
Identifying marine pelagic ecosystem management objectives and indicators

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Abstract :

International policy frameworks such as the Common Fisheries Policy and the European Marine Strategy Framework Directive define high-level strategic goals for marine ecosystems. Strategic goals are addressed via general and operational management objectives. To add credibility and legitimacy to the development of objectives, for this study stakeholders explored intermediate level ecological, economic and social management objectives for Northeast Atlantic pelagic ecosystems. Stakeholder workshops were undertaken with participants being free to identify objectives based on their own insights and needs. Overall 26 objectives were proposed, with 58% agreement in proposed objectives between two workshops. Based on published evidence for pressure-state links, examples of operational objectives and suitable indicators for each of the 26 objectives were then selected. It is argued that given the strong species-specific links of pelagic species with the environment and the large geographic scale of their life cycles, which contrast to demersal systems, pelagic indicators are needed at the level of species (or stocks) independent of legislative region. Pelagic community indicators may be set at regional scale in some cases. In the evidence-based approach used in this study, the selection of species or region specific operational objectives and indicators was based on demonstrated pressure-state links. Hence observed changes in indicators can reliably inform on appropriate management measures.

Highlights

► Stakeholder consultation for listing pelagic ecosystem management objectives. ► Pressures-state link used to identify operational objectives and indicators. ► Population level was found important for marine pelagic communities.

Keywords : Ecosystem-based management, Marine pelagic community, Management objective, MSFD, CFP

1. Introduction

High-level strategic goals for marine ecosystems and fisheries are determined by international policy frameworks such as the European Common Fisheries Policy (CFP) and Marine Strategy Framework Directive for Europe (MSFD) [26]. The CFP is a set of regulations stating that fish stocks should be exploited below or at MSY (maximum sustainable yield) taking ecosystem considerations into account and ensuring that exploitation

30 actions are precautionary, while the MSFD is an EU Environmental Directive, expected to be
31 implemented for fisheries through the CFP as part of an ‘Ecosystem Based Fisheries
32 Management’ (EBFM) framework. The MSFD groups broad ecosystem objectives into
33 categories called descriptors, for which the objective is to reach ‘Good Environmental Status’
34 (GES). Ecosystem state in relation to management objectives (e.g., GES) is determined using
35 indicators. In fisheries management under the MSFD and the CFP, indicators have two roles:
36 providing (a) triggers for management measures (“control” function) and (b) evidence for
37 management performance reporting (“audit” or “assessing” function) (Rice and Rivard,
38 2007). Indicators are thus considered essential for an ecosystem approach to monitoring and
39 managing human pressures on marine ecosystems (De Young et al., 2008; Rice, 2011).

40 The hierarchy of high-level policy driven strategic goals, intermediate general ecological,
41 economic and social objectives, and lower level operational objectives, needs to be defined
42 before choosing suitable indicators (ICES, 2005; Jennings, 2005). In this study the
43 hierarchical framework (Figure 1) was applied to Northeast Atlantic pelagic ecosystems.
44 Pelagic communities have a pivotal role in the function of many large marine ecosystems, but
45 have received much less attention in the scientific literature than demersal systems with
46 respect to which general and which operational objectives might be relevant. However,
47 specifying objectives for the pelagic is equally important for effective implementation of the
48 MSFD.

49 [Figure 1]

50 **2 Methodology**

51 A stakeholder engagement process was undertaken to explore general ecological,
52 economic and social management objectives for pelagic ecosystems (primarily for fish and
53 top predators - birds and marine mammals). Examples of operational objectives, indicators
54 and reference points were then identified for each stakeholder suggested objective based on a
55 review of the scientific literature and expert knowledge (Figure 1). Operational objectives and
56 reference points apply to specific stocks, marine (sub-) regions or fisheries, while most
57 indicators are suitable for any pelagic ecosystem with the same operational objectives.

58 Involvement of ‘stakeholders’ is considered a crucial part of EBFM (Garcia and Cochrane,
59 2005). All parties gain from this relationship, which stems from stakeholders having a right to
60 decide how the marine environment is used, and an associated responsibility for sustainable

61 use (Gray and Hatchard, 2008). Operationally, this requires definition and representation of
62 stakeholders. Here the stakeholder definition by Lorance et al. (2011) was used: public,
63 private/business, associations/groups/NGOs and individual stakeholders. Public stakeholders
64 include fisheries scientists and managers (national and European). Stakeholder involvement
65 was implemented by inviting stakeholders with interest in pelagic fisheries to two separate
66 workshops (the first involving scientists and the second other stakeholders) to explore and list
67 ecological, economic and social management objectives that might be suitable for the
68 management of Northeast Atlantic pelagic ecosystems. The workshops were both organized
69 by scientists, but selection of objectives was independent and intended to give each group the
70 freedom to identify objectives according to their own insights and priorities for pelagic
71 fisheries and ecosystems.

72 An evidence-based approach was then applied to select indicators corresponding to
73 proposed objectives. This approach consists of specifying operational objectives for a given
74 general management objective based on published empirical evidence for a link between
75 manageable pressures and relevant ecosystem states. Thus, a hypothesized pressure-state link
76 based on theory was not taken as sufficient evidence.

77 The evidence-based approach interprets operational objectives at species and region scale
78 and has not previously been applied to large pelagic systems. Ecological indicator
79 developments have focused primarily on demersal communities (Caddy, 2004; Rochet and
80 Trenkel, 2003; Rogers et al., 1999 etc), but see Trenkel et al. (2011), Trenkel and Berger
81 (2013) and Shephard et al. (2014) for some pelagic examples. Pelagic fish species set distinct
82 requirements for indicators, since they can exhibit substantial, environmentally influenced,
83 fluctuations in abundance and wide-ranging mobility (Cury et al., 2003). For small, and
84 medium sized, pelagic fish species, high variability on different scales is created by schooling
85 behaviour, environmentally driven long distance (thousands of kilometers) migrations
86 between spawning, feeding and nursery grounds, and strong recruitment fluctuations (King
87 and McFarlane, 2003). "Small-pelagic" fish communities consist of few species, leading to
88 the term wasp-waist food webs, though these waists are rather barrels if considered in terms
89 of biomass (Fréon et al., 2009; Madigan et al., 2012). In contrast to many demersal mixed-
90 species fisheries, pelagic fishing generally targets single species (Checkley et al., 2009), so
91 direct pelagic fishing impacts affect single stocks, though indirect effects may cause food web
92 perturbations (Rochet et al., 2013). Further, pelagic fisheries do not damage vulnerable
93 benthic habitats and the fisheries exhibit low CO₂ footprints per kg of protein harvested

94 (Parker and Tyedmers, 2014) and use little fuel energy per kJ of energy harvested (Trenkel et
95 al., 2013). The strong environmental forcing of recruitment, growth and survival makes for
96 very uncertain biomass reference-points based on the single species stock assessments used in
97 the management of pelagic fish stocks (Barange et al., 2009; Dickey-Collas et al., 2010). The
98 challenge is increased by the need to broaden management objectives to implement an EBFM
99 for pelagic fisheries under EU jurisdiction (Fu et al., 2012). Lastly, the primary anthropogenic
100 impact on the marine ecosystem in Europe is fishing; fishing can drive shifts in pelagic fish
101 communities (Ward and Myers, 2005).

102 **3 Exploring ecological, economic and social objectives**

103 The stakeholder workshops took place in spring 2013. For the scientist workshop, six
104 participants in the EU-funded Myfish project (www.myfishproject.eu) were selected, based on
105 their experience either in Northeast Atlantic pelagic fisheries, or EBFM. The scientists listed
106 22 potential objectives without seeking agreement on their relevance and defined a
107 categorisation scheme grouping objectives related to societal values, food web structure and
108 flow, fish population structure and flow, habitat quality and quantity, and fisheries yields
109 (Table S1 in Supplementary Material). For each objective, responsiveness to fisheries
110 management was considered.

111 For the second (other stakeholders) workshop, individuals with active involvement in
112 advice, debate or implementation of either management for Northeast Atlantic pelagic stocks
113 or EBFM were invited. The invitation was accepted by eight representatives from three
114 stakeholder categories: NGO (1), fisheries managers (3), and pelagic fishing industry (4),
115 facilitated by three scientists. As in the first workshop participants were asked to list
116 management objectives they considered crucial for pelagic ecosystems and fisheries, and all
117 suggestions were again accepted without challenge by the facilitators. The facilitators asked
118 ‘clarifying’ questions to define distinct objectives, encouraging a wide range of ecological
119 concepts in relation to GES to be considered, but did not disclose the list of objectives created
120 in the first workshop. This led to nineteen objectives being listed (Table S1). For each
121 objective the likelihood that fisheries management could help to reach it was discussed.

122 The two workshops resulted in a total of 26 objectives being suggested (Table 1). There
123 was rather good agreement between the scientists and the other stakeholders: 58% (15)

124 objectives were suggested in both (Table S1, Supplementary material). All 26 objectives were
125 retained for the subsequent steps.

126 [table 1]

127 **4 Identifying operational management objectives and indicators**

128 For each of the 26 objectives, denoted O1 to O26, it was then attempted to identify
129 examples of potential operational objectives for Northeast Atlantic pelagic stocks and
130 ecosystems (Table 1). In each case the available scientific knowledge was considered and, if
131 possible, examples were selected where fisheries management or management of other human
132 activities can be expected to help move the pelagic ecosystem towards GES, i.e. cases with
133 evidence for a pressure-state relationship. In the absence of such evidence no operational
134 objectives were selected while for the identified cases suitable indicators, reference points and
135 management actions were proposed (Table 1). Three criteria were used for selecting
136 indicators: theoretical or empirical basis, measurement, and sensitivity, among the nine
137 criteria proposed by Rice and Rochet (2005). In the following, the supporting evidence for the
138 proposed operational objectives, indicators and reference points are provided. For conciseness
139 and stressing the link with management, objectives were grouped by their ecological or
140 management connection as shown in Figure 2 rather than the objective categorization scheme
141 developed during the workshops.

142 [figure 2]

143 **4.1 Managing catch composition**

144 **4.1.1 Limit slippage and discarding (O1 & O25)**

145 Discarding of target and non-target species is common practice in Northeast Atlantic
146 pelagic fisheries, with discard proportions commonly varying between zero and 10% of total
147 catch by weight (Berrow et al., 1998; Borges et al., 2008; Enever et al., 2007; McCarthy et al.,
148 2011; Pierce et al., 2002; Tsagarakis et al., 2012). Slippage, which refers to the release of
149 catch before hauling on board, and pumping back to sea from chilling tanks also occur
150 (Borges et al., 2008; Pierce et al., 2002). Slippage has been found in 9% of hauls, accounting
151 for ~10% of discards (Borges et al., 2008). McCarthy et al. (2011) found 11% slippage,
152 usually due to mixed species in the catch, or small fishes. Slippage rate and discard proportion
153 are suitable indicators and based on the available knowledge, operational objectives for these

154 for Northeast Atlantic pelagic fisheries (O1) and species (O25) can be set (see examples in
155 table 1). Limits to slippage and discarding may be set on ethical, economic, or ecological
156 grounds. There is no scientific basis for setting reference levels on ethical grounds and no
157 published study was found evaluating the economic consequences of discarding or slipping in
158 pelagic fisheries. In the European context, the recent reform of the CFP includes a limitation
159 of discard rates (Council of the European Union, 2013). Ecological impacts of discarding are
160 widespread, ranging from increased mortality on target and non-target species to influencing
161 the species composition of bird communities as several marine bird species feed on discards
162 (Bicknell et al., 2013; Heath et al., 2014), and their spatial distribution (Bartumeus et al.,
163 2010). Impacts on benthic scavenging communities have also been suggested (Kaiser and
164 Hiddink, 2007). In summary, there are no clear scientific grounds for setting reference levels.

165 Management tools include changes in gear, spatio-temporal closures and development of
166 markets for low value fish species, and of course, landing obligation and catch quotas instead
167 of landing quotas. Allowing some flexibility in quota distribution across vessels could reduce
168 discards caused by lack of quota.

169 **4.1.2 Limit bycatch of marine mammals, birds, and elasmobranchs (O2 & O8)**

170 Bycatch of marine mammals in Northeast Atlantic pelagic trawl fisheries is generally
171 between 0 to 0.07 individuals per haul (Berrow et al., 1998; Fernandez-Contreras et al., 2010;
172 McCarthy et al., 2011; Morizur et al., 1999), but there are also higher rates (Morizur et al.
173 1999, Morizur et al. 2012). Dutch pelagic trawlers have been recorded as having bycatches of
174 several dolphins and whale species (Couperus, 1997), though none have been reported in
175 recent years (ICES 2013). McCarthy et al. (2011) also reported a small bycatch of seabirds,
176 large pelagic species and sharks. For bluefin tuna fisheries, the bycatch of birds, sharks and
177 marine mammals is a major issue (Anderson et al., 2011; Gilman, 2011). All pelagic fisheries
178 in Europe with Marine Stewardship Council (MSC) accreditation now have to prove
179 successful discard and bycatch reduction measures.

180 In the workshops, two different reasons to avoid bycatch emerged: limit bycatch numbers
181 because killing even a low number of animals is ethically unacceptable or limit bycatch rates
182 to ensure viable populations of bycatch species are maintained. In either case operational
183 objectives for bycatch of marine mammals can be set with bycatch rate as indicator. In the
184 second case this rate must reflect the sustainable mortality from bycatch of the population
185 (Tuck, 2011).

186 Management measures which might result in a reduction in bycatch rates include changes
187 in gear characteristics (e.g. escape and deferment devices), modified gear deployment
188 strategies, or spatio-temporal closures.

189 **4.2 Managing contaminants**

190 **4.2.1 Achieve low level of contaminants from land (O3) and limit recruitment** 191 **impairment (O21)**

192 Concerns about contaminants are driven by perceived risks to human health and/or
193 ecosystem functioning. For setting limit targets, it is assumed that whichever provides the
194 lower threshold for the contaminant should be used as the reference limit.

195 A wide range of chemical contaminants have been reported in commercial fish species
196 (Julshamn et al., 2004). There are large differences among Northeast Atlantic marine areas
197 with herring from the Baltic Sea showing the highest contamination levels (Karl and
198 Lahrssen-Wiederholt, 2013). The amount of contaminants in fish products is routinely
199 measured to ensure that the European legislation for reference levels (EC, 2006) is adhered to,
200 making contaminant concentrations feasible indicators of contaminant loads, which can be
201 measured with reasonable accuracy and are readily available.

202 Contaminants can affect marine organisms, as can microplastic fragments (Oliveira et al.,
203 2013). So instead of monitoring contaminant levels the complementary approach is to monitor
204 biological effects using so called biological-effect techniques (Lyons et al., 2010; Thain et al.,
205 2008), although the MSFD does not consider monitoring biological effects. These range from
206 responses measured at the subcellular level to whole-organism responses such as growth
207 impairment, disease occurrence or reduction of reproductive success. A list of candidate
208 bivalves and fish species for biological-effect measurements has been suggested, together
209 with reference levels (Thain et al., 2008), though pelagic fish species were not included. A
210 recent empirical study could not find any evidence for a link between the presence of
211 microplastic in fish stomachs and body condition (Foekema et al., 2013). Hence, as the
212 evidence for a direct link between contaminants and pelagic fish recruitment is still sparse, no
213 operational objectives or indicators were defined for O21. Further research is needed in this
214 area.

215 **4.3 Managing impacts on pelagic organisms**

216 **4.3.1 Maintain exploited stocks (O4)**

217 Maintaining exploited stocks has been a goal of fisheries management since it was realised
218 that the resources of the sea are not infinite. In Europe and elsewhere, the biological indicators
219 used for this are fishing mortality, biomass (or spawning stock biomass), or both (Quinn and
220 Collie, 2005). Both have a number of reference points, including ones compatible with MSY
221 (O24). When fishing is the major force acting on a stock, the two indicators respond rapidly to
222 catch quota changes. For stocks where exploitation is a small proportion of total mortality, as
223 is the case for many pelagic stocks, or the fish are long lived and slow growing, the response
224 to management is often slow or lacking, e.g. sprat in the Skagerrak and Kattegat (ICES,
225 2013).

226 **4.3.2 Maintain food supply for higher trophic levels (O5) and their condition (O11 & 227 O15)**

228 Small pelagic species are an important prey for many higher trophic level predators, and
229 generally only few species occupy this niche. However, this does not generally lead to strong
230 dependence as many piscivorous fish predators are generalist feeders able to buffer variations
231 in single prey abundances (Link and Garrison, 2002; Trenkel et al., 2005). This view is
232 supported by Dickey-Collas et al. (2014) who classed the main predators of small pelagic fish
233 species in the North Sea with respect to their vulnerability to abundance changes in their prey.
234 Only in special circumstances can dependence of predators on certain preys become limiting,
235 such as in ecosystem with few prey species or predators with a small prey portfolio and
236 localised distribution. Baltic Sea cod feeding on sprat and herring seems to be such a case
237 (Eero et al., 2012), there are indications that the pelagic prey of cod may have moved spatially
238 further away (north) from the cod populations. Other documented examples include the
239 dependence of certain seabirds on local abundance of sandeel in the North Sea (Rindorf et al.,
240 2000; Wanless et al., 2005). Marine mammals may be less dependent because of broader
241 dietary spectra and wider geographic distributions (Santos and Pierce, 2003; Trites et al.,
242 1997).

243 Operational objectives for pelagic prey food availability (O5) could usefully be set for the
244 biomass of herring and sprat in the area occupied by Baltic Sea cod and for North Sea sandeel
245 in the distribution areas of dependent seabirds. Aggregate biomass over all pelagic fish

246 species makes a suitable indicator for this objective. A potential reference point can be derived
247 by summing stock level reference points.

248 The two suggested operational objectives for pelagic prey food availability are closely
249 linked with the body condition of cod and the reproductive performance of seabirds, which in
250 turn could be operational objectives for O11 and O15. Parsons et al. (2008) suggested as
251 indicators the productivity (number of chicks fledged per nest) for seabirds, or the body
252 condition for cod, but these indicators may respond to factors other than fishing, e.g. weather
253 conditions or the abundance of alternative prey (Smout et al., 2013).

254 Thus, if the prey species are commercially exploited, their management needs to consider
255 the demands of the wider ecosystem, inter alia by ensuring a sufficient escape rate, but also
256 socio-economic implications for other fisheries (Dickey-Collas et al., 2014).

257 **4.3.3 Maintain functional (O6 & O10) and structural (O7 & O9) pelagic diversity**

258 Function and functioning have several meanings in ecology (Jax, 2005) and ‘functional
259 diversity’ depends on the range of functions included (Petchey and Gaston, 2006). Here, the
260 scope of ecosystem functions was restricted to energy and mass flow in the pelagic food web,
261 excluding services such as gas-exchange and pollution breakdown since predator-prey
262 interactions dominate the nektonic components of the pelagic ecosystem in the context of
263 fisheries management (Pauly and Christensen, 1995). Functional diversity describes a range
264 of roles: e.g. trophic levels, diets, predator identities, among any taxonomic or other
265 organisational abstraction (see Lyashevskaya and Farnsworth, 2012). Reecht et al. (2013)
266 formed functional groups of predators, using morphometric descriptors, whereas Rossberg et
267 al. (2006) resolved morphometric/taxonomic groups into trophic descriptors.

268 For practical purposes, the objectives to “maintain functional diversity” (O6) and to
269 “maintain a functional plankton community” (O10) can be interpreted as maintaining the
270 viability of every functional group of a given pelagic ecosystem. For the relatively small
271 number of cephalopod, fish, bird and mammal species that compose the higher trophic levels
272 of pelagic ecosystems, this might be considered equivalent to maintaining the population
273 viability of these species. This objective may best be achieved by the current stock-based
274 management system using spawning stock biomass and fishing mortality as indicators. This
275 has the advantage of incorporating theoretically robust reference points that are already tested.
276 Dickey-Collas et al. (2014) argue that for forage fish, our current knowledge of their functions
277 is insufficient to treat them as a single group. Somewhat pragmatically this view was extended

278 to the whole pelagic ecosystem, but there is a need for the development of more function-
279 orientated food-web indicators, based on diet choice and the organism traits that give rise to it.

280 Ecological structure is defined as the identities, population sizes and nature of ecological
281 interactions among components of the ecosystem (Noss, 1990). Thus species richness and
282 evenness indicators are (partial) measures of structural diversity. Taking a functional
283 perspective, ecosystem components may identify not species, but functional trait groups, such
284 as body-size categories. Again, for pragmatic reasons, the current stock-based assessment and
285 management system may be found most appropriate to address ecological structure (O7) and
286 prey diversity (O9), simplifying the issue to one of maintaining natural long-term population
287 sizes and age/size structures of existing populations.

288 None of the small and medium-sized pelagic fish species are currently considered
289 endangered or vulnerable in Northeast Atlantic ecosystems (Bay of Biscay: Lorance et al.
290 (2009), elsewhere: IUCN European fish evaluation pers. com (to be published in 2014)). In
291 contrast, several large pelagic species give rise to concern. The IUCN has classed albacore
292 (*Thunnus alalunga*) as ‘near threatened’, Atlantic bluefin tuna (*Thunnus thynnus*) as
293 ‘endangered’, and basking shark (*Cetorhinus maximus*) and porbeagle (*Lamna nasus*) as
294 ‘vulnerable’. Apart from albacore and bluefin tuna, none of the other listed species have
295 directed fisheries, the main fishery-induced mortality is through bycatch, which links these
296 objectives to O2 and O8.

297 **4.3.4 Maintain stock component diversity (O12) and age structure (O13)**

298 Many of the large stocks of small pelagic fish species are made up of several components,
299 which occupy spatially distinct areas at certain life stages. For example, North Sea herring
300 consists of at least four different components with distinct spawning areas (Schmidt et al.,
301 2009). For herring there is genetic distance across geographic space, but no clear distinct
302 genetic isolation across the different spawning components (Mariani et al., 2005).
303 Management measures to maintain stock component diversity (O12) could be area and season
304 based, and in particular should avoid serial depletion of the different components (Al-
305 Humaidhi et al., 2013).

306 The age structure (O13) of a stock might affect communal behaviour such as the choice of
307 migration pathways through ‘entrainment’, with older experienced fish leading younger fish
308 in the migration (Petitgas, 2010); examples include capelin, herring, sardine and anchovy. A
309 potential indicator of this is abundance or proportion of fish that are older than age-at-

310 maturity plus one year (Shephard et al., 2014), with as reference point some deviation from
311 the long-term mean. Maintaining a population of older spawners also helps achieve objectives
312 O14, O16 and by implication O17. Regulating the size/age selection pattern of fisheries
313 (Brunel and Piet, 2013) may be monitored via the juvenile exploitation index: the ratio of
314 fishing mortality on immature and mature individuals (Vasilakopoulos et al., 2012).

315 **4.3.5 Maintain genetic diversity (O16) and phenotypic width (O17)**

316 These objectives concern the ability of populations to respond to future stresses by
317 maintaining a broad gene-pool to support a broad phenotype range. The main threats to the
318 gene pool are non-selective, e.g. excessive fishing leading to a restricted gene pool, and
319 selective, i.e. fishing or climate change directly selecting against certain genotypes. Restricted
320 gene pools are avoided by maintaining healthy population sizes (Reiss et al., 2009).
321 Theoretically fishing can select particular phenotypes or genotypes by altering differential
322 survival in a mixed population, e.g. maturation size reaction norms, or migration rates (Heino
323 and Hanski, 2001). It can also do so through targeting different spawning grounds (covered in
324 relation to O12 above).

325 There is little convincing evidence for fishery induced evolution in pelagic fish. Engelhard
326 and Heino (2004) demonstrated substantial changes in growth and maturation, but considered
327 that this was mainly phenotypic, and at most a weak evolutionary response. However, this
328 does indicate a considerable range of phenotypic plasticity. Similarly, no evidence of climate
329 change induced genetic selection was found by Heath et al. (2012). Therefore, determining
330 operational objectives, other than preventing overly selective fishing (O16), is difficult, as is
331 selecting suitable indicators.

332 **4.4 Managing impacts on habitats**

333 **4.4.1 Maintain spatial distribution of pelagic fish (O14)**

334 Changes in spatial distribution and migration and the possible cause of this were reviewed
335 for a wide range of Northeast Atlantic pelagic species in Petitgas (2010) and Trenkel et al.
336 (2014). Many biotic and abiotic factors across different life stages regulate distributions and it
337 is often difficult to isolate the underlying causes with fishing, local productivity,
338 environmental conditions, spreading of neighbouring big stocks and predator-prey
339 interactions all combining to cause variation in spatial distributions. For example, the
340 appearance and disappearance of anchovy in the North Sea, the Kattegat and Skagerrak has

341 been viewed as a northern migration or extension of the southern population (Alheit et al.,
342 2012) but others now suggest that it is a local population which has become more productive
343 over time (Petitgas et al., 2012; Raab et al., 2013). Neither of these explanations directly
344 involves a mechanism resulting from human activity. Thus, as the factors impacting spatial
345 distributions of pelagic fish are poorly understood, no operational objectives and indicators
346 were proposed.

347 **4.4.2 Maintain spawning habitat (O18)**

348 Most small and medium-sized pelagic fish species are water column spawners, often along
349 the continental shelf edge, notable exceptions being herring and capelin who deposit their
350 eggs on gravel in shallow waters with strong currents (reviewed in Trenkel et al., 2014). For
351 water column spawners, environmental conditions such as temperature and salinity influence
352 the geographic position of spawning habitats, and so management to “maintain” these would
353 be challenging. For herring and capelin gravel extraction or construction on sites might
354 modify suitable spawning habitat and suffocate eggs. Hence operational objectives were
355 selected for herring and capelin only with as indicator the surface area of suitable habitat;
356 reference values have to be case specific.

357 **4.4.3 Maintain juvenile (O19) and feeding (O20) habitats**

358 Most small and medium-sized pelagic fish species have distinct nursery grounds, and many
359 are associated with shallow water at this life stage. For example herring stocks in the
360 Northeast Atlantic tend to have inshore nursery areas (Geffen et al., 2001). Any strong link to
361 a particular location would tend to increase risk, particularly when the nursery habitats occur
362 in areas of high fishing or other anthropogenic pressures. Conversely, as species like
363 mackerel, horse mackerel, anchovy and blue whiting juveniles are found extensively across
364 the continental shelf, the main threat is being bycaught in bottom trawls. Again, defining
365 operational objectives for juvenile or feeding habitats is difficult, not least because there are
366 no documented cases where habitat degradation has impacted stock dynamics.

367 **4.4.4 Maintain migration pathways (O22)**

368 Where migration ways are highly conserved and specific, it should be ensured that physical
369 constructions, such as dams, do not limit recruitment, as has been the case for herring in the
370 North Sea when a dam was built to close off the Zuiderzee (Redeke, 1939). With Marine

371 Spatial Planning (MSP) an operational objective can be set to avoid the obstruction of
372 migration-ways, using the percentage of migration ways impacted as an indicator.

373 **4.5 Managing impacts on fisheries**

374 **4.5.1 Optimal (O23) and maximum sustainable (O23) yield**

375 Optimal fisheries (O23) depend on healthy stocks (O4) and maximised sustainable yield
376 (O24), in addition to accounting for economic, social and other considerations such as the
377 interannual variability of landings. For example, the UK herring market never recovered after
378 the collapse of North Sea herring (Dickey-Collas et al., 2010). For fishers themselves
379 however, interannual variations in economic returns might be compensated between species
380 (Trenkel et al., 2013). Relative interannual stability of landings is a suitable operational
381 objective for pelagic fisheries, with interannual variation in landings as indicator. Suitable
382 management measures are a constant TAC or a cap on its interannual change.

383 **4.5.2 Unobstructed fisheries (O26)**

384 Offshore wind farms are often perceived as limiting access to traditional fishing grounds,
385 thus reducing the space to fish (O26), but there are no documented cases where this has
386 actually happened for pelagic species. If needed, an operational objective could be to maintain
387 physical space for fishing, with the indicator (reference point) being the size of suitable
388 (minimum) fishing area. Management would be through MSP and co-location of activities
389 (Christie et al., 2013).

390 **5 Discussion**

391 Selection of state indicators for marine ecosystems has often been based on data
392 availability and ease of quantification. In this study stakeholder engagement was used to
393 ensure a more credible and legitimate approach to define a set of general and operational
394 management objectives and associated indicators for pelagic ecosystems. General objectives
395 were developed through a participatory process ensuring social license to manage human
396 activities. An evidence based-approach was then applied to identify operational objectives and
397 the indicators needed for verifying that these objectives are met, and if not, be able to propose
398 appropriate management responses.

399 Stakeholder participation resulted in a heterogeneous set of pelagic management
400 objectives, including some which do not correspond to fisheries management, but may
401 profoundly affect the ecosystem (e.g. pollutant contamination); some for which there is
402 currently a lack of sufficient knowledge (e.g. obstruction of natural migration-ways and its
403 impact); and some familiar fish stock-based objectives (Table 1). The majority of identified
404 objectives were considered responsive to anthropogenic impacts in some form, with fisheries
405 being the most frequent (20 out of 26 general pelagic objectives) (Table S1). The operational
406 objectives proposed for each general objective provide relevant examples, rather than an
407 exhaustive list for Northeast Atlantic pelagic ecosystems. Corresponding indicators were
408 selected based on documented (or suspected) direct links with manageable pressures
409 (equivalent to requiring a theoretical or empirical basis) and their sensitivity to management;
410 measurability was a secondary criterion. Rice and Rochet (2005) list other indicator selection
411 criteria which were not used in this study such as cost, public awareness or historical data, but
412 these are clearly relevant for practical implementation.

413 In the following the 26 pelagic management objectives are discussed in terms of
414 implications for management in the light of the experience gained in this study. Specificity to
415 pelagic systems is also considered.

416 **5.1 Objectives related to societal values**

417 The three objectives related to societal value (O1-O3) might be considered the most
418 normative, but they also include ecological effects: slippage involves mortality, but provides a
419 food resource for scavengers and bycatch alters ecological structure and possibly stability
420 (O'Gorman et al., 2011), while pollution can also affect marine organisms not only human
421 health. The ethically perceived ideal level for all these is zero, the optimal operational level
422 being found at some, as yet undetermined, economic equilibrium between the benefits of
423 reducing these ills and the costs in doing so. Fisheries science can define total removal
424 reference levels and sustainable bycatch rates of vulnerable or endangered species from life
425 history and resilience traits. Science guidance is more difficult for contaminants from land as
426 their impact on ecological functioning of pelagic ecosystems is not well understood.

427 **5.2 Objectives related to food web structure and flow**

428 For objectives related to 'normal' structure and flow of the food webs (O4-O11) the
429 proposed operational objectives and indicators are specific to (particular) pelagic ecosystems,
430 and operate mostly at the population level, even for the community indicators. This is

431 because, unlike the demersal case, pelagic fish communities are composed of relatively few
432 species (except with plankton which was not considered here). This gives the systems a
433 potentially low functional redundancy and means it is both necessary and possible, in
434 practical terms, to manage on a species-by-species basis. Almost all exploited pelagic stocks
435 in Europe are already managed through population-level indicators (Barange et al. (2009),
436 Table S2, Supplementary material). The importance of single stock management in the wider
437 context of EBFM has long been recognized (Mace, 2004); it is particularly relevant for
438 pelagic ecosystems as illustrated by Shephard et al. (2014). This means that for maintaining
439 pelagic ecosystem functioning, GES of populations needs to be achieved to achieve GES at
440 the community level. Acknowledging the pivotal role of the population level means that
441 reference points are usually already available and population processes are rather well
442 understood. An important caution here is that pelagic populations can show large natural
443 variability and environmental conditions drive population dynamics. In many cases these will
444 be beyond fisheries management and it is important to remember that these fluctuations in
445 productivity are a natural systemic feature. Care should be taken, as many food web
446 interactions are influenced by local dynamics and many fisheries management targets (such as
447 MSY) are assessed and managed at much larger (sub-) regional scales. For example, foraging
448 success of colony-based sea birds may depend on local populations of pelagic fish, whereas
449 management of fisheries may be sea-wide. In summary, an important contrast with
450 management towards GES for demersal fish communities is that the focus is on population
451 indicators as indicators of the wider functioning of the pelagic food web.

452 **5.3 Objectives related to fish population structure and flow**

453 The objectives related to ‘normal’ structure and flow within fish populations (O12-O17)
454 are principally about maintaining populations of pelagic fish in a healthy state, including
455 phylo-geographic structure, age and size-structure, reproductive rate and body-condition, all
456 of which contribute to the resilience of the pelagic system. Spatio-temporal management is
457 needed to maintain component (phylo-geographic) diversity, though it could lead to fisheries
458 that increasingly take fish from genetically mixed aggregates, thereby blurring the assessment
459 of individual components (Hintzen et al., In Press). Healthy age structure and appropriate
460 indicators and thresholds can be defined, but in practice, the operational objective may follow
461 from direct management of the fisheries age/size selection (Brunel and Piet, 2013). Though
462 the potential to manage growth and age of maturation is very limited, it can be monitored

463 effectively during scientific surveys, but impacts of fishing on genetic or phenotypic diversity
464 are difficult to determine, and to define within an indicator framework. In summary, for
465 objectives related to pelagic populations there are obvious parallels with demersal
466 ecosystems, including stock components, age structures and genetic and phenotypic diversity.
467 The main differences lie in the inability to use spatial occupation as an indicator, and the poor
468 evidence for fishing impacts on genetic diversity, and the wide phenotypic plasticity shown
469 by many pelagic fish species (Engelhard and Heino, 2004).

470 **5.4 Objectives related to habitat quantity and quality**

471 Among the five objectives related to habitat quality and life cycle closure (O18-O22)
472 operational objectives and indicators could only be defined for two. Pelagic ecosystems are
473 characteristically open and connected over large areas and include substantial migrations
474 among several species. The habitats are so wide in geographical scale and ill-defined in
475 boundary, that spatial management and “protection” of habitats is difficult to justify. There
476 are a few exceptions, mainly where habitats are highly specific (e.g. herring spawning on
477 gravel, capelin spawning or sandeel burying in sand). The wide spatial range combined with
478 highly aggregated local distribution of most pelagic fish has an additional consequence for
479 fisheries and ecosystem management. Fishing effort control is unlikely to be an efficient
480 management measure for stocks with density dependent distributions, as fishing catchability
481 increases when the decreasing stocks contract in space (Beverton, 1990; Hamre, 1978;
482 MacCall, 1990) and non-nested large spatial distributions covering all or parts of multiple
483 marine sub-regions in the MSFD provide a challenge for regional management. In summary,
484 this is the category of ecosystem objectives where pelagic ecosystems are most different from
485 demersal ecosystems. Pelagic organisms can be seen as generally having substantial variation
486 in spatio-temporal distribution, much greater than most demersal species. Unfortunately, there
487 is little value in using spatial measures to protect specific habitats in other than the restricted
488 number of cases of benthic spawners.

489 **5.5 Objectives related to fishery yields**

490 The objectives related to fisheries yield (O23-O26) included well known suggestions such
491 as to keep stocks healthy and capable of producing a maximum and stable yield as well as
492 other aspects related to variability in yield. European fisheries management deals primarily
493 with yield and variability, generally through so called long term management plans. Though
494 demersal fisheries have similar demands for stability of the resource, this objective is often

495 automatically fulfilled for long lived stocks fished at moderate rates. While this is also true of
496 comparatively long lived small pelagics such as herring and mackerel, this does not hold for
497 short lived pelagics e.g. anchovy, capelin, sprat and sand eel, which are fished in what is
498 essentially a recruitment fishery on stocks with limited and poorly understood relationships
499 between stock size and recruitment. The characteristic “boom and bust” pattern seen in many
500 small pelagic fisheries in Europe and worldwide, makes determining appropriate fishing
501 pressures difficult in the context of MSY. As with objectives related to habitats, this is a key
502 area where establishing GES, and indeed what is “healthy” for pelagic stocks is not only
503 different from most demersal stocks, but may actually require a different approach: sensitive
504 to the biology and life history characteristics of the species concerned. Additionally, the
505 pelagic fisheries tend to target one, or two species at a time, whereas most Northeast Atlantic,
506 but also Mediterranean demersal fisheries could be considered “mixed fisheries” that target
507 two or three species and collect a suite of bycatch species, all with commercial value (e.g.,
508 Daurès et al., 2009). This leads to the description of pelagic fisheries as “clean” compared to
509 demersal fisheries, further supporting the proposal to build community-level indicators from
510 the population-level.

511 **5.6 Conclusions**

512 In this study a group of stakeholders developed a list of general pelagic GES ecosystem
513 objectives. From these, example operational objectives and matching indicators were
514 identified for Northeast Atlantic pelagic ecosystems. When translating the general
515 management objectives into operational objectives, many were closely linked, in particular
516 via a common management measure (Table 1, Figure 2). Others are linked logically, in the
517 sense that meeting one objective should meet others, i.e. when meeting community level
518 objectives depends on meeting population level objectives. A similar argument implies a
519 spatial hierarchy (from sub-regions to whole systems) of assessments and management
520 responses. Selected indicators often related to the management of fisheries on single stocks,
521 facilitating their implementation, given present practice. It was argued that the relatively small
522 number of fish species present in temperate pelagic ecosystems should allow their use as
523 proxies for wider pelagic community concerns. The greatest gaps identified in our knowledge
524 were those related to the factors regulating pelagic stocks: e.g. what are the roles of old fish,
525 migration pathways or environmental factors? Without understanding causal links, or at least
526 having empirical evidence, theoretically (empirically) based indicators for use in management

527 cannot be suggested (Dickey-Collas et al., 2014). Managing pelagic stocks with respect to
528 MSY is unlikely to be sufficient to provide the maximum social benefit of the fisheries. It is
529 also likely to challenge achieving GES when local factors are active, such as forage
530 requirements for nesting seabirds, or the bycatch from local populations of cetaceans. The
531 tradeoff between maximizing yield and maintaining stability of catches remains unsolved,
532 especially for pelagic species which are inherently highly variable. The high spatio-temporal
533 variability, within a large-scale system (e.g. incorporating migrations) and the role of pelagic
534 fish as intermediate predators and prey, indicates that management for GES probably requires
535 a more integrated approach than currently envisaged in the MSFD and possibly elsewhere.
536 Finally, the evidence-based pressure-state link approach used in this study is suitable beyond
537 pelagic ecosystems for selecting operational objectives and indicators that can fruitfully
538 inform management.

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544 **7 References**

- 545 Al-Humaidhi, A.W., Wilson, J.A., Young, T.H., 2013. The local management of migratory
546 stocks: Implications for sustainable fisheries management. *Fish. Res.*, 141, 13-23.
- 547 Alheit, J., Pohlmann, T., Casini, M., Greve, W., Hinrichs, R., Mathis, M., O'Driscoll, K.,
548 Vorberg, R., Wagner, C., 2012. Climate variability drives anchovies and sardines into
549 the North and Baltic Seas. *Prog. Oceano.*, 96, 128-139.
- 550 Anderson, O.R.J., Small, C.J., Croxall, J.P., Dunn, E.K., Sullivan, B.J., Yates, O., Black, A.,
551 2011. Global seabird bycatch in longline fisheries. *Endangered Species Research*, 14,
552 91-106.
- 553 Barange, M., Bernal, M., Cergole, M.C., Cubillos, L.A., Daskalov, G.M., de Moor, C.L., De
554 Oliveira, J.A.A., Dickey-Collas, M., Gaughan, D.J., Hill, K., Jacobson, L.D., Köster,
555 F.W., Massé, J., Ñiquen, M., Nishida, H., Oozeki, Y., Palomera, I., Saccardo, S.A.,
556 Santojanni, A., Serra, R., Somarakis, S., Stratoudakis, Y., Uriarte, A., van der Lingen,

- 557 C.D., Yatsu, A., 2009. Current trends in the assessment and management of stocks,
558 in: Checkley, D., Alheit, J., Oozeki, Y., Roy, C. (Eds.), *Climate change and small*
559 *pelagic fish*. Cambridge University Press, Cambridge, pp. 191-255.
- 560 Bartumeus, F., Giuggioli, L., Louzao, M., Bretagnolle, V., Oro, D., Levin, S.A., 2010. Fishery
561 discards impact on seabird movement patterns at regional scales. *Curr. Biol.*, 20, 215-
562 222.
- 563 Berrow, S.D., O'Neill, M., Brogan, D., 1998. Discarding practices and marine mammal by-
564 catch in the Celtic Sea herring fishery. *P. Roy. Irish Acad.*, 98B, 1-8.
- 565 Beverton, R.J.H., 1990. Small marine pelagic fish and the threat of fishing: are they
566 endangered? *J. Fish Biol.*, 37 (Supplement A), 5-16.
- 567 Bicknell, A.W.J., Oro, D., Camphuysen, K., Votier, S.C., 2013. Potential consequences of
568 discard reform for seabird communities. *J. Appl. Ecol.*, 50, 649-658.
- 569 Borges, L., van Keeken, O.A., van Helmond, A.T.M., Couperus, B., Dickey-Collas, M., 2008.
570 What do pelagic freezer-trawlers discard? *ICES J. Mar. Sci.*, 65, 605-611.
- 571 Brunel, T., Piet, G.J., 2013. Is age structure a relevant criterion for the health of fish stocks?
572 *ICES J. Mar. Sci.*, 70, 270-283.
- 573 Caddy, J.F., 2004. Current usage of fisheries indicators and reference points, and their
574 potential application to management of fisheries for marine invertebrates. *Can. J. Fish.*
575 *Aquat. Sci.*, 61, 1307-1324.
- 576 Checkley, D., Roy, C., Oozeki, Y., Alheit, J., 2009. *Climate change and small pelagic fish*
577 *stocks*. Cambridge University Press.
- 578 Christie, N., Smyth, K., Barnes, R., Elliott, M., 2013. Co-location of activities and
579 designations: A means of solving or creating problems in marine spatial planning?
580 *Mar. Policy*, 43, 254-261.
- 581 Council of the European Union, 2013. Proposal for a regulation of the European parliament
582 and of the council on the common fisheries policy.
- 583 Couperus, A.S., 1997. Interactions between Dutch midwater trawl and Atlantic white-sided
584 dolphins (*Lagenorhynchus acutus*) Southwest of Ireland. *J. Northw. Atl. Fish. Sci.*, 22,
585 209-218.
- 586 Cury, P., Shannon, L.J., Shin, Y.-J., 2003. The functioning of marine ecosystems: a fisheries
587 perspective, in: Sinclair, M., Valdimarsson, G. (Eds.), *Responsible fisheries in the*
588 *marine ecosystem*. CAB International, Wallingford, pp. 103-123.

- 589 Daurès, F., Rochet, M.-J., Van Iseghem, S., Trenkel, V. M., 2009. Fishing fleet typology,
590 economic dependence, and species landing profiles of the French fleets in the Bay of
591 Biscay, 2000-2006. *Aquat. Living Res.*, 22, 535–547.
- 592 De Young, C., Charles, A., Hjort, A., 2008. Human Dimensions of the Ecosystem Approach
593 to Fisheries: An Overview of Context, Concepts, Tools and Methods, Fisheries Tech.
594 Paper. FAO, Rome, p. 165.
- 595 Dickey-Collas, M., Engelhard, G.H., Rindorf, A., Raab, K., Smout, S., Aarts, G., van Deurs,
596 M., Brunel, T., Hoff, A., Lauerburg, R.A.M., Garthe, S., Haste Andersen, K., Scott, F.,
597 van Kooten, T., Beare, D., Peck, M.A., 2014. Ecosystem-based management
598 objectives for the North Sea: riding the forage fish rollercoaster. *ICES J. Mar. Sci.*, 71,
599 128-142.
- 600 Dickey-Collas, M., Nash, R.D.M., Brunel, T., van Damme, C.J.G., Marshall, C.T., Payne,
601 M.R., Corten, A., Geffen, A.J., Peck, M.A., Hatfield, E.M.C., Hintzen, N.T., Enberg,
602 K., Kell, L.T., Simmonds, E.J., 2010. Lessons learned from stock collapse and
603 recovery of North Sea herring: a review. *ICES J. Mar. Sci.*, 67, 1875–1886.
- 604 Dickey-Collas, M., Payne, M.R., Trenkel, V.M., Nash, R.D.M., 2014. Hazard Warning:
605 model misuse ahead. *ICES J Mar. Sci.*, 71, 2300-2306.
- 606 EC, 2006. Commission regulation (EC) No 1881/2006 of 19 December 2006 setting
607 maximum levels for certain contaminants in foodstuffs. *Official Journal of the*
608 *European Union*, L 364, 5-23.
- 609 Eero, M., Vinther, M., Haslob, H., Huwer, B., Casini, M., Storr-Paulsen, M., Köster, F.W.,
610 2012. Spatial management of marine resources can enhance the recovery of predators
611 and avoid local depletion of forage fish. *Conser. Lett.*, 5, 486-492.
- 612 Enever, R., Revill, A., Grant, A., 2007. Discarding in the English Channel, Western
613 approaches, Celtic and Irish seas (ICES subarea VII). *Fish. Res.*, 86, 143-152.
- 614 Engelhard, G.H., Heino, M., 2004. Maturity changes in Norwegian spring-spawning herring
615 *Clupea harengus*: compensatory or evolutionary responses? *Mar. Ecol. Prog. Ser.*,
616 272, 245-256.
- 617 European Union, 2008. Directive 2008/56/EC of the European Parliament and of the Council
618 of 17 June 2008 establishing a framework for community action in the field of marine
619 environment policy (Marine Strategy Framework Directive). *Official Journal of the*
620 *European Union* 25.6.2008 L164, 19-40.

- 621 Fernandez-Contreras, M.M., Cardona, L., Lockyer, C.H., Aguilar, A., 2010. Incidental
622 bycatch of short-beaked common dolphins (*Delphinus delphis*) by pairtrawlers off
623 northwestern Spain. ICES J. Mar. Sci., 67, 1732-1738.
- 624 Foekema, E.M., De Grujter, C., Mergia, M.T., van Franeker, J.A., Murk, A.J., Koelmans,
625 A.A., 2013. Plastic in North Sea fish. Environmental Science & Technology, 47,
626 8818-8824.
- 627 Fréon, P., Arístgui, J., Bertrand, A., Crawford, R.J.M., Field, J.C., Gibbons, M.J., Tam, J.,
628 Hutchings, L., Masski, H., Mullon, C., Ramdani, M., Seret, B., Simier, M., 2009.
629 Functional group biodiversity in Eastern Boundary Upwelling Ecosystems questions
630 the wasp-waist trophic structure. Prog. Oceanogr., 83, 97-106.
- 631 Fu, C., Gaichas, S.K., Link, J.S., Bundy, A., Boldt, J.L., Cook, A.M., Gabmle, R., Rong Utne,
632 K., Liu, H., Friedland, K.D., 2012. Relative importance of fisheries, trophodynamics
633 and environmental drivers in a series of marine ecosystems. Mar. Ecol. Prog. Ser.,
634 459, 169-184.
- 635 Garcia, S.M., Cochrane, K.L., 2005. Ecosystem approach to fisheries: a review of
636 implementation guidelines. ICES J. Mar. Sci., 62, 311-318.
- 637 Geffen, A.J., Nash, R.D.M., Dickey-Collas, M., 2001. Characterisation of herring populations
638 to the west of the British Isles: an investigation of mixing between populations based
639 on otolith microchemistry. ICES J. Mar. Sci., 68, 1447-1458.
- 640 Gilman, E.L., 2011. Bycatch governance and best practice mitigation technology in global
641 tuna fisheries. Mar. Policy, 35, 590-609.
- 642 Gray, T., Hatchard, J., 2008. A complicated relationship: Stakeholder participation and the
643 ecosystem-based approach to fisheries management. Mar. Policy, 32, 158-168.
- 644 Hamre, J., 1978. The effect of recent changes in the North Sea mackerel fishery on stock and
645 yield. Rapp. P.-v. Réun. Cons. Int. Explor. Mer, 172, 197-210.
- 646 Heath, M.R., Cook, R.M., Cameron, A.I., Morris, D.J., Speirs, D.C., 2014. Cascading
647 ecological effects of eliminating fishery discards. Nature Communications, 5,
648 doi:10.1038/ncomms4893.
- 649 Heath, M.R., Neat, F.C., Pinnegar, J.K., Reid, D.G., Sims, D.W., Wright, P.J., 2012. Review
650 of climate change impacts on marine fish and shellfish around the UK and Ireland.
651 Aquat. Conserv., 22, 337-367.
- 652 Heino, M., Hanski, I., 2001. Evolution of migration rate in a spatially realistic metapopulation
653 model. American Naturalist, 157, 495-511.

- 654 Hintzen, N.T., Roel, B., Benden, D., Clarke, M., Egan, A., Nash, R.D.M., Rohlf, N., Hatfield,
655 E.M.C., In Press. Managing a complex population structure: exploring the importance
656 of information from fisheries independent sources. ICES J. Mar. Sci. doi:
657 10.1093/icesjms/fsu102.
- 658 ICES, 2005. Guidance on the application of the ecosystem approach to management of human
659 activities in the European marine environment, ICES Co-operative Research Report,
660 pp. 22,
661 [http://www.ices.dk/sites/pub/Publication%20Reports/Cooperative%20Research%20Re](http://www.ices.dk/sites/pub/Publication%20Reports/Cooperative%20Research%20Report%20(CRR)/crr273/crr273.pdf)
662 [port%20\(CRR\)/crr273/crr273.pdf](http://www.ices.dk/sites/pub/Publication%20Reports/Cooperative%20Research%20Report%20(CRR)/crr273/crr273.pdf).
- 663 ICES, 2013. Report of the herring assessment working group for the area South of 62 N
664 (HAWG). 2013/ACOM:06, 1283 pp,
665 [http://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/aco](http://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/acom/2013/HAWG/HAWG%202013.pdf)
666 [m/2013/HAWG/HAWG%202013.pdf](http://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/acom/2013/HAWG/HAWG%202013.pdf)
- 667 Jax, K., 2005. Function and "functioning" in ecology: what does it mean? *Oikos*, 111, 641-
668 648.
- 669 Jennings, S., 2005. Indicators to support an ecosystem approach to fisheries. *Fish Fish.*, 6,
670 212-232.
- 671 Julshamn, K., Lundebye, A.K., Heggstad, K., Berntssen, M.H.G., Boe, B., 2004. Norwegian
672 monitoring programme on the inorganic and organic contaminants in fish caught in the
673 Barents Sea, Norwegian Sea and North Sea, 1994-2001. *Food Addit. Contam.*, 21,
674 365-376.
- 675 Kaiser, M.J., Hiddink, J.G., 2007. Food subsidies from fisheries to continental shelf benthic
676 scavengers. *Mar. Ecol. Prog. Ser.*, 350, 267-276.
- 677 Karl, H., Lahrssen-Wiederholt, M., 2013. Factors influencing the intake of dioxins and
678 dioxin-like PCBs via fish consumption in Germany. *Journal of Consumer Protection*
679 *and Food Safety*, 8, 27-35.
- 680 King, J.R., McFarlane, G.A., 2003. Marine fish life history strategies: applications to fishery
681 management. *Fish. Manag. Ecol.*, 10, 249-264.
- 682 Link, J.S., Garrison, L.P., 2002. Trophic ecology of Atlantic cod *Gadus morhua* on the
683 northeast US continental shelf. *Mar. Ecol. Prog. Ser.*, 227, 109-123.
- 684 Lorance, P., Agnarsson, S., Damalas, D., des Clers, S., Figueiredo, I., Gil, J., Trenkel, V.M.,
685 2011. Using qualitative and quantitative stakeholder knowledge: examples from
686 European deep-water fisheries. *ICES J. Mar. Sci.*, 68, 1815–1824.

- 687 Lorance, P., Bertrand, J.A., Brind'Amour, A., Rochet, M.-J., Trenkel, V.M., 2009.
688 Assessment of impacts from human activities on ecosystem components in the Bay of
689 Biscay in the early 1990s. *Aquat. Living Resour.*, 22, 409–431.
- 690 Lyashevskaya, O., Farnsworth, K.D., 2012. How many dimensions of biodiversity do we need?
691 *Ecol. Ind.*, 18, 485-492.
- 692 Lyons, B.P., Thain, J.E., Stentiford, G.D., Hylland, K., Davies, I.M., Vethaak, A.D., 2010.
693 Using biological effects tools to define Good Environmental Status under the
694 European Union Marine Strategy Framework Directive. *Mar. Poll. Bull.*, 60, 1647-
695 1651.
- 696 MacCall, A.D., 1990. *Dynamic geography of marine fish populations*. University of
697 Washington Press, Seattle, W.A., 153 pp.
- 698 Mace, P.M., 2004. In defence of fisheries scientists, single-species models and other
699 scapegoats: confronting the real problems. *Mar. Ecol. Prog. Ser.*, 274, 285-291.
- 700 Madigan, D.J., Carlisle, A.B., Dewar, H., Snodgrass, O.E., Litvin, S.Y., Micheli, F., Block,
701 B.A., 2012. Stable isotope analysis challenges wasp-waist food web assumptions in an
702 upwelling pelagic ecosystem. *Nature Scientific Reports*, 2, 6–54.
- 703 Mariani, S., Hutchinson, W.F., Hatfield, E.M.C., Ruzzante, D.E., Simmonds, E.J., Dahlgren,
704 T.G., Andre, C., Brigham, J., Torstensen, E., Carvalho, G.R., 2005. North Sea herring
705 population structure revealed by microsatellite analysis. *Mar. Ecol. Prog. Ser.*, 303,
706 245-257.
- 707 McCarthy, A., Pinfield, R., Enright, J., Rogan, E., 2011. Pilot observer programme in Irish
708 pelagic trawl and gillnet fisheries: Implementing Council Regulation (EC) No
709 812/2004.
- 710 Morizur, Y., Berrow, S.D., Tregenza, N.J.C., Couperus, A.S., Pouvreau, S., 1999. Incidental
711 catches of marine-mammals in pelagic trawl fisheries of the northeast Atlantic. *Fish.*
712 *Res.*, 41, 297-307.
- 713 Noss, R.F., 1990. Indicators for monitoring biodiversity - a hierarchical approach. *Conserv.*
714 *Biol.*, 4, 355-364.
- 715 O'Gorman, E.J., Yearsley, J.M., Crowe, T.P., Emmerson, M.C., Jacob, U., Petchey, O.L.,
716 2011. Loss of functionally unique species may gradually undermine ecosystems. *Proc.*
717 *R. Soc. B-Biol. Sci.*, 278, 1886-1893.

- 718 Oliveira, M., Ribeiro, A., Hylland, K., Guilhermino, L., 2013. Single and combined effects of
719 microplastics and pyrene on juveniles (0+ group) of the common goby *Pomatoschistus*
720 *microps* (Teleostei, Gobiidae). *Ecol. Ind.*, 34, 641-647.
- 721 Parker, R.W.R., Tyedmers P.H., 2014. Fuel consumption of global fishing fleets: current
722 understanding and knowledge gaps. *Fish Fish.*, DOI: 10.1111/faf.12087.
- 723 Parsons, M., Mitchell, I., Butler, A., Ratcliffe, N., Frederiksen, M., Foster, S., Reid, J.B.,
724 2008. Seabirds as indicators of the marine environment. *ICES J. Mar. Sci.*, 65, 1520-
725 1526.
- 726 Pauly, D., Christensen, V., 1995. Primary production required to sustain global fisheries.
727 *Nature*, 374, 255-257.
- 728 Petchey, O.L., Gaston, K.J., 2006. Functional diversity: back to basics and looking forward.
729 *Ecol. Letters*, 9, 741-758.
- 730 Petitgas, P., (Eds) 2010. Life-cycle spatial patterns of small pelagic fish in the Northeast
731 Atlantic. ICES Cooperative Reserach Report 306, p. 94.
- 732 Petitgas, P., Alheit, J., Peck, M.A., Raab, K., Irigoien, X., Huret, M., van der Kooij, J.,
733 Pohlmann, T., Wagner, C., Zarraonaindia, I., Dickey-Collas, M., 2012. Anchovy
734 population expansion in the North Sea. *Mar. Ecol. Prog. Ser.*, 444, 1-13.
- 735 Petitgas, P., Rijnsdorp, A.D., Dickey-Collas, M., Engelhard, G.H., Peck, M.A., Pinnegar,
736 J.K., Drinkwater, K., Huret, M., Nash, R.D.M., 2013. Impacts of climate change on
737 the complex life cycles of fish. *Fish. Oceanog.*, 22, 121-139.
- 738 Pierce, G.J., Dyson, J., Kelly, E., Eggleton, J.D., Whomersley, P., Young, I.A.G., Santos,
739 M.B., Wang, J.J., Spencer, N.J., 2002. Results of a short study on by-catches and
740 discards in pelagic fisheries in Scotland (UK). *Aquat. Liv. Resourc.*, 15, 327-334.
- 741 Quinn, T.J., Collie, J.S., 2005. Sustainability in single-species populations models.
742 *Philosophical Transactions of the Royal Society London Series B*, 360, 147-162.
- 743 Raab, K., Llope, M., Nagelkerke, L.A.J., Rijnsdorp, A.D., Teal, L.R., Licandro, P., Ruardij,
744 P., Dickey-Collas, M., 2013. Influence of temperature and food availability on
745 juvenile European anchovy *Engraulis encrasicolus* at its northern boundary. *Mar.*
746 *Ecol. Prog. Ser.*, 488, 233-245.
- 747 Redeke, H.C., 1939. The effect of the closure of the Zuiderzee on fish and fisheries. *J. Cons.*
748 *int. Explor. Mer*, 14, 337-346.

- 749 Reiss, H., Hoarau, G., Dickey-Collas, M., Wolff, W.G., 2009. Genetic population structure of
750 marine fish: mismatch between biological and fisheries management units. *Fish Fish.*,
751 10, 361–395.
- 752 Rice, J.C., 2011. Managing fisheries well: delivering the promises of an ecosystem approach.
753 *Fish Fish.*, 12, 209–231.
- 754 Rice, J.C., Rivard, D., 2007. The dual role of indicators in optimal fisheries management
755 strategies. *ICES J. Mar. Sci.*, 64, 775-778.
- 756 Rice, J.C., Rochet, M.-J., 2005. A framework for selecting a suite of indicators for fisheries
757 management. *ICES J. Mar. Sci.*, 62, 516-527.
- 758 Rindorf, A., Wanless, S., Harris, M.P., 2000. Effects of changes in sandeel availability on the
759 reproductive output of seabirds. *Mar. Ecol. Prog. Ser.*, 202, 241–252.
- 760 Rochet, M.J., Collie, J.S., Trenkel, V.M., 2013. How do fishing and environmental effects
761 propagate among and within functional groups? *Bull. Mar. Sci.*, 89, 285–315.
- 762 Rochet, M.J., Trenkel, V.M., 2003. Which community indicators can measure the impact of
763 fishing ? A review and proposals. *Can. J. Fish. Aquat. Sci.*, 60, 86-99.
- 764 Rogers, S.I., Maxwell, D., Rijnsdorp, A.D., Damm, U., Vanhee, W., 1999. Fishing effects in
765 northeast Atlantic shelf seas: patterns in fishing effort, diversity and community
766 structure. IV. Can comparisons of species diversity be used to assess human impacts
767 on demersal fish faunas ? *Fish. Res.*, 40, 135-152.
- 768 Rossberg, A.G., Matsuda, H., Amemiya, T., Itoh, K., 2006. Food webs: Experts consuming
769 families of experts. *J. Theoretical Biology*, 241, 552—563.
- 770 Santos, M.B., Pierce, G.J., 2003. The diet of harbour porpoise (*Phocoena phocoena*) in the
771 northeast Atlantic, in: Gibson, R.N., Atkinson, R.J.A. (Eds.), *Oceanography and*
772 *Marine Biology*, Vol 41, pp. 355-390.
- 773 Schmidt, J.O., van Damme, C.J.G., Röckmann, C., Dickey-Collas, M., 2009. Recolonisation
774 of spawning grounds in a recovering fish stock: recent changes in North Sea herring.
775 *Scientia Marina*, 73S1, 153-157.
- 776 Shephard, S., Rindorf, A., Dickey-Collas, M., Hintzen, N.T., Farnsworth, K., Reid, D.G.,
777 2014. Assessing the state of pelagic fish communities within an ecosystem approach
778 and the European marine strategy framework directive. *ICES J. Mar. Sci.*, 71, 1572-
779 1585.
- 780 Smout, S., Rindorf, A., Wanless, S., Daunt, F., Harris, M.P., Matthiopoulos, J., 2013.
781 Seabirds maintain offspring provisioning rate despite fluctuations in prey abundance: a

- 782 multi-species functional response for guillemots in the North Sea. *J. Appl. Ecol.*, 50,
783 1071-1079.
- 784 Thain, J.E., Vethaak, A.D., Hylland, K., 2008. Contaminants in marine ecosystems:
785 developing an integrated indicator framework using biological-effect techniques. *ICES*
786 *J. Mar. Sci.*, 65, 1508-1514.
- 787 Trenkel, V.M., Berger, L., 2013. An acoustic multi-frequency index to inform on large scale
788 spatial patterns of pelagic ecosystems. *Ecol. Ind.*, 30, 72–79.
- 789 Trenkel, V.M., Daurès, F., Rochet, M.-J., Lorance, P., 2013. Interannual variability of
790 fisheries economic returns and energy ratios is mostly explained by gear type. *PLoS*
791 *ONE*, 8, e70165.
- 792 Trenkel, V.M., Ressler, P.H., Jech, M., Giannoulaki, M., Taylor, C., 2011. Underwater
793 acoustics for ecosystem-based management: state of the science and proposals for
794 ecosystem indicators. *Mar. Ecol. Prog. Ser.*, 442, 285–301.
- 795 Trenkel, V.M., Huse, G., MacKenzie, B., Alvarez, P., Arrizabalaga, H., Castonguay, M.,
796 Goñi, N., Grégoire, F., Hátún, H., Jansen, T., Jacobsen, J.A., Lehodey, P., Lutcavage,
797 M., Mariani, P., Melvin, G., Neilson, J.D., Nøttestad, L., Óskarsson, G.J., Payne, M.,
798 Richardson, D., Senina, I., Speirs, D.C., 2014. Comparative ecology of widely-
799 distributed pelagic fish species in the North Atlantic: implications for modelling
800 climate and fisheries impacts. *Prog. Oceanog.*, 129B, 219–243.
- 801 Trenkel, V.M., Pinnegar, J.K., Dawson, W.A., du Buit, M.H., Tidd, A.N., 2005. Spatial and
802 temporal structure of predator–prey relationships in the Celtic Sea fish community.
803 *Mar. Ecol. Prog. Ser.*, 299, 257–268.
- 804 Trites, A.W., Christensen, V., Pauly, D., 1997. Competition between fisheries and marine
805 mammals for prey and primary production in the Pacific Ocean. *J. Northwest Atlantic*
806 *Fishery Science*, 22, 173-187.
- 807 Tsagarakis, K., Vassilopoulou, V., Kallianiotis, A., Machias, A., 2012. Discards of the purse
808 seine fishery targeting small pelagic fish in the eastern Mediterranean Sea. *Scientia*
809 *Marina*, 76, 561-572.
- 810 Tuck, G.N., 2011. Are bycatch rates sufficient as the principal fishery performance measure
811 and method of assessment for seabirds? *Aquat. Conserv.*, 21, 412-422.
- 812 Vasilakopoulos, P., O'Neill, F.G., Marshall, C.T., 2012. Differential impacts of exploitation
813 rate and juvenile exploitation on NE Atlantic fish stock dynamics over the past half
814 century. *Fish. Res.*, 134, 21-28.

- 815 Wanless, S., Harris, M.P., Redman, P., Speakman, J.R., 2005. Low energy values of fish as a
816 probable cause of a major seabird breeding failure in the North Sea. *Mar. Ecol. Prog.*
817 *Ser.*, 294, 1–8.
- 818 Ward, P., Myers, R.A., 2005. Shifts in open-ocean fish communities coinciding with the
819 commencement of commercial fishing. *Ecology*, 86, 835-847.

Figure 1. Framework linking strategic goals, ecological, social and economic management objectives, operational objectives and indicators for Northeast Atlantic pelagic ecosystems. Feedback processes may occur but were not addressed in this study (dashed lines).

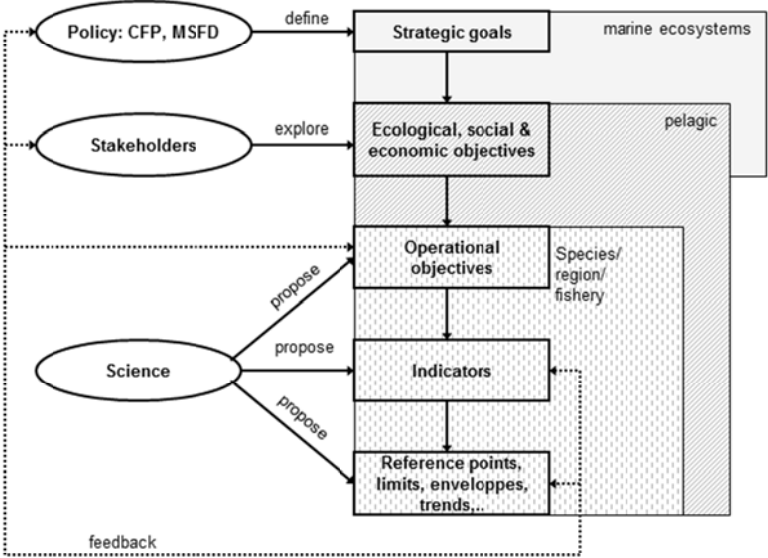


Figure 2. Schematic representation of marine pelagic ecosystem management objectives explored in this study. Circled numbers refer to objectives listed in table 1. Objectives fall into five categories: 1-3 societal values; 4-11 food web structure and flow; 12-17 fish population structure and flow; 18-22 habitat quality and quantity; 23-26 fishery yields.

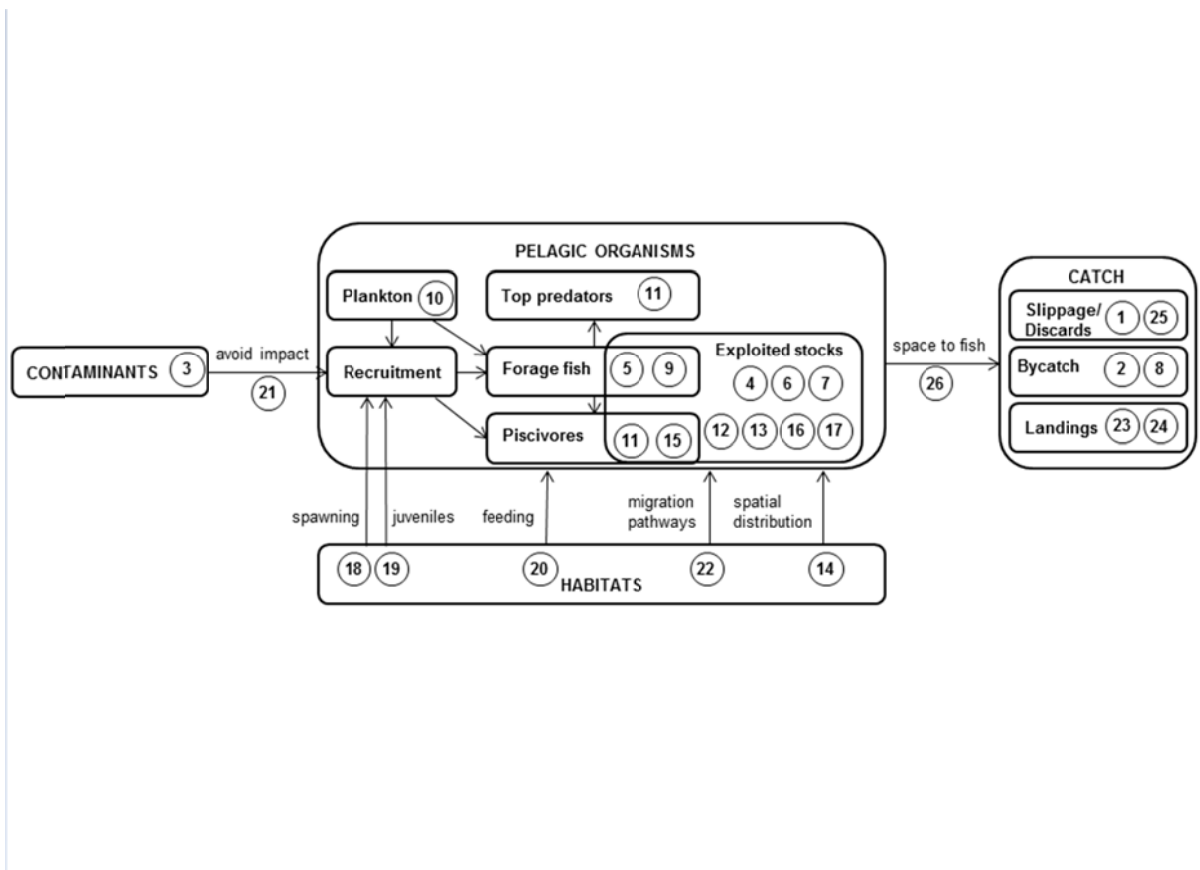


Table 1. Example operational objectives, indicators, reference levels and management actions for pelagic ecological, economic and social objectives identified by stakeholders. Category: C1 societal values, C2 food web structure and flow, C3 fish population structure and flow, C4 habitat quality and quantity, and C5 fishery yields.

Ecological level: C community, P population/stock, I individual.

No	Category	Ecological objective	Level	Example operational objectives	Indicators	Reference levels	Management
O1	C1	Limit slippage, discarding	C	Limit discarding of pelagic trawlers in Bay of Biscay and North Sea	Discards/catch	x% of total catch	Spatio-temporal closures, gear rules, TAC distribution across vessels
O2	C1	Limit marine mammal, birds, pelagic sharks, elasmobranchs bycatch	C	See O8			
O3	C1	Achieve low level of contaminants from land	C	Limit contamination by dioxins and dioxin-like PCBs in Baltic Sea herring	Dioxins and dioxin-like PCB concentration in herring	Sum of dioxins and dioxin-like PCBs < 8 pg/g wet weight (EC, 2006)	Regulate polluting terrestrial activities
O4	C2	Maintain exploited stocks	P	Maintain stock biomass and exploitation rate within safe biological limits	-Stock biomass -Exploitation rate relative to biological reference point	Biological reference points ensuring no impairment of recruitment, e.g. SSB_{lim} , F_{PA}	TAC
O5	C2	Maintain food supply for higher trophic levels	C	Maintain herring and sprat biomass in the Baltic for cod; Maintain sandeel biomass in the North Sea for seabird predators	Prey biomass or F; Predator condition/growth/productivity	>X tons of prey species	TAC
O6	C2	Maintain functional diversity in the pelagic system	C	Manage all exploited pelagic fish stocks sustainably; Improve red listed marine mammals and turtles	-Biomass/abundance - Fishing mortality	Bmsy; Fmsy; IUCN criteria	TAC, Reduce bycatch using gear devices
O7	C2	Maintain structural biodiversity	C	See objective 6			
O8	C2	Limit marine mammal, birds, pelagic sharks, elasmobranchs bycatch	P	Reduce marine mammal and bird bycatch in bluefin tuna fisheries	Bycatch rate	x individuals	Spatio-temporal closures, escape devices/pingers
O9	C2	Maintain prey diversity in the diet of predator x	P	None			
O10	C2	Maintain functional plankton community	C	None			

O11	C2	Predator of pelagic resource condition and growth rate	P	Maintain reproductive success of great skua, European shag and common guillemot in North Sea	Number of chicks fledged per nest	x chicks fledged per nest	Adjust local sandeel catches
O12	C3	Maintain the stock component diversity	P	Maintain all herring spawning stock components	- SSB for each herring spawning component	SSBlim	Area & season based quotas
O13	C3	Maintain a healthy age distribution of the pelagic fish community	P	Maintain age structure in sardine stocks in European waters	-Abundance/ proportion of fish that are older than age-at-maturity - $F_{immature}/F_{mature}$	Long-term mean	TAC and fishery size selection pattern
O14	C3	Maintain spatial distribution of pelagic fish	P	None as factors not understood			
O15	C3	Maintain body condition / growth rate / age at maturity	I	See objectives 5 & 11			
O16	C3	Maintain genetic diversity	P	Avoid overly selective fishing of any species	?		
O17	C3	Maintain phenotypic width / breadth	P	None			
O18	C4	Maintain spawning habitat	P	Maintain herring spawning habitat; Maintain capelin spawning habitat	Size of suitable spawning habitat	x km ² of suitable habitat	Limit gravel extraction/habitat destruction
O19	C4	Maintain juvenile habitat	P	None			
O20	C4	Maintain feeding habitat	P	None			
O21	C4	Limit contaminants that effect recruitment success	P	None			
O22	C4	Maintain migration ways	P	Ensure potential migration ways are not increasingly impacted by bridges, dams, etc.	Proportion of migration ways impacted by physical constructs	x% migration ways impacted	Spatial planning
O23	C5	Optimize yield	P	Interannual stability of landings	Interannual variance of landings	X landings, X% change in landings	constant TAC, capped TAC change
O24	C5	Maximise sustainable yield	P	Stock management compatible with MSY	Fishing mortality	F_{MSY}	TAC, etc.
O25	C5	Limit slippage, discarding	P	Limit slippage and discarding of herring, blue whiting and mackerel in North Sea; Limit discarding of anchovy in Bay of Biscay	Discards/catch per species; Slippage/catch	x% of species catch	Spatio-temporal closures, gear rules, TAC distribution across vessels
O26	C5	Maintain physical space to fish	C	-Maintain space to fish for pelagic fisheries in North Sea	-Size of suitable fishing areas	x km ² of suitable fishing area	Spatial planning

Supplementary Material

Table S1. List of ecological pelagic ecosystem objectives resulting from two workshops held in 2013. Other stakeholders included representatives from management, fishing industry and one NGO. Categories: C1 societal value (non-use value); C2 structure and flow of the food webs; C3 structure and flow within fish populations; C4 habitat quantity and quality; C5 fisheries yields.

Category	No	Objective	Scientists	Other stakeholders	Responsive to management F: Fisheries O: Other
C1	1	Limit slippage, discarding	x	x	F
C1	2	Limit marine mammal, birds, pelagic sharks, elasmobranchs bycatch	x	x	F
C1	3	Achieve low level of contaminants from land		x	O
C2	4	Maintain exploited stocks	x		F
C2	5	Maintain food supply for higher trophic levels	x	x	F
C2	6	Maintain functional diversity in the pelagic system	x	x	F
C2	7	Maintain structural biodiversity	x	x	F
C2	8	Limit marine mammal, birds, pelagic sharks, elasmobranchs bycatch	x	x	F
C2	9	Maintain prey diversity in the diet of predator <i>x</i>	x		F*
C2	10	Maintain functional plankton community		x	O**
C2	11	Predator of pelagic resource condition and growth rate		x	F*
C3	12	Maintain the stock component diversity	x		F
C3	13	Maintain a healthy age structure of the pelagic fish community	x		F
C3	14	Maintain a spatial distribution of pelagic fish	x	x	F
C3	15	Maintain body condition / growth rate / age at maturity	x	x	F
C3	16	Maintain genetic diversity	x	x	F
C3	17	Maintain phenotypic width / breadth	x		F
C4	18	Maintain spawning habitat	x	x	O
C4	19	Maintain juvenile habitat	x	x	F, O
C4	20	Maintain feeding habitat	x	x	O
C4	21	Limit contaminants that effect recruitment success	x	x	O
C4	22	Maintain migration ways	x		O
C5	23	Optimize yield	x	x	F
C5	24	Maximise sustainable yield	x	x	F
C5	25	Limit slippage, discarding	x		F
C5	26	Maintain physical space to fish		x	O

*When strong links exist between fish abundance and fishing and between fish abundance and predator food intake

**When strong links exist between e.g. nutrient run-off and composition of the plankton community

Table S2. List of the small, medium and large pelagic fish stocks exploited and managed (*) in Northeast Atlantic and Mediterranean Sea (>1000 t per year according to FAO).

Pelagic species groups: SP small pelagics; MP medium-sized pelagics; LP large pelagics.

ICES International Council for the Exploration of the Sea (quota advice); GCFM General Fisheries Commission for the Mediterranean Sea (technical measures only); ICCAT International Commission for the Conservation of Atlantic Tunas (quota advice).

<i>Name</i>	English name	Group	Exploited areas (stocks)	Advice organisation
<i>Ammodytes spp.</i>	Sand eel	SP**	North Sea (several)	ICES
<i>Atherina spp.</i>	Sand smelts	SP	Mediterranean	GFCM*
<i>Engraulis encrasicolus</i>	Anchovy	SP	Bay of Biscay, Mediterranean	ICES, GFCM
<i>Mallotus vilosus</i>	Capelin	SP	Barents Sea, Iceland/Greenland	ICES
<i>Micromestitius poutassou</i>	Blue whiting	SP	NE Atlantic	ICES
<i>Sardina pilchardus</i>	European pilchard	SP	Bay of Biscay, Iberian peninsula, Mediterranean	ICES\$, GFCM
<i>Sardinella aurita</i>	Round sardinella	SP	Mediterranean	GFCM*
<i>Spicara smaris</i>	Picarel	SP	Mediterranean	GFCM*
<i>Sprattus sprattus</i>	European sprat	SP	Baltic Sea, North Sea, Mediterranean	ICES, GFCM
<i>Auxis rochei</i>	Bullet tuna	MP	Atlantic, Mediterranean	ICCAT§
<i>Auxis thazard</i>	Fregate tuna	MP	Atlantic	ICCAT§
<i>Belone belone</i>	Garfish	MP	Atlantic, Mediterranean	GFCM*
<i>Brama brama</i>	Atlantic pomfret	MP	Atlantic, Mediterranean	GFCM*
<i>Clupea harengus</i>	Atlantic herring	MP	Norwegian spring-spawners, Celtic Sea, Irish Sea, North Sea autumn spawners,	ICES
<i>Euthynnus alletteratus</i>	Little tunny	MP	Atlantic, Mediterranean	ICCAT§
<i>Ocrynopsis unicolor</i>	Plain bonito	MP	Atlantic, Mediterranean	ICCAT§
<i>Pomatomus saltatrix</i>	Bluefish	MP	Mediterranean	GFCM*
<i>Sarda sarda</i>	Atlantic bonito	MP	Atlantic, Mediterranean	ICCAT§
<i>Scomber colias</i>	Atlantic chub mackerel	MP	Mediterranean	GFCM*
<i>Scomber scombrus</i>	Atlantic mackerel	MP	NE Atlantic, Mediterranean	ICES
<i>Trachurus mediterraneus</i>	Mediterranean horse mackerel	MP	NE Atlantic, Mediterranean	GFCM
<i>Trachurus picturatus</i>	Blue jack mackerel	MP	Mediterranean	GFCM
<i>Trachurus trachurus</i>	Atlantic horse mackerel	MP	North Sea, Mediterranean	ICES, GFCM
<i>Thunnus atlanticus</i>	Blackfin tuna	MP	Atlantic, Mediterranean	ICCAT§
<i>Coryphaena hippurus</i>	Common dolphinfish	LP	Mediterranean	GFCM*
<i>Istiophorus albicans</i>	Sailfish	LP	East Atlantic	ICCAT
<i>Katsuwonus pelamis</i>	Skipjack tuna	LP	NE Atlantic	ICCAT
<i>Makaira nigricans</i>	Atlantic blue marlin	LP	North Atlantic	ICCAT
<i>Seriola dumerili</i>	Greater amberjack	LP	Mediterranean	GFCM*
<i>Sphyraena sphyraena</i>	European baracuda	LP	Mediterranean	GFCM*
<i>Tetrapturus albidus</i>	Atlantic white marlin	LP	North Atlantic§	ICCAT
<i>Thunnus alalunga</i>	Albacore	LP	North Atlantic, Mediterranean	ICCAT
<i>Thunnus albacares</i>	Yellowfin tuna	LP	Atlantic	ICCAT
<i>Thunnus obesus</i>	Bigeye tuna	LP	Atlantic	ICCAT
<i>Thunnus thynnus</i>	Bluefin tuna	LP	NE Atlantic incl. Mediterranean	ICCAT
<i>Xiphia gladius</i>	Swordfish	LP	North Atlantic, Mediterranean	ICCAT

**sandeel are pelagic feeders but spend a significant proportion of their time buried in the sediment;

§, \$ catch data collated, no stock assessment

*no stock assessment