Pelagic habitat: exploring the concept of good environmental status.

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Abstract

Marine environmental legislation is increasingly expressing a need to consider the quality of pelagic habitats. This paper uses the European Union marine strategy framework to explore the concept of good environmental status (GES) of pelagic habitat with the aim to build a wider understanding of the issue. Pelagic ecosystems have static, persistent and ephemeral features, with manageable human activities primarily impacting the persistent features. The paper explores defining the meaning of "good", setting boundaries to assess pelagic habitat and the challenges of considering habitat biodiversity in a moving medium. It concludes that for pelagic habitats to be in GES and able to provide goods and services to humans, three conditions should be met: i) all species present under current environmental conditions should be able to find the pelagic habitats essential to close their life cycles; ii) biogeochemical regulation is maintained at normal levels; iii) critical physical dynamics and movements of biota and water masses at multiple scales are not obstructed. Reference points for acceptable levels of each condition and how these may change over time in line with prevailing oceanographic conditions, should be discussed by knowledge brokers, managers and stakeholders. Managers should think about a habitat hydrography rather than a habitat geography. Setting the bounds of the habitats requires a consideration of dimension, scale and gradients. It is likely that to deal with the challenges caused by a dynamic environment and the relevance of differing spatial and temporal scales, we will need to integrate multidisciplinary empirical data sets with spatial and temporal models to assess and monitor progress towards, or displacement from GES of the pelagic habitat.

Introduction

In 2008, the European Union enacted a novel piece of legislation requiring its countries to define, and then monitor progress towards achieving, good environmental status (GES) for, amongst other things, pelagic habitats (European Commission, 2008, 2010). This legislation is called the Marine Strategy Framework Directive (MSFD, Bigagli *et al.*, 2015) and it sits within a patchwork of European legislation designed to protect and encourage sustainable exploitation of the marine environment under the Integrated Maritime Policy (Apitz *et al.*, 2006; European Commission, 2007; Boyes and Elliot, 2014). The Directive provides a framework of guidance and actions for EU member states. For a range of anthropogenic pressures, and states of the marine environment, each country is asked to define "good environmental status" as a target and make the binary decision of whether they have achieved it or not (Borja *et al.*, 2010). If the answer is that they have not, the countries should implement management measures to ensure that they will reach GES.

Under descriptor 1 of the MSFD, which covers biodiversity, countries have to consider GES of habitats. This is not dissimilar to Essential Fish Habitat (EFH) in USA legislation. Under the provisions of the Magnuson Stevens Fisheries Conservation and Management Act (NOAA, 1996), a statutory mandate requires all fisheries management plans to include descriptions of "essential fish habitat", to identify adverse fishing impacts and to conserve and enhance EFH. "Essential fish habitat" is defined as waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity. In 2017, a new EU decision was published (European Commission, 2017) which further described what should be considered around the quality of pelagic habitat under the MSFD. When compared to other components of the marine ecosystem, the impact of human activities on pelagic systems may appear minimal (Papathanasopoulou et al., 2016), but no consensus exists regarding the definition of GES for pelagic habitats. A clear understanding of the attributes required for pelagic habitats to be in GES is required to guide monitoring and management objectives.

This paper will use the arena of the MSFD to explore what is good environmental status for pelagic habitat, and we hope that this example will provide useful insights for other similar legislative higher order objectives for pelagic habitat, such as EFH and the like.

The challenge and the legislation

Knowledge brokers are being asked to provide guidance on what is an ecosystem in a good or bad state, a question that is intrinsically normative (Turnhout *et al.*, 2007). The phrase "good environmental status" means different things to different people and is value laden. It is probable that a decade ago, we would have been discussing stewardship of "productive pelagic ecosystems", but the MSFD uses concepts which require public support and is also prone to moving social norms (Mee *et al.*, 2008). Tett *et al.* (2013) draw parallels between the use of GES and the phrase "ocean health", suggesting that the terms are metaphors for a vision that aggregates over system components. The MSFD and various studies attempt to aid the decision and assessment process by providing descriptive guidance (Mee *et al.*, 2008; Borja *et al.*, 2013; Tett *et al.*, 2013). The guidance for habitats in the MSFD states

"*Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions*." (European Commission, 2008).

This is further expanded in the 2010 supporting decision

"*the term habitat addresses both the abiotic characteristics and the associated biological community, treating both elements together in the sense of the term biotope*…. *The three criteria for the assessment of* *habitats are their distribution, extent and condition (for the latter, in particular the condition of typical species and communities), accompanied with the indicators related respectively to them*." (European Commission, 2010).

The 2017 revised decision says that the condition of "*Pelagic broad habitat types (variable salinity, coastal, shelf and oceanic/beyond shelf) … including biotic and abiotic structure and functions … is not adversely affected due to anthropogenic pressures*" (European Commission, 2017). This should be assessed at the scale of habitat adversely affected in square kilometres (km^2) and as a proportion (percentage) of the total extent of the habitat type. In the term GES, the word "good" is in relation to humans and thus linked to the provision of goods and services, and stewardship and conservation for future generations (intergenerational equity). The 2017 revision introduces the concept of habitat adversely affected by anthropogenic pressures. In addition, any definition of good or adversely affected is often influenced by the suite of data, readily available, with which to produce metrics as indicators of a pelagic habitat rather than an operational definition of GES.

Similar to "good", what "essential" means could also be considered normative. The Magnuson Stevens Fisheries Conservation and Management Act emphasizes the quality of habitats with respect to effect on growth, reproduction, and/or survival of different life stages and ultimately on the productivity of fishery species. The definition of EFH is therefore organism-centered rather than anthropocentrically defined, and integrates both pelagic and benthic habitats.

Diverse services are provided by the marine pelagic habitat (or combined habitats) such as the regulation of ocean circulation and weather, carbon recycling and balance, production of living resources, and tourism. Any consideration of good pelagic habitat needs to relate to the perceived priorities and objectives of society. Any consideration of adverse pressures, needs to be in relation to some framework. Anthropocentric, societal definitions of marine habitat and habitat quality can lead to the misclassification of marine habitats based upon terrestrial analogies and teleologies. The possibility of falling into traps of misclassification is particularly high in pelagic ecosystems that are embedded in turbulent heterogeneous liquids.

Igniting the discussion

An open theme session was held at the 2016 ICES annual science conference in Riga, Latvia with the title "What is a good pelagic habitat?" (http://ices.dk/news-and-events/asc/ASC2016/Pages/Theme-session-J.aspx). The session was advertised to address the demands for clearer understanding on what is good pelagic habitat as society is asking for guidance on what is a good or bad pelagic system. The focus of the session was on the higher order objectives and was attended by 20-40 participants. Various presentations illustrated the services provided by pelagic habitats such as the regulation of ocean circulation and weather, carbon recycling and balance, production of living resources, importance of species or functional biodiversity and tourism. The session split into three subgroups to consider what is meant by good pelagic habitat, how can we quantify it and what are the features that distinguish it from other habitats? At the end of the session, all participants were invited to contribute to the construction of a food for thought article building on the ideas discussed. This paper is the result of the process.

Pelagic habitat

Pelagic habitats, following the MSFD definition as a biotope used in this paper, can be viewed as having faster dynamics and lower levels of predictability when compared to terrestrial and marine benthic habitats (Ray, 1991; Gray, 1997; Hyrenbach *et al.*, 2000). Living in liquid is different from living in gas, and the vital rates of all marine organisms are controlled to a great degree by the properties of and processes occurring within the ocean's turbulent liquid (Purcell, 1977; Andersen *et al.*, 2015; Manderson, 2016). Bertrand et al.

(2014) describe the pelagic ecosystem as that where the 'substrate' consists of constantly moving water masses, where ocean surface turbulence creates ephemeral oases. Pelagic habitats are also defined by the frontal structures and subsides created and delivered by divergent and convergent flows (Tew Kai, 2009; Della Penna, 2017). The combination of the properties of pelagic systems has led to a formalisation of 'seascape ecology' as opposed to, the rather different, terrestrial 'landscape ecology' (Manderson, 2016). Ban et al (2014) highlight for the ocean system, that many species are widely distributed and wide ranging; the sizes and boundaries of biogeographical domains vary significantly by depth; habitat types exhibit a range of stabilities, from ephemeral (e.g., surface frontal systems) to hyper-stable (e.g. deep sea); and vertical and horizontal linkages are prevalent.

It could be said that a holistic approach that does not compartmentalise habitats (i.e. not treating benthic and pelagic habitat separately) is more in keeping with an integrated management. Within and across life history stages, many marine organisms are obligate integrators of benthic and pelagic properties and processes occurring within the oceans. However, most biodiversity legislation (including the MSFD) requires habitats to be defined and delineated on the basis of a patch-based view of seascapes analogous to the operational paradigm of terrestrial landscape ecology (Ray, 1991). This aids assessment, targeted management action, and communication of relevant issues. There are techniques to define boundaries between pelagic habitats using hydrographic variables and their spatial gradients calculated at an appropriate spatial scale (see Alvarez-Berastegui *et al*., 2014). It is useful to think about pelagic habitats in terms of the static, persistent and ephemeral aspects (Hyrenbach *et al.*, 2000), with the static being bathymetric and coastal features, the persistent being hydrographic and climatic features which often vary seasonally, and the ephemeral being short lived and less predictable gradients in water qualities (Hyrenbach *et al.*, 2000). Other classification approaches to pelagic habitats exist (see Kavanaugh *et al.*, 2016) and the concept of gradient approaches is beginning to be considered even in terrestrial ecology (McGarigal and Cushman 2005; Cushman *et al.,* 2010) but we chose to keep the classification simple. Biological features can similarly be considered across these environmental axes of the seascape (Hidalgo *et al.*, 2015).

The MSFD mentions "prevailing physiographic, geographic and climatic conditions" (European Commission, 2008). In pelagic habitats, these prevailing conditions can be highly variable and dominate our observations of trends in state (McQuatters-Gollop, 2012). Pelagic organisms are embedded in a turbulent advective environment; their size determines how they are affected by the properties of the liquid and their scales of variability (e.g. effect of Reynolds number, advection or migration, etc., Kavanaugh *et al.*, 2016). Their behaviour and self-organisation (e.g. schooling behaviour) also impact their distribution in relation to physical/environmental forcing (see figure 10 in Bertrand et al 2008). Hidalgo *et al.* (2015) suggest that the effect of static and ephemeral features on our observations of biodiversity is often overridden by different non-linear effects in the pelagic environment. Predictability is challenged by the dynamics of the system. In most pelagic systems the prevailing conditions are a consequence of bathymetry, location, relative depth, temperature, salinity, oxygen, circulation, ice cover, carbon dioxide, light and turbidity. Many of these properties are highly dynamic because they are strongly forced directly or indirectly by the dynamics of the atmosphere and planetary motions. The consequences of the behaviour of organisms and the issue of scale (temporal and spatial) further complicate any assessment of habitat quality (e.g. Bertrand *et al.*, 2010; Louzao *et al.*, 2011; Miller *et al.*, 2015; Cisewski and Strass, 2016).

Many species inhabit the water column only temporarily such as meroplankton, mysids, or benthopelagic fish. Other species migrate over long distances or between coastal and offshore areas at daily to multi-annual time scales. Consequently, understanding the composition and trophic structure shared by a set of interacting communities and its dynamical implications for the persistence of biodiversity remains challenging (Melián *et al.*, 2005).

Scale, monitoring and boundaries

When monitoring and assessing the pelagic ecosystem care needs to be taken about the relevant scales, both spatial and temporal (see figure 3 in Kavanaugh *et al.*, 2016). The concept of scale was recently highlighted as one of the most useful ecological concepts to emerge in the last 100 years of ecological research (Reiners *et al*., 2017) but it is also one of the most challenging when applying ecological concepts into operational management (see Stommell, 1963; Steele, 1978; Ban *et al*., 2014). Temporally, the pelagic ecosystem varies within a day (e.g. diel migration, tidally driven changes in turbulence), across seasons (e.g. stratification), years and even multi-decadal cycles too. These cycles impact the persistent and ephemeral features. Spatially, variation of communities can range across many scales (Scales *et al.,* 2017). Since Schneider (2001) suggested that little is known about the importance of small- and large-scale processes on the structure of communities, progress has been made in understanding the dynamics and distribution of pelagic organisms across their habitat (Alvarez-Berastegui *et al.*, 2014; Bertrand *et al.,* 2014; Scales *et al.,* 2017).

Tett *et al.* (2013) define good ecosystem status (good ocean health) as "*the condition of a system that is self-maintaining, vigorous, resilient to externally imposed pressures, and able to sustain services to humans. It contains healthy organisms and populations, and adequate functional diversity and functional response diversity. All expected trophic levels are present and well interconnected, and there is good spatial connectivity amongst subsystems*." This definition requires an understanding of open marine systems and the interconnections between static elements and sub-systems. Pelagic habitats usually do not have distinct boundaries and are often defined by latitudinal and hydrographic gradients, semipermeable frontal boundaries between different water masses, and defined differences in density and current flows which may be seasonally variable (Alvarez-Berastegui *et al.*, 2014; Hidalgo *et al.*, 2015). Inshore, the relevant dynamics can be constrained by the geometry and geography of coastlines and the seabed along with characteristic seasonal frequencies of frontal formation and disintegration and associated changes in temperature, precipitation, and winds as well as tidal forcing. Concepts of GES, therefore, need to be spatially and temporally relevant to specific ecological processes or ecosystem services (Mee *et al.*, 2008). As with integrated ecosystem assessments, setting of boundaries is a key stage of an assessment of habitat (Dickey-Collas, 2014). The ideas behind conservation of habitat diversity and the role of functional redundancy in maintaining ecosystem resilience have been heavily influenced by research performed in terrestrial systems, shallow water reefs and benthic communities. These properties of promoting resilience are probably equally important in pelagic systems but less easily defined. Gray (1997) emphasised that it was important to consider the issue of scale in seascape diversity as relevant scales are determined by the specific ecological or ecosystem process. The spatial aspects of the MSFD (the subregions, the lack of coverage in the high seas and limits in coastal waters) may not be robust enough to cope with the range of spatial scales of pelagic habitat (see Ban *et al*., 2014). The results of analysing temporal trends can be affected by the spatial scale of monitoring, with incorrect assessments if linear relationships are assumed (Bartolino *et al.*, 2012). The metrics used as indicators to assess and monitor GES have yet to be sufficiently tested for their robustness and applicability at different spatial scales (e.g. Wasmund *et al.*, 2017). Current monitoring of pelagic ecosystems generally does not exist at the spatial or temporally relevant scales necessary to assess prevailing conditions and some fine or large scale anthropogenic pressures. However, rapid advances in technology and the implementation of various levels of 'Ocean Observation Systems' are making the attainment of appropriate observational and monitoring data achievable (e.g. Kavanaugh *et al.*, 2016; Manderson, 2016; Trenkel *et al.*, 2016). Further advances are being made to develop the monitoring and statistical methods to assess the interaction of scale and habitat (Mayor *et al.*, 2007; Pittman and Brown, 2011).

With increasing accuracy, we can model the impact of global, regional and local events in the pelagic system and explore future scenarios in relation to prevailing conditions and changes in pressures (Fernandes *et al.*, 2013; Akimova *et al.*, 2016; Queirós *et al.*, 2016). Hufnagl *et al.* (in press) investigated 10 different physical models for the oceanography of the southern North Sea and suggested that most models showed systematic biases during all years in comparison to the ensemble median, indicating that, in general, inter-annual variation was represented equally by the models but absolute values of movement and temperature experienced by particles varied when modelling particles through the system. We can also determine aspects of connectivity with an appropriate spatial scale of dispersal, and the broad scale influence of oceanography on near shore oceanographic dispersal variability (Watson *et al.*, 2011; Treml *et al.*, 2012). Monitoring, assessment and the setting of thresholds need to be designed/accountable for this variability, probably by using targeted finer scale monitoring of areas of concern within broader scale seascape integrated modelling of larger regions.

Assessments for management

Even with a definition of GES, the variability in prevailing conditions makes reaching the GES target challenging. It is also often unclear which human activities are putting pressure on the state of the pelagic ecosystem (Shephard *et al.*, 2015). The revised MSFD decision (European Commission 2017) states that the pelagic habitat must not be adversely affected due to anthropogenic pressures. When considering the pelagic habitat, it is important to consider the influence of upstream events. When assessing GES and where we are in relation to it, many researchers propose the use of the Driver-Pressure-State-Impact-Response (DPSIR) framework to guide management measures (Gimpel *et al.*, 2013; Knights *et al.*, 2013). This assumes that there are direct levers that can be pulled to reduce or increase the human pressures resulting in ecosystem response in a predicted direction. This poses problems when prevailing conditions are thought to have more impact on the pelagic system than any direct consequence of a human-caused pressure (McQuatters-Gollop, 2012). The obvious example of a clear DPSIR relationship is how fishing and hunting influence populations and ecosystem structure (Shephard *et al.*, 2014). However, interactions with other drivers often complicate such a clear relationship, making causal relationships more difficult to disentangle, e.g. in the case of fishing pressure and climate change acting simultaneously (Planque *et al.*, 2010; Planque, 2015). However, when the influence of anthropogenic pressures is less easy to detect, such as when prevailing conditions play a strong role in habitat dynamics, surveillance indicators can be used to monitor pelagic community structure (Shephard *et al.*, 2015). If a surveillance indicator shows an unwelcome trajectory, beyond predefined thresholds, management action should be triggered. But the lack of defined GES for pelagic habitat means that the objectives for monitoring and action are not so clear.

Good environmental status of the pelagic habitat is not synonymous with setting up a marine protected area (MPA) for pelagic habitat. The latter can be seen as a tool to help achieve the former (Game *et al.*, 2009). Pelagic MPAs have tended to focus on biodiversity or productivity “hotspots” (Etnoyer *et al.*, 2004; Scales *et al.*, 2014). The behaviour of animals is often explored in relation to oceanography and geography (e.g. Vilchris *et al.*, 2006; Kobayashi *et al.*, 2008; Louzao *et al.*, 2011) providing information of relevant areas in need of protection. Ban *et al.* (2014) explore this further (see Figure 1 in their paper). The MSFD clearly states that there should be no further loss of diversity in genes, species or habitats (Borja *et al.*, 2013), and goods and services are also derived from pelagic habitats not associated with biodiversity hotspots. It is therefore as important to conserve the low biodiversity habitats as the hotspots (Gray, 1997, e.g. the central Arctic Ocean, and estuaries), requiring a toolset wider than MPAs alone.

A pelagic habitat can also be in a natural ecological state even when that state may be perceived to be ‘negative’ by societies. In some areas, the accumulation of high concentrations of algal toxins in shellfish can be driven by natural forces (prevailing conditions) but considered by society as ‘negative’ owing to the economic impact resulting from enforced closures of shellfish harvesting areas (Gowen *et al.*, 2012). Similarly, high biomass blooms of the dinoflagellate *Karenia mikimotoi* can result in mortalities of the benthos or farmed fish; however, these events may be driven by natural bloom formation offshore and transport in coastal currents (Davidson *et al.*, 2009; Gillibrand *et al.*, 2016) and not human activities. Because marine ecosystems are nonlinear with complex feedback loops and multiple stable states, cyclic disturbances may cause collapses in ecosystem states due to changes in natural oceanographic forcing. Such collapses can be perceived to be negative by humans in the short term. However they may in fact be necessary for periodically resetting some ecosystem trajectories toward "healthier" states. Oceanographic disturbance and ecosystem state collapses related to El Niño and La Niña cycles are hypothesized to underlie ecosystem dynamics in the highly productive Peruvian upwelling system (Bakun and Weeks, 2008). Ecosystem dynamics resulting from prevailing oceanographic conditions need to be distinguished from those resulting from human impacts, particularly eutrophication (Gowen *et al.*, 2012) and pollution events (e.g. oil spills). Although defining good environmental status is normative, when setting targets we must avoid labelling natural but unwished for conditions as Bad Environmental Status.

What is good pelagic habitat?

The contributions to the open theme session and the subgroup discussions described above provided the input material for considering the requirements for GES for pelagic habitats. The issues discussed included retaining sustainable exploitation and a resilient ecosystem. A comprehensive definition of a resilient ecosystem remains elusive, however, here we consider resilience as an ability of the ecosystem to return to a state from which it was perturbed. The aim of the exploration was to find a pragmatic approach to ensure resilience and sustainability using tangible and operational phraseology. The key services offered and properties required from pelagic habitats were then considered and selected based on expert knowledge and information in the literature. The identified services related to regulation and habitat functions as defined for example by de Groot et al. (2002). They included services provided by all habitats, terrestrial and marine, as well as services more specific to the pelagic habitat.

Life cycle maintenance is considered an essential marine and coastal ecosystem service (Liquete *et al.* 2013). For considering this habitat function the framework developed by Petitgas *et al*. (2013) to analyse climate impacts on habitats was viewed as useful, in that it allows for an analysis of habitat requirement by life stage. Because it provides linkages between and integrates requirements across life stages, such a framework could be developed for assessing the status of pelagic habitats. In addition, it can be used to assess impacts across the entire life cycle, including where necessary information on benthic-pelagic connectivity through organisms that use the both benthic and pelagic habitats at different life stages. This would be applicable when considering both exploitation and conservation objectives.

Pelagic habitats contribute to the functioning of the global bio-geochemical system, in particular to ocean nourishment (Liquete *et al*. 2013). The main services are nutrient cycling (for example C, O, N, P, S, Si, Fe) and gas regulation (Costanza *et al*. 1997). The oceans have been a net sink of increased atmospheric carbon dioxide, with ocean warming expected to reduce this role (see chapter 13 Millenium Ecosystem Assessment 2005 http://www.millenniumassessment.org/documents/document.282.aspx.pdf). The sea surface – air interface, the upper boundary of the pelagic habitat, plays an important role in this gas exchange between the ocean and the atmosphere. Within the pelagic habitat, growing and moving organisms contribute to nutrient transportation and recycling. Algal blooms will occur naturally, however, in coastal waters along with hypoxia are signs of pollution and eutrophication surpassing system capacity and an immediate resilience for suppressing catastrophic events. Linkages between marine and terrestrial ecosystems occur because the major human activities impacting these services are land based (MEA 2005).

Linked to both of these functions is the inherent physical nature of the liquid substrate. The physical qualities of the pelagic habitat warrant additional attention, including temperature, salinity and energy gradients. As highlighted by Ban *et al*. (2014), Hidalgo *et al*. (2015) and Scales *et al*. (2017) the pelagic habitat is structurally different from terrestrial and benthic, i.e. solid habitats. The unique properties and the consequences of the pelagic habitat needs to be incorporated into any assessment of GES. These properties contribute to the wider habitat function.

Following on from these considerations, we offer a very simple concept when defining GES for pelagic ecosystems. It is possible to consider the pelagic habitat as hydrography-driven, rather than geography-driven. This means that specific conditions and habitats are not fixed in space or time. This concept will allow scoping for national/regional definitions of GES. We are aware that the MSFD expects future anthropogenic impact and economic and social development of the seas; the MSFD does not strive towards returning European marine waters to a pristine state. What actually constitutes a pristine state is a matter of much debate due to the long and short term dynamic nature of the environment. Instead, the MSFD emphasises sustainable use of the marine system and recognises that GES should be a realistic and attainable target (European Commission, 2008). This contrasts to the organism focused Essential Fish Habitat concept. Here we suggest three key overlapping and interactive properties of the state of the system that ensure essential services that must be prioritised as contributors to GES.

1. Life cycle closure for marine organisms.

Central to the provision of goods and services, and conservation priorities, is that pelagic habitats maintain their ability to act as reproduction (including spawning and mating), nursery, and feeding grounds, as well as migration and advection routes, for marine organisms, resulting in no further decrease in global and regional natural biodiversity in line with prevailing oceanographic conditions. This includes organisms that spend all life stages in the water column and those that use it during various stages of their life cycle. For generational equity, no species - with its essential habitat - should be threatened by anthropogenic activity. This property produces what is called a habitat ecosystem service (e.g. Costanza *et al*. 1999, de Groot *et al*. 2002).

2. The global and regional roles of pelagic systems in biogeochemical regulation.

The pelagic ecosystem fulfils a wide range of roles in the regulation, recycling, transfer, storage and release of biochemical components and processes of relevance to global, regional and localised health of the seas and the whole planet. These roles include cycling of carbon, oxygen, nutrients, carbon sequestration, and many others. When determining GES, these roles must be acknowledged. The biochemical functions of the pelagic system should not move beyond what is considered normal under prevailing climatic conditions, supporting the key structural and functional aspects of pelagic ecosystems.

3. The physically dynamic nature of pelagic habitats.

The pelagic system provides movement of energy and materials that are important at the global, regional and local scales. GES should account for this role of the liquid in determining trophic and life cycle coupling. The movement of water, the interaction with weather, the provision of renewable energy, the advection of substances, coastal erosion, etc., are all relevant to the definition of GES. Consideration of pelagic habitat state must consider both Lagrangian and Eulerian aspects of that state, thus an awareness of the impact of upstream and consequences for downstream events. Whilst most of this movement and impacts of hydrodynamics is not manageable at anything except the local scale, a recognition that movement of organisms, materials and energy is a key part of pelagic habitats must be included in GES considerations.

For all of the three to be achieved all anthropogenic activities and pressures need to be managed or mitigated and the influence of physics understood (Ban *et al.,* 2014). This management includes achieving or maintaining low anthropogenic nutrient input maintaining stoichiometry of elements and minimizing the introduction of litter (including plastic), near zero contaminant pollution, and sustainable fishing; maintaining healthy plankton communities; and due consideration for siting permanent marine structures and regulating marine traffic, to maintain efforts to reduce introduced non-native and invasive species

(OSPAR, 2010; HELCOM, 2010). This requires management measures for the terrestrial landscape to be enacted too, as pressures are often sourced up stream on land.

Salience, legitimacy and credibility

This food for thought article was written by scientists with an interest in research in the pelagic ecosystem. Some of us work closely at the science/policy interface. We wrote this paper to stimulate discussion about higher order objectives for the pelagic habitat (Jennings, 2005), and it can be seen as an initiation of a dialogue between scientists and society (recognised as Mode 2 science by Gibbons *et al.*, 1994). Under the MSFD, the definition of GES is the responsibility of EU member states, hopefully working together through the European Regional Seas conventions (e.g. OSPAR and HELCOM). We would hope that any setting of a vision for pelagic GES would involve a scoping process between knowledge brokers, managers, and stakeholders. A similar exercise took place to explore the ecosystem approach objectives for pelagic fisheries (Trenkel *et al.*, 2015), where two independent scoping exercises gave remarkably similar results for potential higher order objectives.

However, in contrast to the exploration of higher order objectives carried out by Trenkel *et al.* (2015), we did not scope with stakeholders from beyond the scientific realm and limited the exploration to scientists joining the dedicated theme session by interest, without attempting to balance expertise of attendees. This leads us to likely criticism in terms of the salience, legitimacy and credibility of our message (Cash *et al*., 2002). The word 'salience' requires that the intervention by a group is appropriate at the time, and we argue that the MSFD being executed in Europe makes such a discussion very relevant. However, we acknowledge that our intervention lacks much legitimacy, because we have not engaged in wider stakeholder dialogue and we do not formally represent society as self-appointed interested parties. As scientists with an interest in pelagic research, and an interest in applied research, it is valid to question our motives to initiate the discussion. We have an interest in the profile of the issue being raised, i.e. we are clearly stakeholders (Funtowicz and Ravetz, 1993). By using a session at the ICES annual science conference, we have attempted to create an open arena for the discussion amongst the scientific community. We have sought to improve our credibility by describing our methods and publishing this article in a peer reviewed journal. The idea behind the article was to provide a resource to enable discussion with a broader stakeholder community.

Conclusion

Pelagic ecosystems have static, persistent and ephemeral features, with manageable human activities impacting, primarily, persistent features. Managers should think about a habitat hydrography rather than a habitat geography. Setting the bounds of the habitats requires a consideration of dimension, scale and gradients. For pelagic habitats to be in GES and able to provide goods and services to humans, three conditions should be met for pelagic waters: i) all species present under current environmental conditions have access to the pelagic habitats essential to close their life cycles; ii) biogeochemical regulation is maintained at normal levels; iii) critical physical dynamics and movements of biota and water masses at multiple scales are not obstructed. Reference points for acceptable levels of each condition and how these may change over time in line with prevailing oceanographic conditions, need to be discussed by knowledge brokers, managers and stakeholders. It is likely that to deal with the challenges caused by a dynamic environment and the relevance of differing spatial and temporal scales, we will need to integrate multidisciplinary empirical data sets with spatial and temporal models to assess and monitor progress towards, or movement from, GES of the pelagic habitat.

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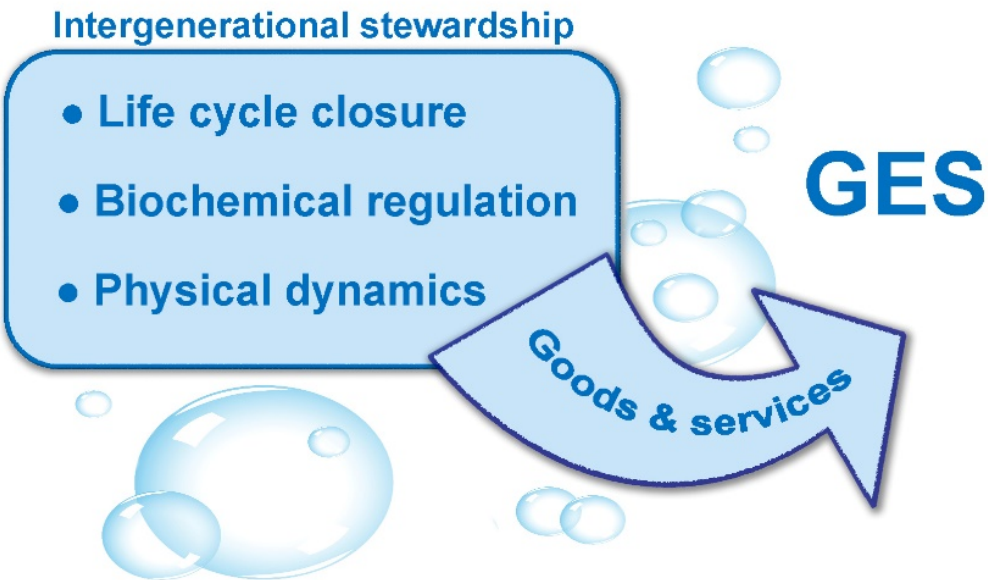

Figure 1. Three key properties of the state of the pelagic system as contributors to GES.