). In recent years, legislation and policy have also moved in this
68 direction, increasingly requiring scientists and managers to be holistic in their work, advice, and
69 decision-making, rather than looking at single or few elements in isolation (e.g. Marine Strategy
70 Framework Directive (MSFD; European Union, 2008), Common Fisheries Policy (CFP; European
71 Union, 2013), Maritime Spatial Planning Directive (MSPD; European Union, 2014), Magnuson–
72 Stevens Fishery Conservation and Management Act (MSA: *Magnuson-Stevens Fishery Conservation
73 and Management Act.*, 1996), Australia's Oceans Policy (Environment Australia, 1999), Canadian
74 Oceans Act (Department of Fisheries and Oceans, 1996); Oceans Act of 2000 (US Congress, 2000),
75 South African National Water Act (Government of the Republic of South Africa, 1998), etc.). Within
76 Europe, the MSFD specifically enshrines the ecosystem approach in a legislative framework to
77 manage European seas in a sustainable, holistic manner, through establishing (by 2020) and
78 maintaining 'good environmental status' (GES) of the marine ecosystem (European Union, 2008).
79 The current CFP specifically aims to deliver economically, environmentally and socially sustainable

80 fisheries. The CFP also acknowledges that the impacts of human activities on all components of the
81 ecosystem are not fully understood, and makes specific references to multi-annual ecosystem-based
82 management plans (European Commission, 2018; European Union, 2013). The MSPD requires us to
83 manage our waters more coherently by ensuring cross-sectoral human activities at sea take place in
84 an efficient, safe and sustainable way (European Union, 2014). Taken together, these Directives
85 require us to look at fisheries in the context of the suite of other human induced pressures affecting
86 our marine ecosystems.

87 Efforts to implement ecosystem approaches to fisheries management (EAFM) and ecosystem-based
88 fisheries management (EBFM), as well as the necessary research to underpin them have increased
89 dramatically in recent years (Borja et al., 2016; Korpinen and Andersen, 2016; Pitcher et al., 2009;
90 Trochta et al., 2018), partly in response to legislation. However, actual practical tactical
91 implementation of EBFM in the real world has been much rarer (Borja et al., 2011; Skern-Mauritzen
92 et al., 2016). Efforts have ranged in scale and ambition, from simply incorporating some 'ecosystem
93 knowledge' into single species assessment models at one extreme, to building complex ecosystem
94 models that incorporate the suite of **Drivers, Activities, Pressures, State, Impacts (human Welfare),**
95 **management Responses (as Measures);** (*sensu* DAPSI(W)R(M) after Borja et al., 2016). Ecosystems
96 approaches by definition should include all sectors (Borja et al., 2016; Dickey-Collas, 2014; Fitzpatrick
97 et al., 2010), yet they rarely do (but see Knights et al., 2015). It is perhaps the daunting complexity of
98 what can and/or should be included in EBFM that has led to the rarity of 'real-world'
99 implementation, yet in order to advance EBFM, fisheries (and its pressures) must be placed within
100 the context of the wide range of others sectors and the pressures they create if measures are to be
101 in anyway effective.

102 Common perception often assumes that fishing is the sector creating the most pressures, affecting
103 the widest range of ecosystem components, and with the greatest impact. However, is this really the
104 case? And if so, does it apply everywhere equally? What pressures beyond 'extraction of species'

105 and 'sea floor degradation' does it create, and which ones should we be most concerned about? And
106 importantly, is focusing on fisheries the most efficient way to reduce risk and pressure on the marine
107 environment? Many questions remain, and thus much is to be gained by placing fisheries within the
108 wider context of the ecosystem.

109 To deliver holistic ecosystems-based marine management, managers must know the causal drivers
110 of impact if they are to be managed (Knights et al., 2014). Integrated ecosystem assessments (IEA's)
111 have been proposed as a framework to facilitate ecosystem-based management, and to steer
112 management efforts to achieve multiple objectives (Dickey-Collas, 2014; Harvey et al., 2017; Levin et
113 al., 2014, 2009). IEA takes a birds-eye view to assess the suite of pressures that co-exist, identify the
114 sectors that cause them, and the ecosystem components affected by them, thus providing the
115 context in which the sectors and pressures operate. Conceptually, IEA is both simple and sensible,
116 yet implementation is more difficult (Dickey-Collas, 2014; Walther and Möllmann, 2014). The data,
117 monitoring and modelling requirements of full ecosystem based management are many and
118 daunting (Borja et al., 2016; Harvey et al., 2017; Hilborn, 2011; Hobday et al., 2011; McQuatters-
119 Gollop, 2012). Inevitably an extensive list of pressures and threatened ecological components results
120 from such an IEA, and resources are rarely, if ever, sufficient to address them all (Halpern et al.,
121 2007). Therefore tough decisions must be made, and priorities specified. IEA can play a central role
122 in the decision-making process by providing holistic information that is based on best available
123 understanding and knowledge, which then allows comparisons and judgements to be made (i.e.
124 identification of trade-offs) and the most appropriate objectives for management to be determined
125 (Walther and Möllmann, 2014).

126 There are many tools and stages in the IEA toolbox that are applicable at a range of scales (Harvey et
127 al., 2017; Levin et al., 2014, 2009). One key element, however, is risk assessment (Battista et al.,
128 2017; DePiper et al., 2017; Fletcher, 2015; Hilborn, 2011; Hobday et al., 2011; Holsman et al., 2017;
129 Korpinen and Andersen, 2016; Slater et al., 2017). In broad terms, risk assessment comprises

130 identification (scoping) of relevant pressure elements to include in your assessment (in consultation
131 with stakeholders), ~~and~~ an analysis of the 'susceptibility' of ecosystem components, and their ability
132 to recover ('resilience') post-impact (Levin et al., 2009). Assessments may be quantitative (i.e.
133 indicator-based, see review in Borja et al., 2016), qualitative (e.g. ODEMM, Robinson et al., 2014), or
134 a mixture of the two (e.g. Bayesian Network Analysis, Fletcher et al., 2014); indeed a wide range of
135 methodologies for applying such risk assessments exist (see Korpinen and Andersen, 2016).
136 Quantitative and qualitative assessments are not mutually exclusive, in fact they are often
137 complimentary, each filling the gaps left by the other and can be used together in a series of steps.

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

156 on the ODEMM approach, for Ireland’s marine waters to inform ecosystem management within the
157 context of the MSFD, CFP and MSPD, and to place fisheries within the context of wider
158 anthropogenic pressures.

159 **2. MATERIALS & METHODS:**

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

177 Scores were applied with a ‘current status’ and ‘standard practice’ view (i.e. business as usual rather
178 than potential risk assessment). Majority assessment was applied to the scoring of broad ecological
179 components; i.e. where habitats were assessed, emphasis was on assemblage and ecosystem

180 functioning rather than focused on single species. Consensus was sought from the panels; best
181 evidence/majority rules applied where consensus was not immediately forthcoming.

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

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

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

215 ~~D. Pedreschi & M. Moriarty joined as the chairs and facilitators of the re-assessments.~~

216 Following the guidelines provided in the ODEMM guidance documents and published papers (for
217 full methodological details see: Knights et al., 2015, 2013; Robinson et al., 2014, 2013; White et al.,
218 2013) ‘Proportional Connectance’, ‘Impact Risk’ (product of the ‘overlap’, ‘frequency’ and ‘degree of
219 impact’ scores) and ‘Recovery Lag’ (product of ‘resilience’ and ‘persistence’ scores) boxplots and
220 estimates were produced in R. The code used to produce these estimates is publically available for
221 use at (http://github.com/PaulBouch/ODEMM_Celtic_Sea). The Impact Risk scores were log
222 transformed to allow better visual comparison between the scores and their ranks. Both the sum
223 and the means were used in the ranking process to avoid the methodological influence and bias that
224 can be introduced through the use of only one method– both methods of aggregation are influenced
225 by the number of impact chains present although ‘summation’ is less sensitive to such fluctuations.
226 Bias was further mitigated by selecting the highest impacting *individual* linkage chains to
227 recommend foci for action to decision-makers. These highest risk chains were identified by ranking
228 the risk scores (Total Risk, Impact Risk and Recovery Lag) as outlined in Piet et al. (2015).

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

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

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

249 **3. RESULTS:**

250 **3.1 Irish Assessment Results**

251 *3.1.1 Sectors*

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

254 Risk places *Fishing* as the highest risk sector. *Waste Water* tops the average list due to the
255 combination of high median Impact Risk scores coupled with a relatively long Recovery Lag (median
256 ~60 years; Figure 3). *Fishing* has a higher Impact Risk score, but generally a much shorter Recovery
257 Lag; within 10 years for most impact chains. Comparison of the proportional connectance plots
258 (Figure 3) helps to further explain the differences, with *Fishing* demonstrating a proportional
259 connectance double that of *Waste Water*, reflecting the wide range of habitats and species that
260 interact with fishing activities. Individual *Fishing* chains span the entire range of possible Impact Risk
261 values, while *Waste Water* has a more restricted range. Irrespective of the method used, the top five
262 highest risk sectors remain the same, albeit with changes in the order (i.e. *Waste Water*, *Land-based*
263 *Industry*, *Fishing*, *Shipping*, and *Tourism/Recreation*).

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

269 3.1.2. Pressures

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

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

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

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

291 3.1.3. Ecological Characteristics

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

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

310 **3.2 Prioritization**

311 The highest risk chains were determined as those that contributed over 1% of the risk scores (Impact
312 Risk and Total Risk) to the assessment. These ~~5960~~ chains accounted for ~~64.52~~% of the Impact Risk
313 score, and 64% of the Total Risk score. Forty-four of these identified chains related to *Fishing*, via the
314 pressures *Abrasion*, *Litter*, *Bycatch*, *Incidental Loss* and *Selective Species Extraction*. The remaining
315 sectors (*Land-based Industry*, *Waste Water* and *Shipping*) all related to the pressure of *Litter* on
316 deep-sea habitats, marine mammals, and elasmobranchs.

317 **3.3 Marine Strategy Framework Directive**

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

330 **3.4 Comparison to North East Atlantic (NEA) assessment**

331 The majority of impact chains in the Irish waters assessment exist at site or local scales (see Table B1
332 for scoring criteria), with only 272 chains (15%) considered as 'widespread', matching the findings of
333 the ODEMM NEA assessment (Robinson et al., 2014). Similarly, 'rare' and 'occasional' were the most
334 commonly assigned frequencies (58%); however, our assessment classified many more pressures as
335 being 'persistent' (36%) compared to the NEA assessment (3%). The majority of pressures were
336 assessed as having a 'low' degree of impact (66%), with the remaining as 'chronic' (18%) and 'acute'
337 (16%). This again contrasts with the NEA assessment which assessed about 80% of the pressures as
338 being 'chronic'. The 'persistence' of the pressures in the environment were classified as 52% 'low'
339 (<2 years), 15% 'medium' (2-10 years), 14% 'high' (10-100 years) and 20% were continuous (> 100
340 years). Similar to the NEA assessment, the 'continuous' category was predominantly used for
341 pressures that were unlikely to be removed, such as for structures related to *coastal infrastructure*,
342 *telecoms*, *renewable* and *non-renewable energies* and *aquaculture* as appropriate.

343 The majority of ecological characteristics were considered to be moderately resilient (2-10 years;
344 62%); only 7% of ecological characteristics were assigned high resilience (recovery within 2 years).
345 Deep-sea habitats and species, and long-lived mammals and elasmobranchs, were considered 'low'
346 resilience (10-100 years) accounting for 31%, however a special case was also used in relation to the
347 pressure of *Invasive Species*. It was felt that all species and habitats that could be affected by
348 *Invasive Species* demonstrate 'low' resilience when the threat occurs (i.e. when an invasive species
349 establishes). For instance, *Coastal Pelagic* environments are generally assessed as 'high' resilience to
350 most pressures. However, if an *Invasive Species* managed to establish, it was felt they would have
351 'low' resilience as returning to pre-impact conditions (eradication) is highly unlikely. As such, all
352 *Invasive Species* linkages were assigned 'low' resilience (7%).

353 **4. DISCUSSION**

354 **4.1 The Irish EEZ Assessment**

355 4.1.1 Pressures and Risks in the Irish EEZ

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

369 *Fishing* was found to produce a wide range of pressures beyond simply extracting target
370 commercial species, as illustrated in Figure 1. Filtering through the most impactful chains (Figure 2)
371 highlights the importance of *Fishing* as a source of pressures, as 445 of the top 6599 impact chains
372 belong to this sector, suggesting that summation may be the more appropriate descriptive statistic.
373 The Total Risk score for *Bycatch* (ranked second), surpasses that of *Selective Species Extraction*
374 (ranked third), as *Bycatch* affects far more species than those targeted for commercial exploitation
375 (Burgess et al., 2018). This highlights how identification of the relevant categories for your
376 assessment can provide interesting insights. From the results of this assessment, it is indeed
377 appropriate to focus on fisheries for ecosystem-based management, as the largest individual impact
378 chain risk scores are stemming from this sector. However, fisheries do not act in isolation and it is
379 important to place it in the context of all its activities, and those of other sectors, with their
380 potentially cumulative effects (Jennings and Kaiser, 1998). Similar to Halpern et al. (2007), some of

Formatted: Font: Calibri

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

384 *4.1.2 Comparison of Irish waters to North East Atlantic*

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

403 *4.1.3 Risk Assessment and Management through the Implementation of ODEMM*

404 Through our implementation of the ODEMM approach, we progressed from the scoping exercise
405 producing a horrendogram with 1,8749 identified links (Figure 1), and no indication of risk scores,

406 through to being able to identify the impact chains that are responsible for the majority of the
407 identified risk (Figure 2). This process highlights just ~~60~~⁵⁹ sector-pressure-ecological characteristic
408 pathways that are responsible for 64% of the Total Risk. This reduced number of impact chains
409 provides a feasible set of pathways for targeted management objectives that are most likely to
410 provide the greatest 'return on investment'. Potential management actions could include: spatial or
411 temporal controls to reduce/remove the spatio-temporal footprint of the identified sector and/or its
412 pressure; input or output controls to reduce the degree of impact (and together reduce the Impact
413 Risk score); and/or remediation/restoration efforts to improve the current state of the ecological
414 characteristic affected and thus reduce the Recovery Lag (Piet et al., 2015). Furthermore, co-benefits
415 may be realized through targeting these high risk chains, where implementing measures to mitigate
416 or remediate the highest identified risks may bring about improvements in risk scores across a range
417 of other impact chains, MSFD descriptors, and ecosystem services through synergistic effects
418 (Robinson et al., 2014). For example, action taken to reduce inputs of litter into the marine
419 environment (or equally to remove it from marine waters) would not only benefit seabirds, but a
420 plethora of other organisms (all other ecological characteristics in our framework; see Appendix C).
421 Similarly, spatio-temporal management of fisheries (e.g. real-time incentives fishery management;
422 Kraak et al., 2015) may provide benefits not only in reduction of some of the top highlighted *Fishing-*
423 *related risks (Abrasion, Litter, Bycatch, Incidental Loss and Selective Species Extraction)* but would
424 also reduce other impacts caused by *Fishing (e.g. Smothering and Noise)*. Further, examination of
425 the linkage framework (Appendix C) shows that reduction in these pressures would reduce the risk
426 related to 6 of the 11 MSFD descriptors (*Biological Diversity, Commercial Fishing, Food Webs, Sea-*
427 *floor Integrity, Litter and Noise*) and 20 of the 21 identified ecosystem services (excluding *Sea*
428 *Water*). Finally, if the top risks emergent from the system are assessed as outside of the
429 management remit within the assessment area (e.g. due to insufficient information or conflicting
430 institutional priorities), the assessment can be revised in light of this information. As Hobday et al.
431 (2011) note, employing a precautionary approach that requires the inclusion of all possible linkages

432 means it is possible to include false positives during the assessment process, but these can be
433 screened out when data is available to eliminate them. Once appropriate areas of action are
434 identified, the ODEMM approach can help to identify the relative costs and benefits of
435 implementation of specified measures in terms of ecosystem services and possibly even economics
436 (Hussain et al., 2013).

437 **4.2 Using ODEMM**

438 *4.2.1 Definitions and interpretations of terminology*

439 Although (to our knowledge) this is the first application of the methodology outside of the ODEMM
440 project, it was important to use an established methodology that provides an open access common
441 tool that can facilitate direct comparisons between different regions. In this same spirit, our
442 adaptation of the published methodology has been outlined here (see Section 2 and Appendix C,),
443 and the code developed for producing the outputs provided freely on GitHub (Section 2). During our
444 implementation of the approach we encountered a few issues. Almost exclusively these related to
445 the application of definitions and interpretations. Panelists (and even workshop leaders) were
446 occasionally uncomfortable with some of the definitions and rules that apply to the pressure
447 assessment. It would appear that this is not an issue limited to the Irish experience as the ODEMM
448 project revised and updated its guidelines throughout the project (Robinson et al., 2013; Robinson
449 and Knights, 2011), nor is it limited to the ODEMM project (see Halpern et al., 2007). In particular
450 issues related to the definition of ‘resilience’ and ‘persistence’ (outlined above), were raised.

451 According to the scoring rules, ‘resilience’ is based on generation times and the time taken
452 (following impact and cessation of the pressure) to recover to its current status, but “resilience”, as
453 defined in an ODEMM evaluation, should be independent of all other assessment criteria and thus
454 does not vary between sectors or pressures. The reason for this is to avoid conflating the *degree of*
455 *impact* with *resilience*. For instance, this means that the resilience of a sublittoral habitat to *abrasion*
456 from *navigational dredging* should be the same as its resilience to *noise* from *tourism/recreation*:

457 resilience is an inherent property of the ecological characteristic of interest. This proved to be
458 distinctly uncomfortable, and frustrating, for many participants, even resulting in the generation of
459 an 'exception' during our assessment, as outlined above for *Invasive Species* (Section 3.4.4). The
460 expert panel felt that within the framework of a 'current status' assessment, that the appropriate
461 'degree of impact' score for *Invasive Species* was low, reflecting a belief that overall there is a low
462 risk of establishment of a given invasive species. However, in cases where an invasive species
463 manages to establish, then the 'resilience' of the system/species affected is 'low'. This interpretation
464 is breaking the rules by somewhat conflating the 'degree of impact' and 'resilience', particularly as a
465 'low degree of impact' by definition 'never causes a noticeable effect for the ecological component
466 of interest in the area of interaction' – which *Invasive Species* clearly can. However, the panel felt
467 that neither 'chronic' nor 'acute' adequately captured the *current* risk for this category. As the
468 assessment scores were assigned by an expert panel, we have honored their scoring, but note it as a
469 special case, whilst highlighting it as a 'quirk' associated with working with panels. We suggest that
470 perhaps a change in terminology, such as renaming 'resilience' to something more akin to 'average
471 turnover time' might make participants more comfortable, as within our experience, the term
472 resilience encourages individuals to relate scoring to the specific impact under consideration. We
473 encourage those that may employ this methodology in the future to carry out the 'resilience' scoring
474 as one of your first exercises, as it need only be done once for each ecological characteristic, as
475 clarified in (Robinson et al., 2013).

476 The second difficulty encountered was in the omission of an 'intensity' factor, to indicate how severe
477 the pressure is, or what proportion of a component is affected - more than a simple overlap of
478 spatial footprints (e.g. similar to 'resistance' and 'functional impact' as per Halpern et al., (2007)).
479 For instance, a small proportion of species encompassed by an ecological component category (e.g.
480 demersal fish) may be highly susceptible (beyond recovery) to a given pressure. However, other
481 species may be very robust to the same pressure, and overall ecosystem functioning is maintained,
482 thus the risk score may be low, despite being acute for certain elements of that ecological

483 characteristic. Related to this is the acknowledgement by Robinson et al., (2014) that there is no
484 specified point for when a 'chronic' becomes a problem, due to a lack of knowledge of where these
485 thresholds exist for many pressures. Throughout the guidance documents 'degree of impact' is
486 referred to as an indication of severity, however, given the lack of a threshold for when 'chronic'
487 may become 'acute' the distinction seems more a description of mechanism than an indication of
488 severity, and a description as such can tempt panelists to interpret them as 'high', 'medium' and
489 'low' categories, which they are not.

490 *4.2.2 Work load*

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

508 descriptor highlighted for action. This could prove to be particularly useful for filtering out the
509 appropriate information of interest where different departments or agencies are responsible for
510 different aspects of MSFD reporting, monitoring and actions.

511 *4.2.3 Further Recommendations*

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

528 **4.3 The experience of applying the ODEMM approach**

529 Through our experience working with ODEMM we maintain that it is a flexible framework that can
530 be adapted as required. Scoping and qualitative risk assessment, whilst just one part of the IEA cycle
531 is a critical first step on the way to the goal of informed ecosystem-based management (Knights et
532 al., 2014; Levin et al., 2009; Walther and Möllmann, 2014). The risk assessment presented here can

533 be adjusted to answer specific questions for management strategy evaluation (MSE) – the next
534 necessary stage of the IEA cycle (Harvey et al., 2017; Levin et al., 2014, 2009; Piet et al., 2015), or
535 used to highlight specific areas of interest that may require finer examination or require quantitative
536 data streams. MSE as developed by ODEMM thus far only allows for relative comparisons, assuming
537 management options are 100% effective and operate on 100% of the activity (either in time or
538 space; Piet et al., 2015). True MSE would require more underlying data and modelling tools to be
539 used in concert with high-level tools such as ODEMM for specific management options and scenario-
540 testing. ODEMM frameworks can be linked to, and further informed by, analyses such as integrated
541 trend analyses (Kenny et al., 2009) and food web models (e.g. Ecopath with Ecosim; Heymans et al.,
542 2016) to inform missing parameters, answer specific trade-offs questions, and to model identified
543 management options (Borja et al., 2016; Levin et al., 2009)

544 The assessment presented herewith is a living tool, consistent with the idea that the IEA framework
545 is a an iterative process necessary for adaptive management (Dickey-Collas, 2014; Harvey et al.,
546 2017; Levin et al., 2014, 2009). It should be consistently reviewed, to evolve for each new purpose,
547 and when new data becomes available (OSPAR Commission, 2010; Pikitch, 2004). As such data
548 becomes more available, knowledge and understanding improve and precautionary limits can be
549 eased in deference to true understanding (Pikitch, 2004). In reality for such a process to work
550 requires not one person or team, but a synergistic group effort. The authors, along with
551 international colleagues have made steps in this direction (and will continue to do so), making our
552 assessment results available to the International Council for the Exploration of the Seas (ICES) to
553 provide data and understanding that underpins the ICES ecosystem overviews (ICES, 2016a, 2016b).

554 *4.3.1 Future implementation and ongoing work*

555 The potential future avenues of this research are many, including downsizing to help address specific
556 management issues, such as marine spatial planning conflicts where single sector development plans

557 dominate, often resulting in unsustainable use (Böhnke-Henrichs et al., 2013), or delving deeper into
558 particular sectors and/or pressures identified as areas of interest in this assessment.

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

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

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

581 **5 CONCLUSIONS**

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

596 **FIGURES:**

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

602
603 **Figure 2.** Horrendogram of the top identified risks by Impact Risk (black) and Total Risk (Red) scores.

604
605 **Figure 3:** Proportional Connectance, Impact Risk, Impact Rank and Recovery Lag Boxplots. Each
606 component assessed is listed in order of its average Total Risk Rank. The thick black vertical lines on
607 the boxplots indicate the median values, with the box lengths representing the 25% quartiles and
608 the whiskers representing 1.5 times the interquartile range. Outliers are shown as black dots. The

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

611
612

613 **TABLES:**

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

616

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

621

622 **SUPPLEMENTARY INFORMATION:**

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

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

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

632

633 **ACKNOWLEDGEMENTS:**

634 The authors would like to acknowledge the many individuals that contributed to these assessments
635 and workshops over the years. Without their knowledge, this assessment would not be possible. We
636 would also like to acknowledge the ODEMM project group who developed the methodologies
637 implemented in this study. This analysis was funded under the Beaufort Ecosystem Approach to
638 Fisheries Management award, as part of the Irish Government's National Development Plan (NDP),

639 the Beaufort Marine Research Award is grant aided by the Department of Communications, Energy
640 & Natural Resources (DCENR) & the Department of Agriculture, Fisheries & Food (DAFF) under the
641 Strategy for Science Technology & Innovation (SSTI) & the Sea Change Strategy.

642 **CONTRIBUTORS:**

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

650

651 REFERENCES

- 652 Battista, W., Karr, K., Sarto, N., Fujita, R., 2017. Comprehensive Assessment of Risk to Ecosystems
653 (CARE): A cumulative ecosystem risk assessment tool. *Fish. Res.* 185, 115–129.
654 <https://doi.org/10.1016/j.fishres.2016.09.017>
- 655 Böhnke-Henrichs, A., Baulcomb, C., Koss, R., Hussain, S.S., de Groot, R.S., 2013. Typology and
656 indicators of ecosystem services for marine spatial planning and management. *J. Environ.*
657 *Manage.* 130, 135–145. <https://doi.org/10.1016/j.jenvman.2013.08.027>
- 658 Borja, A., Elliott, M., Andersen, J.H., Berg, T., Carstensen, J., Halpern, B.S., Heiskanen, A.-S., Korpinen,
659 S., Lowndes, J.S.S., Martin, G., Rodriguez-Ezpeleta, N., 2016. Overview of Integrative
660 Assessment of Marine Systems: The Ecosystem Approach in Practice. *Front. Mar. Sci.* 3.
661 <https://doi.org/10.3389/fmars.2016.00020>
- 662 Borja, A., Elliott, M., Andersen, J.H., Cardoso, A.C., Carstensen, J., Ferreira, J.G., Heiskanen, A.-S.,
663 Marques, J.C., Neto, J.M., Teixeira, H., Uusitalo, L., Uyarra, M.C., Zampoukas, N., 2013. Good
664 Environmental Status of marine ecosystems: What is it and how do we know when we have
665 attained it? *Mar. Pollut. Bull.* 76, 16–27. <https://doi.org/10.1016/j.marpolbul.2013.08.042>
- 666 Borja, Á., Galparsoro, I., Irigoien, X., Iriondo, A., Menchaca, I., Muxika, I., Pascual, M., Quincoces, I.,
667 Revilla, M., Germán Rodríguez, J., Santurtún, M., Solaun, O., Uriarte, A., Valencia, V., Zorita,
668 I., 2011. Implementation of the European Marine Strategy Framework Directive: A
669 methodological approach for the assessment of environmental status, from the Basque
670 Country (Bay of Biscay). *Mar. Pollut. Bull.* 62, 889–904.
671 <https://doi.org/10.1016/j.marpolbul.2011.03.031>
- 672 Breen, P., Robinson, L.A., Rogers, S.I., Knights, A.M., Piet, G., Churilova, T., Margonski, P.,
673 Papadopoulou, N., Akoglu, E., Eriksson, A., Finenko, Z., Fleming-Lehtinen, V., Galil, B.,
674 Goodsir, F., Goren, M., Kryvenko, O., Leppanen, J.M., Markantonatou, V., Moncheva, S.,
675 Oguz, T., Paltriguera, L., Stefanova, K., Timofte, F., Thomsen, F., 2012. An environmental
676 assessment of risk in achieving good environmental status to support regional prioritisation
677 of management in Europe. *Mar. Policy* 36, 1033–1043.
678 <https://doi.org/10.1016/j.marpol.2012.02.003>
- 679 Burgess, M.G., McDermott, G.R., Owashi, B., Peavey Reeves, L.E., Clavelle, T., Ovando, D., Wallace,
680 B.P., Lewison, R.L., Gaines, S.D., Costello, C., 2018. Protecting marine mammals, turtles, and
681 birds by rebuilding global fisheries. *Science* 359, 1255–1258.
682 <https://doi.org/10.1126/science.aao4248>
- 683 Department of Fisheries and Oceans, 1996. An act respecting the oceans of Canada.
- 684 DePiper, G.S., Gaichas, S.K., Lucey, S.M., Pinto da Silva, P., Anderson, M.R., Breeze, H., Bundy, A.,
685 Clay, P.M., Fay, G., Gamble, R.J., Gregory, R.S., Fratantoni, P.S., Johnson, C.L., Koen-Alonso,
686 M., Kleisner, K.M., Olson, J., Perretti, C.T., Pepin, P., Phelan, F., Saba, V.S., Smith, L.A., Tam,
687 J.C., Templeman, N.D., Wildermuth, R.P., 2017. Operationalizing integrated ecosystem
688 assessments within a multidisciplinary team: lessons learned from a worked example. *ICES J.*
689 *Mar. Sci.* <https://doi.org/10.1093/icesjms/fsx038>
- 690 Dickey-Collas, M., 2014. Why the complex nature of integrated ecosystem assessments requires a
691 flexible and adaptive approach. *ICES J. Mar. Sci.* 71, 1174–1182.
692 <https://doi.org/10.1093/icesjms/fsu027>
- 693 Environment Australia, 1999. Australia's oceans policy: caring, understanding, using wisely. Bd. 1: ...
694 Environment Australia, Canberra.
- 695 European Commission, 2018. Reforming the Common Fisheries Policy (CFP): Building a brighter
696 future for fish and fishermen.
- 697 European Environment Agency (Ed.), 2006. The changing faces of Europe's coastal areas, EEA report.
698 European Environment Agency; Office for Official Publications of the European
699 Communities, Copenhagen, Denmark : Luxembourg.

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

- 700 European Union, 2014. DirectiveE 2014/89/EU of the European Parliament and of the Council of 23
701 July 2014 establishing a framework for maritime spatial planning. Off. J. Eur. Union 257.
- 702 European Union, 2013. Regulation(EU) No 1380/2013 of the European Parliament and of the Council
703 of 11 December 2013 on the Common Fisheries Policy, amending Council Regulations (EC)
704 No 1954/2003 and (EC) No 1224/2009 and repealing Council Regulations (EC) No 2371/2002
705 and (EC) No 639/2004 and Council Decision 2004/585/EC. Off. J. Eur. Union 354.
- 706 European Union, 2008. Directive 2008/56/EC of the European Parliament and of the Council of 17
707 June 2008 establishing a framework for community action in the field of marine
708 environmental policy (Marine Strategy Framework Directive). Off. J. Eur. Union 164, 19–40.
- 709 Firth, L., Knights, A.M., Thompson, R., Mieszkowska, N., Bridger, D., Evans, A., Moore, P., O'Connor,
710 N., Sheehan, E., Hawkins, S., 2016. Ocean sprawl: challenges and opportunities for
711 biodiversity management in a changing world., in: *Oceanography and Marine Biology: An*
712 *Annual Review*. pp. 189–262.
- 713 Fitzpatrick, M., Graham, N., Rihan, D., Reid, D.G., Sutton, G., MacMullen, P., 2010. Reversing the
714 burden of proof in fisheries management in the context of an integrated ecosystem
715 approach ICES CM 2010/P:13.
- 716 Fletcher, P.J., Kelble, C.R., Nuttle, W.K., Kiker, G.A., 2014. Using the integrated ecosystem
717 assessment framework to build consensus and transfer information to managers. *Ecol. Indic.*
718 44, 11–25. <https://doi.org/10.1016/j.ecolind.2014.03.024>
- 719 Fletcher, W. (Rick) J., 2015. Review and refinement of an existing qualitative risk assessment method
720 for application within an ecosystem-based management framework. *ICES J. Mar. Sci.* 72,
721 1043–1056. <https://doi.org/10.1093/icesjms/fsu142>
- 722 Government of the Republic of South Africa, 1998. National Water Act. An Act to provide for
723 fundamental reform of the law relating to water resources; to repeal certain laws; and to
724 provide for matters connected therewith.
- 725 Halpern, B.S., Selkoe, K.A., Micheli, F., Kappel, C.V., 2007. Evaluating and Ranking the Vulnerability of
726 Global Marine Ecosystems to Anthropogenic Threats. *Conserv. Biol.* 21, 1301–1315.
727 <https://doi.org/10.1111/j.1523-1739.2007.00752.x>
- 728 Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C., Bruno, J.F., Casey,
729 K.S., Ebert, C., Fox, H.E., Fujita, R., Heinemann, D., Lenihan, H.S., Madin, E.M.P., Perry, M.T.,
730 Selig, E.R., Spalding, M., Steneck, R., Watson, R., 2008. A Global Map of Human Impact on
731 Marine Ecosystems. *Science* 319, 948–952. <https://doi.org/10.1126/science.1149345>
- 732 Harvey, C.J., Kelble, C.R., Schwing, F.B., 2017. Implementing “the IEA”: using integrated ecosystem
733 assessment frameworks, programs, and applications in support of operationalizing
734 ecosystem-based management. *ICES J. Mar. Sci.* <https://doi.org/10.1093/icesjms/fsw201>
- 735 Heymans, J.J., Coll, M., Link, J.S., Mackinson, S., Steenbeek, J., Walters, C., Christensen, V., 2016. Best
736 practice in Ecopath with Ecosim food-web models for ecosystem-based management. *Ecol.*
737 *Model.* 331, 173–184. <https://doi.org/10.1016/j.ecolmodel.2015.12.007>
- 738 Hilborn, R., 2011. Future directions in ecosystem based fisheries management: A personal
739 perspective. *Fish. Res.* 108, 235–239. <https://doi.org/10.1016/j.fishres.2010.12.030>
- 740 Hobday, A.J., Smith, A.D.M., Stobutzki, I.C., Bulman, C., Daley, R., Dambacher, J.M., Deng, R.A.,
741 Dowdney, J., Fuller, M., Furlani, D., Griffiths, S.P., Johnson, D., Kenyon, R., Knuckey, I.A., Ling,
742 S.D., Pitcher, R., Sainsbury, K.J., Sporcic, M., Smith, T., Turnbull, C., Walker, T.I., Wayte, S.E.,
743 Webb, H., Williams, A., Wise, B.S., Zhou, S., 2011. Ecological risk assessment for the effects
744 of fishing. *Fish. Res.* 108, 372–384. <https://doi.org/10.1016/j.fishres.2011.01.013>
- 745 Holsman, K., Samhour, J., Cook, G., Hazen, E., Olsen, E., Dillard, M., Kasperski, S., Gaichas, S., Kelble,
746 C.R., Fogarty, M., Andrews, K., 2017. An ecosystem-based approach to marine risk
747 assessment. *Ecosyst. Health Sustain.* 3, e01256. <https://doi.org/10.1002/ehs2.1256>
- 748 Hussain, S., Baulcomb, C., Bloomfield, H., Böhnke-Henrichs, A., Culhane, F., Fofana, A., Frid, C., de
749 Groot, R., Koss, R., Robinson, L.A., 2013. The ODEMM Approach to Analysing the Costs &

750 Benefits of Marine Management. Deliverable 12, EC FP7 'Options for Delivering Ecosystem-
751 based Marine Management'.

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

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

755 Jennings, S., Kaiser, M.J., 1998. The effects of fishing on marine ecosystems. *Adv. Mar. Biol.* 34, 201–
756 352.

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

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

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

769 Knights, A.M., Koss, R.S., Robinson, L.A., 2013. Identifying common pressure pathways from a
770 complex network of human activities to support ecosystem-based management. *Ecol. Appl.*
771 23, 755–765.

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

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

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

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

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

791 Levin, P.S., Kelble, C.R., Shuford, R.L., Ainsworth, C., deReynier, Y., Dunsmore, R., Fogarty, M.J.,
792 Holsman, K., Howell, E.A., Monaco, M.E., Oakes, S.A., Werner, F., 2014. Guidance for
793 implementation of integrated ecosystem assessments: a US perspective. *ICES J. Mar. Sci.* 71,
794 1198–1204. <https://doi.org/10.1093/icesjms/fst112>

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

796 McQuatters-Gollop, A., 2012. Challenges for implementing the Marine Strategy Framework Directive
797 in a climate of macroecological change. *Philos. Trans. R. Soc. Math. Phys. Eng. Sci.* 370,
798 5636–5655. <https://doi.org/10.1098/rsta.2012.0401>

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

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

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

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

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

810 Pitcher, T.J., Kalikoski, D., Short, K., Varkey, D., Pramod, G., 2009. An evaluation of progress in
811 implementing ecosystem-based management of fisheries in 33 countries. *Mar. Policy* 33,
812 223–232. <https://doi.org/10.1016/j.marpol.2008.06.002>

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

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

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

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

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

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

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

836 US Congress, 2000. Oceans Act of 2000.

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

840 White, L.J., Koss, R.S., Knights, A.M., Eriksson, A., Robinson, L.A., 2013. ODEMM Linkage Framework
841 Userguide (Version 2). ODEMM Guidance Document Series No.3. EC FP7 project (244273)
842 ‘Options for Delivering Ecosystem-based Marine Management. University of Liverpool.
843