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1 **Title:** Evaluation of ecosystem-based management strategies based on risk assessment

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13
14 **Abstract**

15 This study presents a comprehensive and generic framework that provides a typology for the
16 identification and selection of consistently defined ecosystem-based management measures and allows
17 a coherent evaluation of these measures based on their performance to achieve policy objectives. The
18 performance is expressed in terms of their reduction of risk of an adverse impact on the marine
19 ecosystem. This typology consists of two interlinked aspects of a measure, i.e. the “Focus” and the
20 “Type”. The “Focus” is determined by the part of the impact chain (Driver-Pressure-State) the
21 measure is supposed to mitigate or counteract. The “Type” represents the physical measure itself in
22 terms of how it affects the impact chain directly; we distinguish Spatio-temporal distribution controls,
23 Input and Output controls, Remediation and Restoration measures. The performance of these measures
24 in terms of their reduction in risk of adverse impacts was assessed based on an explicit consideration
25 of three time horizons: past, present and future. Application of the framework in an integrated
26 management strategy evaluation of a suite of measures, shows that depending on the time horizon,
27 different measures perform best. “Past” points to measures targeting persistent pressures (e.g. marine
28 litter) from past activities. “Present” favours measures targeting a driver (e.g. fisheries) that has a high
29 likelihood of causing adverse impacts. “Future” involves impacts that both have a high likelihood of
30 an adverse impact, as well as a long time to return to pre-impacted condition after the implementation
31 of appropriate management, e.g. those caused by permanent infrastructure or persistent pressures such
32 as marine litter or specific types of pollution.

33
34 **Key words**

35 DPSIR; Ecosystem-based management; Spatio-temporal distribution controls; Remediation;
36 Restoration; Marine Strategy Framework Directive

37
38
39 **1 Introduction**

40
41 All marine ecosystems are impacted by human activities (e.g. Glover and Smith 2003; Halpern *et al.*
42 2007) and in many cases, the exploitation of resources is occurring at an unsustainable rate resulting in
43 a deteriorated ecosystem. Impacts are caused by the multitude of sectors in operation to exploit a wide
44 range of habitats and species (ecosystem components), thereby forming a complex network of
45 interactions (Leslie and McLeod, 2007; Liu *et al.*, 2007; Knights *et al.*, 2013) that may cause harm to
46 the environment (Levin *et al.*, 2009; Goodsir, submitted). This has left current sectoral approaches to
47 the management of marine and coastal resources apparently incapable of conserving the marine
48 ecosystem and exploitation rates remaining unsustainable (Smith *et al.*, 2007). A widely promoted
49 solution is an ecosystem approach to management also known as ecosystem-based management
50 (EBM) (Airoldi & Beck, 2007; EC, 2008; Halpern *et al.* 2007); a concept in which the network of
51 impacts is identified and managed. However, the number of impacts can make the identification and
52 management of detrimental pathways difficult (Bottrill *et al.*, 2008; but see Knights *et al.*, 2013) and
53 presents a major challenge to resource managers in transforming the ecosystem approach from a
54 concept into an operational framework (Leslie and McLeod, 2007). This challenge can be addressed

55 by the development of a comprehensive generic framework for integrated decision-making on the
56 exploitation of marine resources.

57
58 The effective management of human impacts requires that the pathways through which activities cause
59 harm are identified (Fletcher *et al.*, 2010; Leslie and McLeod, 2007). Linkage-based frameworks (e.g.
60 DPSIR) have been developed for marine and terrestrial environments (Elliott, 2002; Holman *et al.*,
61 2005; La Jeunesse *et al.*, 2003; Odermatt, 2004; Scheren *et al.*, 2004), adopting a causal-chain
62 approach to infer pressure-state relationships between human activities and ecosystem state
63 (Rounsevell *et al.* 2010). The number of potential links between sectors and the state of the ecosystem
64 (Airoldi and Beck, 2007; Knights *et al.*, 2013) can increase the difficulty of decision-making,
65 especially when time is limited (Haynes, 2009). In support, several frameworks for formal decision-
66 making are available (Jeffrey, 1983; Jeffrey, 1992; Resnik, 1987) with risk assessment in particular
67 providing a flexible, problem-solving approach that is capable of linking the relationship between
68 human activities and the environment supporting the decision-making needs of environmental
69 managers (Hope, 2006). Risk assessment in general describes the likelihood and consequences of an
70 event. In the context of EBM, it evaluates the degree to which human activities interfere with the
71 achievement of management objectives that are related to particular ecological characteristics
72 (Samhuri and Levin, 2012) and is increasingly seen as a way to integrate science, policy and
73 management (CENR, 1999).

74
75 To date, risk assessment has been used to assess a wide range of environmental issues. Early efforts
76 addressed a single ecosystem component and considered few threats (e.g. Francis, 1992), followed by
77 more comprehensive frameworks that were developed for species (e.g. Kappel, 2005; Samhuri and
78 Levin, 2012) or features (e.g. Zacharias and Gregr, 2005; Halpern *et al.*, 2007). In none of these cases
79 was a specific link to existing environmental policy made. But in perhaps the most extensive
80 framework to date, Driver-Pressure-State combinations for entire ecosystems were developed
81 (Robinson *et al.* 2013; Knights *et al.* in press) and these combinations (which were referred to as
82 “impact chains”) were explicitly linked to existing policy objectives, namely the Marine Strategy
83 Framework Directive (MSFD) and its qualitative descriptors of good environmental status (GES) (EC,
84 2008a). Assessing the risk to an ecosystem from a particular impact chain can be done using
85 quantitative approaches (e.g. Francis, 1992; Samhuri and Levin, 2012) or qualitative approaches (e.g.
86 Breen *et al.*, 2012; Fletcher, 2005; Fletcher *et al.*, 2010). Ecological risk assessments (e.g. Fletcher,
87 2005; Campbell and Gallagher, 2007; Astles *et al.*, 2006) tend to be based on a likelihood-
88 consequence approach for estimating the risk of a rare or unpredictable event (i.e. calamities)
89 (Williams *et al.*, 2011). However, when an assessment of on-going (current) pressure is needed (i.e.,
90 normal operations, where the likelihood equals 100%), then an exposure-effect analysis is more
91 suitable (Smith *et al.*, 2007) using qualitative descriptors such as habitat resistance and resilience to
92 assess the vulnerability of habitats (Bax and Williams, 2001) and more recently, assess the potential
93 for EBM at a sub-regional scale (Samhuri and Levin, 2012).

94
95 Building on the vulnerability measures of Halpern *et al.* (2007), Robinson *et al.* (2013) conducted a
96 qualitative pressure assessment that assesses the threat from different driver-pressure combinations to
97 the state of the ecosystem components (thus making up impact chains) for all European regional seas.
98 From this, Knights *et al.* (in press) used an exposure-effect analysis with five criteria to assess risk for
99 each impact chain which can be interpreted as the likelihood or degree to which human activities
100 interfere with the achievement of policy objectives. Risk can then be assessed for each Driver,
101 Pressure or State component through aggregation across those impact chains that include that
102 particular Driver, Pressure or State component. This, in turn, allows for an evaluation of how risk will
103 decrease over time once management on one or more of these components or combinations of
104 components is implemented.

105
106 The logical next step towards achieving policy objectives is the choice of appropriate ecosystem-based
107 management (EBM) measures to mitigate those risks affecting these objectives (Samhuri and Levin,
108 2012). To that end we developed a comprehensive framework for integrated Management Strategy
109 Evaluations (iMSE) framework that links directly to the risk assessment approach described (e.g.

110 Halpern *et al.*, 2007; Knights *et al.*, in press), providing guidance for the identification and selection of
111 consistently defined measures, and also allowing an evaluation of the effectiveness of these measures
112 through their reduction of risk. For this, the effectiveness of a management measure depends on both
113 (a) the number of impact chain(s) it targets; (b) the weighting of the chains based on the five risk
114 criteria; and (c) the likelihood the measure can reduce the impact of these chains. Measures that target
115 a selection of impact chains that together contribute a high proportion of the risk to the ecosystem
116 being assessed are likely to be most effective.

117

118 **2 Material and methods**

119

120 **2.1 Summary of risk assessment approach**

121 This framework for the identification, selection and evaluation of management measures (MMs) is
122 based on the most extensive risk assessment approach to date consisting of Driver-Pressure-State
123 combinations (so-called “impact chains”) that each contribute to the risk of not achieving policy
124 objectives (Knights *et al.*, in press). Risk is determined based on scores given to five criteria. These
125 are: (1) the spatial (Extent), and (2) temporal (Frequency) overlap of a sector-pressure and ecological
126 characteristic, which together describe the exposure of the ecological component to a sector-pressure
127 combination in terms of their spatio-temporal overlap; (3) the Degree of Impact (DoI) of the sector-
128 pressure on that characteristic describing the severity of the impact where interactions occur; whilst
129 the potential for recovery after the impact has occurred is described by (4) the Persistence of the
130 pressure (the number of years before the pressure impact ceases following cessation of the activity
131 introducing it), and (5) the Resilience of the ecological characteristic (recovery time in years) (see full
132 details of criteria in Robinson *et al.*, 2013). Based on these criteria, Knights *et al.* (in press) allocated
133 scores and considered two aspects of risk:

- 134 • Impact Risk (IR) = the likelihood of an adverse ecological impact following a sector-pressure
135 introduction = Extent * Frequency * DoI
- 136 • Recovery Lag (RL) = the time it takes for an impacted ecological component to return to pre-
137 impacted condition after the implementation of a measure = Persistence * Resilience.

138

139 **2.2 Selection of MMs**

140 As MMs tend to either reduce the exposure to a pressure, the severity of impacts where there are
141 interactions, or actively promote recovery, it is possible to select measures using the five criteria
142 described above, and thus to target particular aspects of risk in the ecosystem (Table 1). Linked to
143 these risk assessment criteria, the selection of MMs can then also be guided by two distinct aspects of
144 a MM: the “Focus” and the “Type” of measure. The “Focus” is determined by the element(s) of the
145 impact chain (i.e. Driver-Pressure-State) that the measure targets. A measure may involve only one
146 single element in the impact chain (i.e. Driver, Pressure or State), the combination of two (i.e. Driver-
147 Pressure or Pressure-State), or all three making the measure more specific as more elements are
148 combined (see first column in Table 1 and examples in Table 2). The “Type” distinguishes six
149 categories, loosely based on the measures distinguished in (EC, 2008b), that mitigate or counteract the
150 impact of the human activity on the ecosystem directly. Each category links specifically to one of the
151 risk criteria (Table 1).

152

153 Table 1. A typology for ecosystem-based management measures based on the impact-chain “Focus” and control “Type” of a
154 measure distinguishing three groups of generic measures: affecting several impact chains and either exclusively reduce
155 impact risk (red); reduce recovery lag (green); or reduce both impact risk and recovery lag (yellow). White cells indicate no
156 possible combination of “Focus” and “Type”. The numbers in the cells correspond to the management measures in Table 2.

157

Focus	Type					
	Spatial distribution controls	Temporal distribution controls	Input control	Output control	Remediation	Restoration
D	1,2		6			
D-P	3			7,8	13	
P	4			9	14	
P-S	4			10	15	
S	5					17,18,19
D-P-S				11,12	16	20
Risk assessment criteria	Extent	Frequency	Degree of Impact		Persistence	Resilience
Aspects of risk	Impact Risk				Recovery Lag	
Time horizon	Present				Past	
	Future					

158

159 The measure types “Spatial distribution controls”, “Temporal distribution controls”, “Input control”
160 and “Output control” each (or in combination) mitigate or counteract aspects of Impact Risk. The first
161 two involve a reduction of the extent in space and time of the activity and are further considered as a
162 single type, i.e. Spatio-temporal distribution controls, because in addition to spatially closed areas, e.g.
163 Marine Protected Areas (MPAs) (Browman and Stergiou, 2004), or seasonal closures (Dinmore *et al.*,
164 2003) there are Real Time Closures (RTCs) (Bailey *et al.*, 2010) which are essentially a combination
165 of both. The latter two come originally from fisheries management and affect the DoI where “input
166 control” applies to capacity (size of the fleet) or effort (fishing activity), and “output control” applies
167 to the reduction of the catch itself (FAO, 2003). In this integrated framework, i.e. beyond fisheries
168 management, we interpreted input controls as only mitigating the Driver while output controls mitigate
169 the Pressure, possibly in combination with either some Driver or some State component. While the
170 four types of controls (i.e. spatial distribution, temporal distribution, and input/ output control)
171 mitigate the risk of potential impact (respectively linked to assessment criteria: Extent, Frequency and
172 DoI), the mitigation of any already existing impacts occurs through the reduction of the Recovery Lag,
173 for which we distinguish between the reduction of pressure persistence through “Remediation”
174 measures, and the increase of the resilience of the state component(s) through “Restoration” measures.
175

176

2.3 Evaluating effectiveness of MMs

177 For the evaluation of the effectiveness of MMs, a non-exhaustive list of examples of MMs was
178 compiled (Table 2) that could reduce risk through the various pathways indicated in Table 1. The
179 process of identification and selection of possible MMs was based on three groupings of measures (see
180 colours in Table 1) distinguishing between fairly generic measures (several impact chains) and very
181 specific measures (involving few impact chains), and either aimed at the reduction of Impact Risk or
182 Recovery Lag. The aim was to select examples that together covered most of the boxes shown in
183 Table 1, so that the utility of the approach in evaluating effectiveness could be explored fully.
184

185

186 For the evaluation of the effectiveness of measures we assumed a full implementation of the measure
187 (i.e. a 100% reduction of the risk criteria linked to the type of measure). For example, if the MM
188 covered a ban on littering (not specified to any sector), then any impact chain that contained Marine
189 Litter as pressure would be removed and the reduction in risk (across the whole ecosystem) associated
190 with this is calculated to express the effectiveness of the MM. Using the two different risk aspects
191 mentioned earlier, i.e. Impact Risk and Recovery Lag, we considered it relevant to assess the
192 effectiveness of MMs against three time horizons:

- 192 • “Past” - aimed at recovery of already affected ecosystems as reflected by the Recovery Lag
193 (RL) score,

- 194 • “Present” – aimed at reducing the likelihood of an adverse ecological impact from current
195 activities as reflected by the Impact Risk (IR) score, while
- 196 • “Future” – aimed at reducing the likelihood of impacts, specifically those that require a long
197 time to recover from. This is reflected by Total Risk (TR) which is the product of RL and IR.

198 These “Time Horizon” perspectives were used in the process of identification and selection of possible
199 management measures, as well as the subsequent evaluation of these measures.

200

201 **3 Results**

202 The results show (1) the application of our framework incorporating the European risk assessment data
203 to guide the identification and selection of MMs for the North East Atlantic (NEA) region, followed
204 by (2) an evaluation of the effectiveness of measures in reducing risk to the ecosystem across three
205 management time horizons.

206

207 **3.1 Identification and selection of MMs**

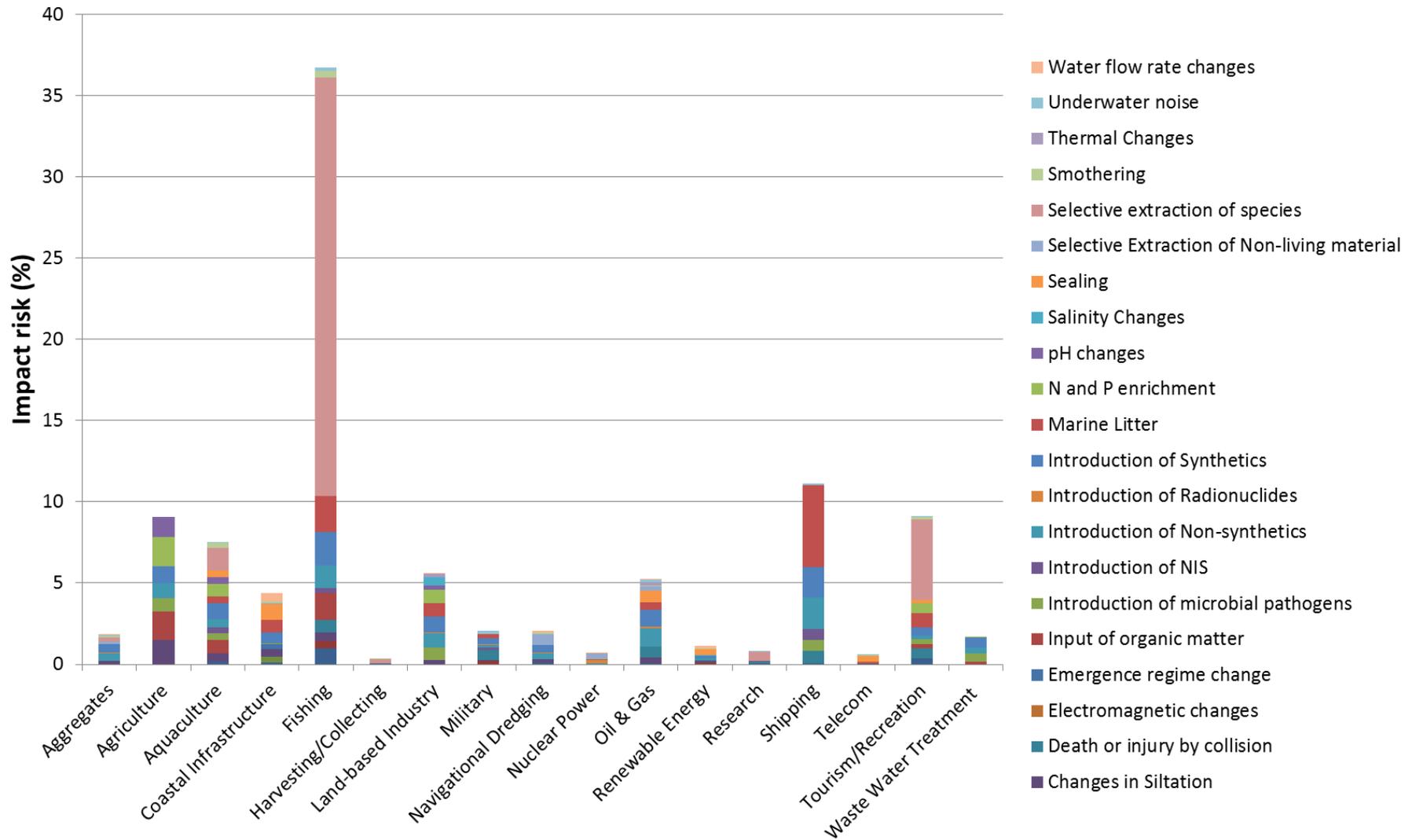
208 The identification and selection of MMs was approached differently for each of the three (color coded)
209 groups of generic measures identified using the typology in Table 1. As the type of measures intended
210 to mitigate the IR mostly involve a focus on Driver and/or Pressure, the selection of these measures
211 can be guided by information such as represented in Figure 1. This shows that for the NEA, fishing is
212 by far the most important driver (37% across all pressures), and selective extraction of species (33%
213 across all drivers) the main pressure, the combination contributing 26% to IR, making these the most
214 likely candidates (separately or in combination) for MMs aimed at mitigating IR. Other important
215 drivers are shipping (11%) and tourism/recreation (9%) while marine litter and the introduction of
216 synthetics are the next important pressures each contributing 11% to IR.

217

218 The type of measures intended to reduce the RL mostly involve a focus on Pressure and/or State (see
219 Table 1, Figure 2). The four least resilient ecosystem components, i.e. both demersal and pelagic fish,
220 marine mammals, and seabirds contribute to 88% (across all pressures) of the RL while the five most
221 persistent pressures, i.e. sealing, marine litter, introduction of synthetics, introduction of non-
222 synthetics, introduction of radionuclides, contribute to 81% (across all components) of the RL. For
223 more specific measures (i.e. focus on P-S rather than P or S) any combination of these pressures and
224 ecosystem components can be considered. Each combination contributes to approximately 3-4% of the
225 RL.

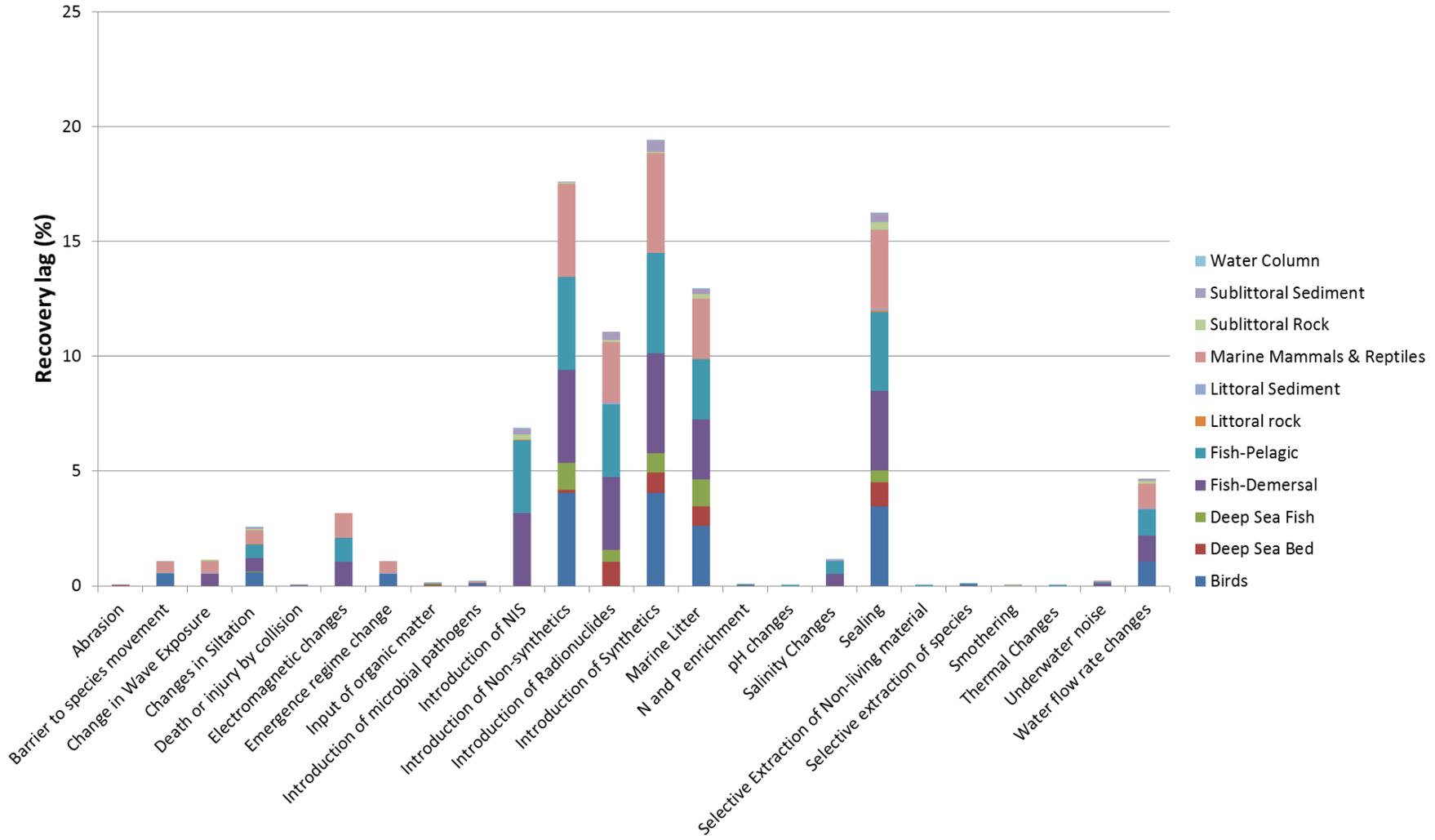
226

227 The third group to guide the identification and selection of measures involves very specific measures
228 (i.e. focus on specific D-P-S combination), which depending on the choice of the type of management
229 measures, may reduce the IR (i.e. any of the control types), RL (i.e. Remediation, Restoration) or TR
230 (all control types). When individual impact chains are ordered according to their contribution to the
231 overall IR, RL or TR (Figure 3) we find that notably for IR and TR there are a few, but different,
232 individual impact chains that contribute disproportionately (i.e. furthest to the left with a relative
233 contribution to risk > 1), and thus should be targeted by specific management measures. For IR, it is
234 fishing affecting demersal, pelagic and deep sea fish as well as the sublittoral sediment habitat through
235 the pressure biological extraction. These four individual chains together contribute more than 22% to
236 the total IR. In contrast, for TR marine litter from shipping affecting the least resilient ecosystem
237 components (i.e. seabirds, marine mammals and fish) emerges as the main contributors causing close
238 to 10% of the TR. The driver coastal infrastructure is affecting the littoral habitats (both sediment and
239 rock) through sealing as well as some other pressures. The pressure marine litter is caused mainly by
240 shipping and fisheries and affects all ecosystem components.



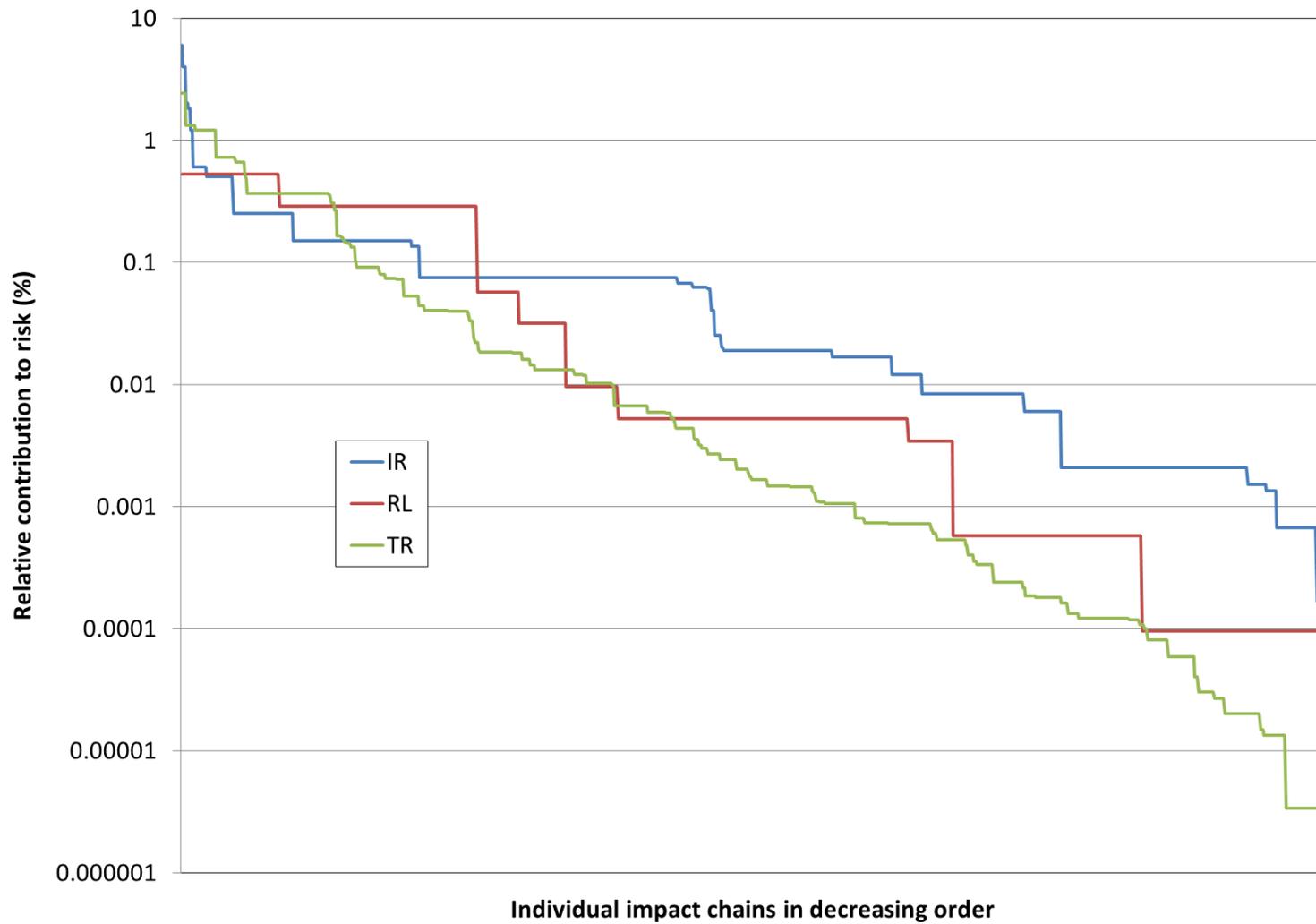
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Figure 1. Impact Risk per Driver-Pressure combination expressed as the % contribution to the total risk of an adverse impact.



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Figure 2. Recovery Lag per Pressure – State combination expressed as the % contribution to the total time it takes for the impacted ecological components to return to pre-impacted condition after the introduction of the pressures has stopped.



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Figure 3. Relative contribution to Total Risk (TR) and the two aspects (IR=Impact Risk, RP=Recovery Potential) that determine TR by each individual impact chain arranged in decreasing order. Note the logarithmic scale of the y-axis.

251 3.2 Effectiveness of MMs at reducing risk over three time horizons

252 Guided by the above results, we selected a non-exhaustive suite of 20 potential management measures
 253 (Table 2) and calculated the reduction in IR, RL and TR the full implementation of these measures
 254 would achieve. We phrased the measures 1-3 as “Spatio-temporal closures/restrictions....” in line with
 255 our assertion that often measures contain both spatial and temporal dimensions. In this assessment
 256 MMs 1 and 2 are conventional fisheries management measures but here considered in an EBM context
 257 where not only more pressures are considered than the commonly used “biological extraction of
 258 species” (i.e. catch) but also other components of ecosystem state than fish. The distinction between
 259 MMs 1 and 2 lies not only in the subset of fish they target (i.e. respectively pelagic versus demersal)
 260 but also in that the demersal fishery impacts the seafloor habitats through physical disturbance (i.e.
 261 abrasion, smothering and changes in siltation). Other pressures, such as marine litter and underwater
 262 noise apply to both fisheries. Because the MMs 1 and 2 are assumed to involve a spatio-temporal
 263 closure for the fishing vessels belonging to a specific metier (i.e. demersal or pelagic), we consider
 264 these MMs as focussed on the Driver only. However, in Table 2 we used the selection of the State
 265 components, pelagic fish and demersal fish, to focus on the appropriate fishing metiers.
 266 MMs 4 and 5 are explicitly spatial but this should not imply that measures with also a temporal
 267 component can be conceived for those cells in table 1. No Take zones, or totally closed areas
 268 (Horwood *et al.*, 1998), can be defined as marine areas in which the extraction of living and non-living
 269 resources is permanently prohibited, except as necessary for monitoring or research to evaluate
 270 effectiveness (NRC, 2001, cited by Jones, 2006). Although this measure can be introduced to reduce
 271 the risk for a specific ecosystem component (Focus = P-S), it could also be introduced to protect all
 272 components in that area (Focus = P). Based on this definition, the measure affects all impact chains
 273 that include the pressures ‘selective extraction of non-living resources’ or ‘selective extraction of
 274 species’; and are not related to the driver ‘research’. Although in some cases the focus could include
 275 specific components of State, all ecosystem components were included in this assessment.
 276 MMs 8, 9 and 13-15 all involve marine litter but the % risk reduction achieved varies considerably
 277 because of the difference in focus of the measures. MM 9 is the least specific and therefore results in
 278 the largest potential reduction. Even though MM 8 and MM 13 both involve the mitigation of effects
 279 of marine litter from fisheries we distinguished between MM 8 which involves all litter and MM 13
 280 mitigating only the effects of “ghost-fishing”, here assumed to affect fish only. MM 14 will only
 281 remove marine litter from fishable habitats while MM 15 was assumed to affect only the littoral
 282 habitats and the ecosystem components that inhabit the intertidal zone.

283
 284 Table 2 shows that management measures cause different reductions in the three aspects of risk which
 285 correspond to the three time horizons for management we considered. From a “Present” perspective,
 286

287 Table 2. Non-exhaustive list of potential management measures, how these were interpreted in terms of “Focus”, the number
 288 of impact chains affected based on this “Focus” and the maximum potential reduction that can be achieved if the measures
 289 are fully implemented and effective. The numbers correspond to those in Table 1. RL=Recovery Lag, IR=Impact Risk and
 290 TR=Total Risk.

Nr.	Management measure	Focus	Number Impact Chains	Potential reduction (%)		
				RL	IR	TR
1	Spatio-temporal closures of the pelagic fishery	D (Fisheries) P (All pressures except those disturbing the seabed) S (Excluding demersal and deep sea fish and all seafloor habitats)	27	0	11	9
2	Spatio-temporal closures of the demersal fishery	D (Fisheries) P (All pressures specifically related to this type of fishery) S (Excluding pelagic and deep sea fish but including all habitats)	52	0	25	9
3	Spatio-temporal restrictions to the discharge of ballast water	D (Shipping, Military) P (Non-indigenous species)	4	0	1	3
4	No take zone(s)	P (Selective extraction of species and	46	0	34	2

		non-living resources) S (may be applied, e.g. a specific seafloor habitat but was not in this assessment)				
5	Closed areas for deepwater coral or seamounts	S (Deep sea bed)	28	0	3	6
6	Decommissioning fishing vessels	D (Fisheries)	76	0	37	18
7	System for identification of oil spills from offshore installations	D (Oil & Gas) P (Non-synthetic compounds)	10	0	1	2
8	Biodegradable fishing gear	D (Fisheries) P (Marine Litter)	11	0	2	6
9	Ban on littering	P (Marine Litter)	76	0	11	27
10	Fish guide	P (Selective extraction of species) S (Fish)	11	0	19	2
11	MSC	D (Fisheries) P (Selective extraction of species)	10	0	26	2
12	TAC/Quota	D (Fisheries) P (Selective extraction of species) S (Fish)	3	0	14	1
13	Retrieval of lost or abandoned fishing gear	D (Fisheries) P (Marine Litter) S (Fish)	3	1	0	4
14	Collection of fished litter (fishing for litter scheme)	P (Marine Litter) S (Sub-littoral habitats and water column)	21	0	0	1
15	Additional beach cleaning	P (Marine Litter) S (Seabirds, Mammals, Littoral habitats)	30	5	0	9
16	Cleaning pollution from offshore drilling operations, e.g. drilling muds and cuttings	D (Oil & Gas) P (Synthetic and Non-synthetic compounds) S (Excluding deep sea)	17	2	0	3
17	Breeding program Seabirds	S (Seabirds)	79	17	0	12
18	Breeding program Fish	S (Demersal fish)	130	25	0	29
19	Breeding program Marine mammals	S (Marine mammals)	110	22	0	16
20	Optimise shape burrow pits for ecological development	D (Aggregates) P (Abrasion, Selective extraction of non-living resources) S (Sediment habitats but not deep sea)	4	0	0	0

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we only consider measures that affect the likelihood of current activities to cause an adverse impact (MMs 1-12 where RL is not affected) and do not consider the remaining management measures (MMs 13-20 where IR is not affected), which are specifically intended to reduce existing adverse impacts and hence only relevant for the “Past” perspective. All management measures are relevant for the “Future” perspective for which TR applies.

The “Past” perspective (RL column in Table 2) shows that the most effective (and very generic) Restoration measure (MM 18) targeting the most impacted ecosystem component (i.e. demersal fish) performs better in terms of a reduction of the RL than the best (and relatively specific) Remediation measure (MM 15) targeting the 4th important pressure (i.e. Marine litter).

The “Present” perspective (IR column in Table 2) shows that measures targeting what is currently the main driver causing adverse impacts (i.e. fisheries) either through a Spatio-temporal closure (MM 2), Input control (MM 6) or Output Control (MM11) cause the largest reductions in IR and that there is only a weak relationship between the performance of the measures and the number of impact chains targeted by the measure.

310 The “Future” perspective (TR column in Table 2) shows that an Output control (MM 9) on a relatively
311 persistent pressure (i.e. marine litter) performs almost equally well as a very extensive Restoration
312 measure (MM 18) on a fairly resilient ecosystem component affected by many different drivers.

313

314 **4 Discussion**

315 This framework shows how EBM can be developed for the NEA based on the type of risk assessments
316 available for this region as well as the other European MSFD regions. The results illustrate two phases
317 in the EBM process: 1) identification/selection and 2) evaluation of management measures.

318

319 Table 1 combined with Figures 1-3 are mostly relevant for the first phase where the table helps to
320 identify the measures while the figures are examples of how the information from the risk assessment
321 can be used to select potential measures. Following the three “Time Horizon” perspectives, the figures
322 revealed that the main adverse impacts from “Past” activities come from persistent pressures such as
323 the introduction of (non-)synthetics, radionuclides or non-indigenous species, marine litter and sealing.
324 A “Present” management perspective would focus on the potentially large adverse impacts of current
325 fishing practices which, however, can be mitigated in the relatively short term. A “Future” perspective
326 could focus the decision-makers on a few impact chains involving widespread activities such as
327 shipping or fishing causing persistent pressures (e.g. marine litter or non-indigenous species) that
328 affect ecosystem components that require long recovery times (e.g. marine mammals, birds) which are
329 likely to cause persistent adverse impacts with high likelihood.

330

331 For the second phase where the management measures were evaluated, we assumed the measure to be
332 100% effective (i.e. full implementation and compliance) of each measure, e.g. spatial distribution
333 control aimed at a specific driver effectively results in a closure of 100% of the area covered by that
334 driver thereby effectively reducing the likelihood of any impact through all relevant impact chains of
335 that driver to 0. Similarly we assumed that restoration of a specific ecosystem component resulted in
336 the complete recovery to pre-impact levels of that ecosystem component. While we acknowledge that
337 in reality it is probably not feasible to ever achieve such goals, it is considered appropriate for the
338 purpose of this exercise because 100% effectiveness results in higher reductions (i.e. ten-fold
339 compared to a more realistic 10% effectiveness) while giving the same relative performance of the
340 measures, both qualitatively (i.e. the same measure will always come out best) as well as
341 quantitatively (i.e. the degree to which one measure outperforms the other).

342

343 The evaluation of the management measures can be based on both a qualitative (i.e. based on ranked
344 order) and quantitative (based on % potential reduction of risk) perspective of the relative performance
345 of the measures but there are several reasons why this framework should only be used for a qualitative
346 evaluation. Firstly, even though TR and its two aspects (IR and RL) are based on criteria that represent
347 real-world characteristics, the way these characteristics are assessed (Robinson *et al.*, 2013) and how
348 subsequently the achieved reduction in the criteria and thus (aspects of) risk are calculated prevent any
349 simple (i.e. linear) relationship to real-world characteristics of anthropogenic pressure (e.g. fishing
350 intensity, or quantity of some contaminant) or ecosystem state (e.g. the abundance of a species or
351 quality of a habitat) that would determine the true relative performance of these measures. Secondly,
352 ultimately the selection of management measures is not only based on their performance to improve
353 ecosystem state but also on various socio-economic considerations. These determine the potential
354 reduction the measure can achieve as well as the likelihood this is actually achieved. In this
355 framework, a reduction in any of the criteria that determine IR, RL and thus TR would give the same
356 reduction in that aspect of risk and can therefore be implemented interchangeably. In this framework it
357 makes no difference if a Temporal distribution- (Reducing Extent), Spatial distribution- (Reducing
358 Frequency), Input- or Output control (Reducing DoI) is implemented as they all reduce IR (of those
359 impact chains targeted by the Focus-part of the measure) with the same level of effectiveness.
360 Similarly for Remediation and Restoration in relation to RL. In reality, however, the selection of a
361 measure, determined by “Type” and “Focus”, will be mostly decided based on socio-economic and
362 institutional considerations (Knights *et al.* 2014) resulting in a very different level of effectiveness for
363 each of those criteria (linked to “Type”) and thus different reductions of IR, RL or TR.

364

365 In this framework the “Type” only determines which aspect of TR (i.e. IR or RL) is reduced and the
366 choice is largely determined by the “Time horizon” perspective, while the “Focus” is strongly linked
367 to (aspects of) risk through the observed relationship between the number of impact chains targeted
368 and the reduction of (those aspects of) risk.

369
370 While each measure “Type” is directly linked to a risk assessment criterion such that it is obvious how
371 the implementation of the measure reduces the criterion (e.g. Spatial distribution controls reduce the
372 Extent of the overlap), this is less clear for the Input/Output control measures linked to the DoI. While
373 in reality the Input/Output control directly relates to the intensity or amount of the activity causing the
374 pressure, this is not the case in our framework because intensity is not considered in the definition of
375 DoI (i.e. severity of a single interaction event between the pressure and an ecosystem component,
376 Robinson *et al.*, 2013). In fisheries management, for example, this implies some output control, e.g.
377 technical measure, could reduce the DoI (e.g. from acute to chronic, see Robinson *et al.*, 2013) but
378 others, e.g. Total Allowable Catch (TAC), cannot as it only affects the intensity of the pressure. For
379 this evaluation we assumed any output control would reduce the DoI but the suitability of this
380 framework to evaluate input/output control measures would improve if the intensity or amount of (the
381 activity causing the) pressure was explicitly included in the assessment of severity.

382
383 The “Type” of measures in this paper include several measures that occur in the MSFD Annex VI
384 Programmes of Measures, namely “Input controls”, “Output controls”, “Spatial and temporal
385 distribution controls” and “Mitigation and remediation tools”, where the latter MSFD measure
386 includes both our restoration and remediation measures. The other potential MSFD measures, i.e.
387 “Management coordination measures”, “Measures to improve the traceability”, “Economic
388 incentives”, “Communication, stakeholder involvement and raising public awareness”, are essentially
389 indirect measures that affect our proposed, direct, measures through some (implementation)
390 mechanism and are therefore not explicitly considered in this framework.

391
392 In order to include all the measures occurring in the MSFD Annex VI Programmes of Measures, we
393 can expand our framework into a hierarchy based on existing typologies of measures (ARCADIS,
394 2012; van Vliet, 1999) that distinguishes between physical measures (identical to our five “Types”),
395 which may be carried out by any stakeholder (i.e. industry, NGO, policy) and three types of
396 instruments that are implemented at a governmental level and may initiate these physical measures.
397 These three types of instruments, i.e. regulatory, economic and social, thus have an indirect effect on
398 the impact chain insofar as respectively institutional, market-based, or participatory aspects are
399 involved.

400
401 Regulatory instruments emerge from the principle that human nature is self-centered/egoistic and
402 should be controlled by the government (van Vliet, 1999). These instruments directly influence the
403 behavior of actors by imposing rules that limit or prescribe the actions of the target group (ARCADIS,
404 2012). Irrespective of the management mechanism employed, all instruments are built on a common
405 legal basis and require enforcement and control if they are to be successful.

406 Economic instruments may also be used. Their effectiveness is based on the principle that the pursuit
407 of individual economic self-interest will lead to the optimal benefit for everyone (van Vliet, 1999).
408 These instruments are defined by the OECD as “fiscal and other economic incentives and
409 disincentives to incorporate environmental costs and benefits into the budgets of households and
410 enterprises” (UN, 1997). The common underlying rationale is inspired by the polluter-pays principle
411 (UN, 1997) and involves a modification of the actors’ behavior through the price of a commodity in
412 the market such that acceptable levels of pollution, optimum rates of resource use or depletion are
413 achieved and thus the protection of the environment is ensured. Examples of such instruments are fee-
414 based systems, subsidies, liability and compensation regimes and trading systems (ARCADIS, 2012).

415 A key feature of social instruments is the participatory nature and the essence of legitimacy lies in the
416 involvement of stakeholders in decision-making, thereby improving the knowledge system on which
417 policy making is based and possibly leading to higher compliance rates (van Vliet, 1999). Sectors are
418 stimulated to take actions based upon their own motivation, often through information (education,
419 training) or awareness raising campaigns. Good or bad image building and associated perception from

420 society (e.g. through communication or certification) can provide important incentives to adapt
421 behavior.

422
423 Some of the measures considered in our framework do not require the implementation of any
424 instrument by regional managers to initiate change. For example, many sectors are often in the process
425 of continuous development and application of new technologies (i.e. technical measures for output
426 control). In addition there are voluntary initiatives of private stakeholders, which can initiate
427 community action (i.e. remediation measures).

428
429 This typology of MMs was developed to help implement the MSFD (EC, 2008a) and together with our
430 framework could contribute to EBM as it merges the three pillars of sustainability, i.e. environmental,
431 economic and social (UN, 2005) with the institutional context. While the framework developed in this
432 study assesses the performance of the potential MMs in terms of their reduction of the risk of an
433 adverse ecological impact, and the time it takes to return to pre-impacted conditions after the
434 implementation of the MM, the final choice of the actual MMs requires an interpretation of the
435 feasibility of the guidance coming from this type of framework in a real-world context. The
436 instruments to initiate them should be based on the outcome of this process considered in the
437 appropriate institutional and socio-economic context.

438
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442
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