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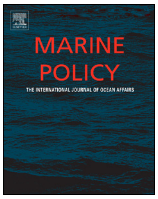

Better integration of sectoral planning and management approaches for the interlinked ecology of the open oceans

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ABSTRACT

Open oceans are one of the least protected, least studied and most inadequately managed ecosystems on Earth. Three themes were investigated that differentiate the open ocean (areas beyond national jurisdiction and deep area within exclusive economic zones) from other realms and must be considered when developing planning and management options: ecosystem interactions, especially between benthic and pelagic systems; potential effects of human activities in open oceans on ecological linkages; and policy context and options. A number of key ecological factors differentiate open oceans from coastal systems for planners and managers: (1) many species are widely distributed and, especially for those at higher trophic levels, wide ranging; (2) the sizes and boundaries of biogeographical domains (patterns of co-occurrence of species, habitats and ecosystem processes) vary significantly by depth; (3) habitat types exhibit a wide range of stabilities, from ephemeral (e.g., surface frontal systems) to hyper-stable (e.g., deep sea); and (4) vertical and horizontal linkages are prevalent. Together, these ecological attributes point to interconnectedness between open ocean habitats across large spatial scales. Indeed, human activities – especially fishing, shipping, and potentially deep-sea mining and oil and gas extraction – have effects far beyond the parts of the ocean in which they operate. While managing open oceans in an integrated fashion will be challenging, the ecological characteristics of the system demand it. A promising avenue forward is to integrate aspects of marine spatial planning (MSP), systematic conservation planning (SCP), and adaptive management. These three approaches to planning and management need to be integrated to meet the unique needs of open ocean systems, with MSP providing the means to meet a diversity of stakeholder needs, SCP providing the structured process to determine and prioritise those needs and appropriate responses, and adaptive management providing rigorous monitoring and evaluation to determine whether actions or their modifications meet both ecological and defined stakeholder needs. The flexibility of MSP will be enhanced by the systematic approach of SCP, while the rigorous monitoring of adaptive management will enable continued improvement as new information becomes available and further experience is gained.

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1. Introduction

People are continuously discovering more about the patterns and processes of open ocean ecosystems [1], yet countries have been slow to incorporate open ocean areas into their management plans and policies to meet international obligations for marine

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management and protection [2]. In this paper, the open ocean is defined as marine regions beyond the geologic continental shelf of coastal States, or areas found beyond the 200-meter bathymetric contour, including the whole water column and seabed. This area includes deep regions within the territorial sea and exclusive economic zones (EEZs) and on the outer continental shelf of coastal States, extended continental shelf of coastal States, as well as areas beyond national jurisdiction (ABNJ, the high seas and international seabed Area). Under the United Nations Convention on the Law of the Sea (UNCLOS), States are required to protect and preserve the marine environment, including rare and fragile ecosystems and the habitat of depleted, threatened or endangered species and other forms of marine life (UNCLOS Article 194 (5)). Furthermore, States have committed to protecting at least 10% of coastal and marine areas by 2020 through the Convention on Biological Diversity (CBD) Aichi target 11. The June 2012 UN Conference on Sustainable Development ("Rio+20") reaffirmed many of such goals, including a commitment to urgently address conservation and sustainable use of biodiversity in ABNJ [3]. Commitments also extend beyond general conservation mandates to sustainable use of living marine resources. This is another challenge for managing the open ocean given the data paucity and political pressures.

At present, countries are a long way from achieving these commitments. Currently less than 3% of the ocean is protected, only 0.17% in ABNJ [4–6], and only about 10% of ABNJ is managed approaching an integrated manner [7]. Previous arguments against open ocean marine protected areas (MPAs) were based on perceived (i) physical and biological complexity, and challenges related to (ii) design, (iii) enforcement and (iv) governance [8,9]. These apparent impediments are being overcome, and as more large open ocean MPAs are created, lessons are being learned that can be applied to current and future protected areas [5,10]. Furthermore, large open ocean MPAs are essential to reach Aichi target 11 for protection of 10% of the world's ocean. However, these areas must be both ecologically representative and effectively managed [5]. Still, large geographic gaps in protection remain in the open ocean, particularly in ABNJ, leaving many ecosystems vulnerable to current or future over-exploitation. While designation of MPAs is actively being pursued, no overarching systematic approach for identifying and designating MPAs or managing the multiple and expanding human activities and impacts exists to date [7]. Indeed, management institutions in ABNJ are single-sector focused (e.g., fisheries, shipping, or mining) and have neither an adequate mandate for integrated planning, nor the capacity to effectively coordinate across multiple management regimes [11].

The purpose of this paper is to examine current knowledge about ecological considerations and linkages in open oceans, how they might be affected by human activities, and recommend management approaches that would better take the interlinked ecology of open oceans into account. In particular, three themes that differentiate open oceans from other realms when contemplating planning and management options are considered: ecosystem interactions, especially between benthic and pelagic systems; the potential effects of human activities in open oceans on ecological linkages; and the management and governance context. Particular attention is paid to ABNJ, where comprehensive governance and management are lacking but also within EEZs, where management in many countries could be improved. The implications of these characteristics of the open ocean for planning for conservation and sustainable use are discussed.

2. Open ocean ecosystem characteristics key to management

A number of key ecological factors differentiate open oceans from coastal systems for planners and managers: (1) many species are widely distributed and, especially for those at higher trophic levels, wide ranging; (2) the sizes and boundaries of biogeographical domains vary significantly by depth; (3) habitat types exhibit a wide range of stabilities, from ephemeral (e.g., surface frontal systems) to hyper-stable (e.g., deep sea); and (4) vertical and horizontal linkages are prevalent. Below each of these points are expanded upon as a basis for discussing requirements for integrated planning and management.

2.1. *Wide distributions and ranges of species*

Many species in the open ocean are widely distributed (e.g., plankton, [12], tuna, [13]), and for the high trophic levels in particular, wide ranging (e.g., seabirds, [14], turtles, [15], tuna, [16], many species, [17], [18]). Such wide-ranging species serve as ecological linkages between otherwise distant geographic regions. While planning should thus consider similar broad spatial extents, this does not necessarily translate into extremely large portions of species' ranges needing to be protected [19]. For example, many wide-ranging marine animals show site fidelity at particular times during their lives or have relatively small and well-defined areas of critical habitat (Fig. 1). In addition, most wide-ranging species spend portions of their migrations in both national EEZ waters as well as ABNJ [20]. Parts of distributions important to marine animals are related to the temporal and spatial predictability of the physical habitats with which they are associated, as evidenced by predictable seasonal aggregations of fishes, birds, turtles and mammals (e.g., [21,22,23] that can assist in the design of MPAs [24–27]).

2.2. *Depth-related differences between biogeographical domains*

Biogeography underpins an approach in which scientists use biological and physical data to partition ecosystems into ecological units at particular scales, from broad-scale ecological provinces to finer-scale "seascapes" [28]. In the open ocean, biogeographic units occur in three dimensions, where an array of ecosystems are shaped by an equally diverse set of oceanographic processes [29]. Open oceans thus require multiple biogeographic classifications and dimensions to even crudely describe general provinces. Surface pelagic classifications, largely based on productivity regimes, were developed almost 20 years ago [30], while other pelagic and benthic classifications emerged more recently [29,31–33]. Much less is known about the rest of the water column, although linkages are known to occur both vertically and horizontally. Determining biogeographic boundaries in open oceans is inherently difficult, and made more so by limited sampling of physical and biological attributes. Yet to effectively represent the diversity of open ocean systems within MPAs or in areas of enhanced management, biogeographic regions should be included in planning efforts [28]. Furthermore, much remains to be understood about the differences between pelagic and benthic realms, and there seems to be little correlation between boundaries of provinces at different depths [34,35]. A planning and management challenge is thus to fully represent biogeographic regions when these are not yet well known.

2.3. *Habitats of varying stability*

In contrast to coastal and terrestrial regions, pelagic habitats are largely based on properties of water masses, whereas physical structures, such as seafloor geomorphic features (e.g., seamounts) and habitat-forming species (e.g., deep sea corals and sponges aggregations) play a major role in benthic ecosystems. At broad scales, seafloor biogeographies have boundaries generally coincident with changes in physical oceanographic properties [33,34,36]. Surface waters (approximately the top 100 m) of the open ocean are highly dynamic and are dominated by relatively ephemeral features that move in space and through time, such as eddies and fronts [37]. These features aggregate prey, and organisms at higher trophic levels are adapted to foraging in this dynamic environment [e.g., [38–41]. Nevertheless, important physical processes in the pelagic ocean often exhibit regular seasonal patterns of spatio-temporal variability [23,26,42,43]. Currents in the deeper reaches of the open ocean are slow moving relative to surface waters, and temperature, pressure and salinity are more constant [44]. In pelagic systems, there is more vertical variability at the surface than at depth, and likely more structure again near the seafloor. Managing for the stability of deep-sea ecosystems while simultaneously accounting for the ephemeral nature of pelagic waters is another challenge for open ocean management.

2.4. *Vertical and Horizontal linkages*

Even though the stability of open ocean characteristics varies by depth, vertical and horizontal linkages are critical in the transfer of physical (e.g., energy, heat), chemical (e.g., oxygen, nutrients) and biological (e.g., detritus, diel migrations, migratory species) elements that support ecological structure and function. Many organisms living at great depths rely on organic matter sinking to depth for sustenance, either directly or indirectly. This "rain" of organic matter is typically diffuse and patchy, and therefore many organisms adapted to abyssal plains are wide- ranging, slow growing or both [45]. The descent of material from above also contributes to depletion of oxygen, because organisms in the water column feed on the organic matter, resulting in an oxygen minimum zone (i.e., excess oxygen demand creates hypoxia in deeper regions (~100–1200 m)) [46]. Coupling between benthic and pelagic ecosystems can also occur on short time scales, with benthic ecosystems responding to nutrient influxes from pelagic systems on the order of days even at depths of over 1400 m [47]. Even at abyssal depths (~4000–6000 m), benthic communities respond to spring peaks in productivity and associated particle flux within two months [48]. Near-surface seamounts, ridges and open ocean islands provide a direct link between the photic zone and deep-sea habitats, influencing the diversity, density and behavior of both benthic and pelagic organisms; hydrodynamic and biotic features of these features appear to cause changes in ecological structure of deep-pelagic fish assemblages, for example [49–51]. Horizontally the open ocean has an influence on the entire ocean ecosystem. Ocean currents move water masses, marine animals undertake extensive migrations, and many coastal marine species have extensive pelagic stages during which they are found in the open ocean for large proportions of their life history [18,52–54], thereby linking coastal and open ocean marine systems. The influx of nutrients into coastal systems from deep, pelagic regions via oceanographic processes such as upwelling are critical to maintaining nearshore coastal ecosystems [55] and shelf-edge systems [56] and also further increases the linkage between benthic and pelagic systems in some coastal areas. These characteristics highlight the importance of managing open ocean ecosystems for the health of both benthic and coastal regions.

These complexities and ecological linkages highlight the scientific underpinnings for managing open oceans as integrated linked systems (coastal–continental shelf-open ocean, horizontally and vertically within open oceans, and benthic-deep pelagic–pelagic). To date, however, human activities in open oceans have been managed based on individual human activities (e.g., shipping, hydrocarbon extraction), if managed at all [7]. Yet, as outlined below, these activities likely affect multiple ecosystems and their linkages, and hence a more integrated and precautionary approach to management is needed.

3. Human activities and their potential effects on ecological linkages in open oceans

Key human activities taking place in open oceans and currently or potentially affecting marine biodiversity are fishing, shipping, and non-renewable resource extraction (i.e., oil and gas, deep-sea

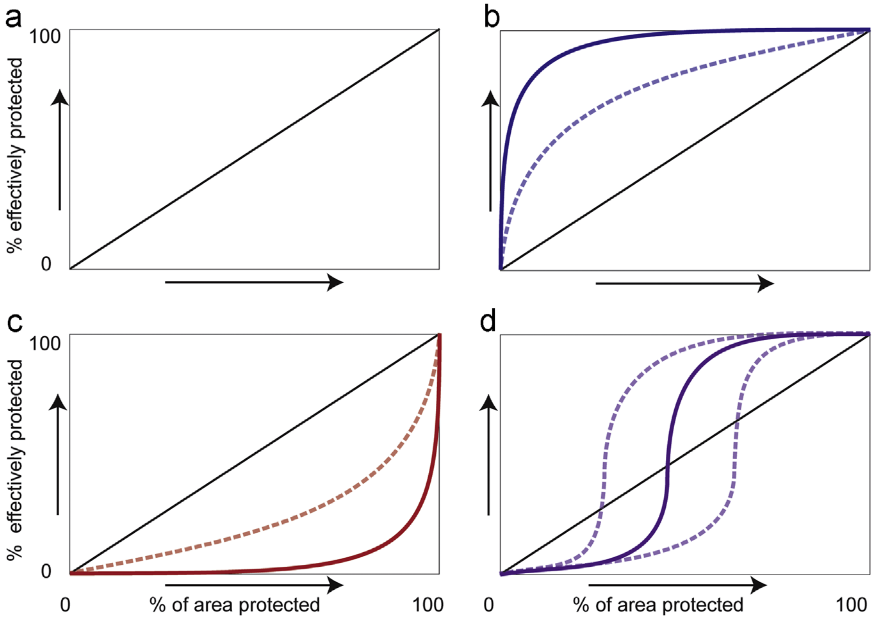

Fig. 1. Conceptual representation of the benefit species or populations might gain from area protected. (a) The diagonal black line represents a population that has a uniform or random distribution in space, where the area protected corresponds to the effectiveness of protection (i.e., if 10% of the area is protected, 10% of the population is effectively protected). (b) Represents a case where a population is highly aggregated, where a small percentage of area protected might capture a large part of the population if located optimally and assuming the population does not move extensively outside of this area (e.g., aggregated benthic species). The dashed lined indicates another example of a similar curve, for example when less information is known about the population. The dashed curve can be moved upwards with additional information. (c) Depicts a population where a large area is required to effectively protect a small proportion of the population (e.g., a population where individuals are wide-ranging without much spatial clustering, such as tropical tunas). Additional information on species distribution may help reduce the area necessary for effective protection (e.g., from solid red line to dashed red line). (d) Depicts a threshold effect, where the percentage of a population effectively protected increases rapidly once a proportion of the area has been protected (e.g., where a wide-ranging population is only vulnerable at some time or space in its life history). The purple dashed lines are examples of other thresholds.

mining). Because these, and other human activities in open oceans, have been reviewed elsewhere [1,57], here the focus is only on ways in which these activities might be affecting the ecological linkages previously described. More indirect anthropogenic impacts such as climate change and ocean acidification are also key concerns that have the potential to seriously impact ocean systems and marine biodiversity.

At present, fishing is the main anthropogenic activity that directly affects open ocean systems. Overfishing is a well-documented impact that has been shown to influence ecological linkages, cause range contractions, and change the overall structure of ecosystems [58–61]. Fishing affects both vertical and horizontal linkages in open oceans. Vertical linkages are affected in two ways. First, if biomass is reduced substantially through fishing, fewer organisms exist to serve as a link between shallow and deep pelagic areas (e.g., surface pelagic fishes that dive deep to forage). Second, in fisheries that have a lot of bycatch that is disposed overboard, or vessels that process fish on board and dispose of unwanted biomass at sea (e.g., factory trawlers), an increase in ‘marine rain’ results from the influx of organic material in a small area. This biological waste can reach significant depths; a fishery in New Zealand was reported to reduce oxygen levels to 800 m depth, possibly altering benthic community composition [62,63]. Horizontally, fishing also reduces the number of individuals that migrate long distances, often targeting the larger species and individuals that tend to have longer migratory ranges. Furthermore, marine species vary greatly in their resilience to fishing pressures, with a tendency for long-lived species with low population growth rates and/or large body size to be most vulnerable [64]. Fishing might thus substantially change food webs in which vulnerable fished species occur, likely affecting ecological linkages to areas deeper and outside of the immediate fisheries area [65,66]. Numerous species meeting these criteria, such as deep-sea fishes, sharks, rays, tunas and marine mammals, have experienced significant declines [67–69]. Furthermore, the spread of fisheries towards deeper waters is a major concern because of the low productivity of these ecosystems, combined with weaker regulatory regimes and the difficulty of accurate ecosystem assessments; these factors may result in unsustainable practices [70–72].

With about 90% of all goods being transported by sea [73], shipping traffic has increased in many parts of the world, and has potential horizontal and vertical ecological impacts through noise, pollution, and litter. Vessel noise, which travels long distances, can mask vocalizations and natural sounds; the effects of masking are still poorly characterized but suggested to be potentially significant [74–76]. Sound effects can be separated into chronic noise, as related to shipping traffic, or event noise such as pile driving or seismic surveys. Deep diving marine mammals, such as beaked whales, are generally the most sensitive to interactions with direct sound sources [77]. The ecological effects of the physical disruption of holopelagic habitats, such as *Sargassum* mats and their associated communities, by shipping traffic are currently unknown, but suggested to have potentially significant effects [77]. Shipping is also known as the dominant global vector for marine invasive species, disrupting a number of ecosystems [78]. Some discharges from ships (e.g., small and large oil discharges, gray water, sewage) can be harmful, and, if toxic chemicals are taken up by marine flora and fauna, contribute to bioaccumulation, potentially affecting higher trophic levels in particular. Eventually some of these toxins sink, with deep-sea sediments hypothesized as a final accumulation site for some man-made pollutants [1]. Litter from vessels (disposed illegally) continues to accumulate, with about 6.4 million tons per year dumped into the ocean. Part of this litter sinks, and highly erosive deep-sea storms, which affect about 10% of the deep-sea floor, can transport the litter along with benthic fauna [1]. Indeed, in some places, litter is the main source of solid substrata at bathyal depths [1]. Thus the increase in shipping appears to be having ecological effects not just on surface waters, but also in the deep sea.

Non-renewable resource extraction is being proposed for the deep seas, with anticipated ecological effects to the seabed and water column. For instance, manganese nodule deposits that were found during the Challenger expedition in the late 19th Century have been the subject of interest since the 1960s (e.g., see speech by Mr. Pardo in 1967 [79], and spurring negotiations for the Law of the Sea), while the comparatively recent discoveries of polymetallic massive sulfide deposits associated with hydrothermal vent systems and cobalt crusts associated with seamounts have engendered a new interest in deep seabed mining for silver, gold, and rare earth metals [80]. In ABNJ, the International Seabed Authority has entered into eleven 15-year exploration contracts for polymetallic nodules in the Clarion-Clipperton Fracture Zone and two contracts for exploration for polymetallic sulfides in the South-West Indian Ridge and the Mid-Atlantic Ridge [81]. Mining and oil and gas extraction could directly affect the seafloor, disturbing sediments, which might spread far horizontally and vertically, depending on oceanographic conditions. Disposal of tailings, or the leftover and non-valuable portion of mining material, could also involve wide-ranging impacts on species and ecosystems. Impacts on stable deep-sea ecosystems could feasibly be very longlasting, and perhaps reverberate to shallower ecosystems. Potential accidental spills are also a concern and, as has become evident through the Deepwater Horizon oil spill, little is known about the impacts on deep-water ecosystems [82,83]. Furthermore, mid-frequency sonar produced by oil and gas prospecting could lead to injury or mortality in deep-diving pelagic species [84]. Temporary hearing loss could occur and decompression-like symptoms (‘the bends’) have been observed when cetaceans surface too quickly in reaction to sonar [84,85]. While the long-term effects of these threats on overall ecosystem health are poorly understood, they contribute to cumulative impacts on ecosystems that likely influence ecosystem functioning [86].

Ocean warming and acidification pose perhaps the greatest combined long-term threat to open ocean ecosystems. Changes such as a possible shutdown of the thermohaline circulation [87], the major mechanism controlling large-scale ocean circulation, could dramatically impact horizontal and vertical linkages in open oceans. Even without a dramatic shutdown, species distributions will change [88–91]; availability of organic matter will be altered and likely reduced due to increased stratification leading to decreased productivity [44]; and ocean circulation patterns both at the surface and at depth will change [1]. The anthropogenic signal in ocean acidification is already clearly detectable and the effects will extend to most organisms with calcified shells or hard structures [92,93]. Furthermore, expansion of oxygen-minimum layers could result in reduced habitat for pelagic organisms [94]. Climate change and its effects might thus greatly alter horizontal and vertical ecological linkages in open oceans.

4. Policy approaches towards effective management and conservation

At present, governance of open ocean systems involves many challenges [7,95–99]. The governance context of open oceans differs markedly between areas within and beyond national jurisdictions. Within countries' EEZs, governments have the legal capacity to introduce legislation and policies to support integrated planning and management of the environment and resource extraction. Examples of countries with ocean policies and legislation include Australia, Canada, New Zealand, the United States and European Union member States. Implementation of management nevertheless varies widely and few have yet adopted measures to reflect the interlinked ecology of open ocean systems [100]. In ABNJ, existing legal instruments focus on single-sectors and lack mechanisms, mandates or institutions for integration or coordination, conservation or precaution [7]. In particular, existing instruments are in need of integration with one another and further development with regard to the establishment of MPA networks and environmental impact assessments that take into account cumulative impacts [7,96,98,101].

4.1. *Systematic conservation planning and marine spatial planning in the open ocean*

The interconnected nature of open ocean systems, and the multiple effects that human activities have on these systems and their linkages, necessitates comprehensive management. Two common policy approaches to planning on land and in the nearshore environment would be valuable to adapt for open ocean management: systematic conservation planning (SCP) and marine spatial planning (MSP) (Table 1, Fig. 2). SCP outlines an inclusive and comprehensive approach for determining conservation and management actions to efficiently, cost-effectively and realistically achieve specific quantitative conservation goals and objectives determined collaboratively by stakeholders [102,103]. While conservation is a primary goal in SCP, other goals can simultaneously be planned for as well. MSP is a place-based approach to ocean planning, aimed primarily at reducing conflicts among marine users [104,105]. MSP can include conservation and ecosystem-based management goals, but does not necessarily do so [105]. Thus combining these ideas would result in comprehensive ocean planning that includes conservation and reduced conflicts between users as key goals.

Both SCP and MSP have to be integrated into spatial management if they are to address linked open ocean systems. Marine protected areas and other area-based management tools (e.g., zoning, partial closures, single species fisheries closures) are cornerstones in conservation and sustainable resource management more generally [102,106]. Given the diversity of open ocean systems and multiple goals for their management, a variety of spatial tools will be needed – tools that range in scale and levels of protection. Different tools will have different effectiveness for various aspects of biodiversity, depending on the relative movement and vulnerability of species or other features of interest (Fig. 1). Similarly, different tools will vary in effectiveness for users, depending on the legal regime under which they operate and their monitoring and enforcement capabilities. While fixed spatial management might be effective for discrete, static benthic habitats such as hydrothermal vents, seamounts or cold-water coral populations, management of pelagic species and ephemeral events in the pelagic or benthic realms is more challenging

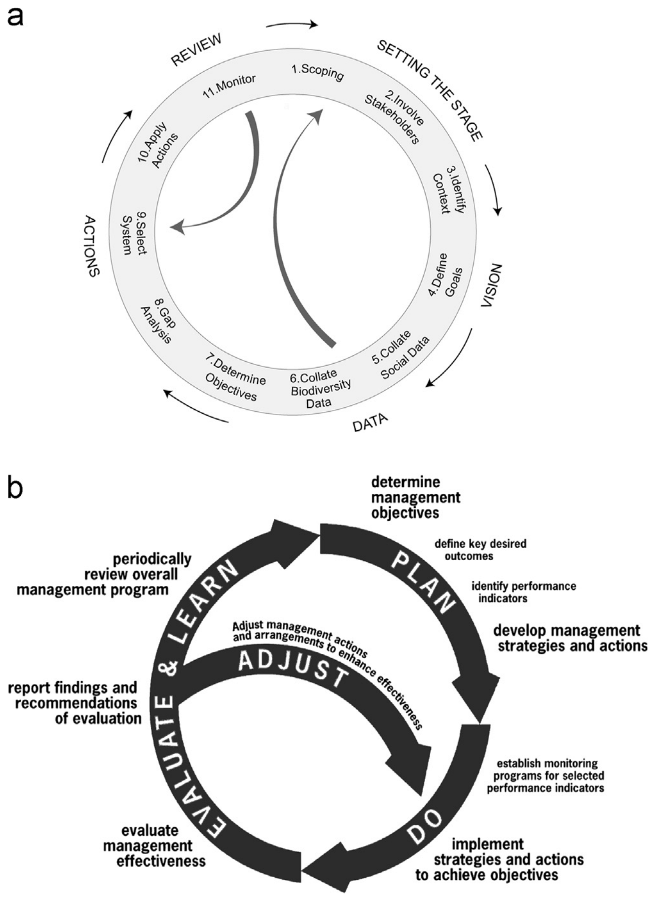

Fig. 2. Systematic conservation planning and adaptive management. (a) Systematic conservation planning visualized as an iterative framework, with the arrows in the middle illustrating examples of feedbacks between stages. (b) Adaptive management cycle (http://www.cmar.csiro.au/research/mse/).

Table 1
Comparison of systematic conservation planning, marine spatial planning and adaptive management.

Systematic conservation planning (stages from Pressey and Bottrill 2009)	Marine spatial planning (characteristics from Collie et al. 2013)	Adaptive management (steps from Holling 1978)
1. Scoping	Realistic expectations	
2. Involve stakeholders	Stakeholder inclusion	
3. Identify context	Legal mandate and political capacity	
4. Define goals		Determine management objectives
5. Collate social data		
6. Collate biodiversity data		
7. Determine objectives	Operational management objectives	Define key desired outcomes Identify performance indicators
8. Gap analysis		
9. Select system		Develop management strategies and actions
10. Apply actions		Implement strategies and actions to achieve objectives
11. Monitor	Feedback and adaptive learning	Establish monitoring programs for selected performance indicators Evaluate management effectiveness Report findings and recommendations of evaluation Adjust management actions and arrangements to enhance effectiveness Periodically review overall management program

[9,24,107]. For example, highly pelagic species such as tunas or seabirds might only be effectively protected in parts of their ranges when they are congregated, such as breeding or spawning grounds (Fig. 1b–d) [25].

Other spatial management options, such as mobile MPAs that follow oceanographic features such as eddies or frontal systems or event-triggered spatial closures that respond to observations of, for example, spawning aggregations or migrations into rivers, have been proposed [9,108–111]. Assuming mechanisms are also adopted to monitor compliance, these more dynamic approaches to spatial management could be effective for protecting species associated with dynamic phenomena. Spatial management tools will be most effective where their spatial and temporal extent is matched with the spatio-temporal predictability of open ocean features (Fig. 3), and the spatial extent and capabilities of responsible governing bodies, recognizing that predictability in time and space can guide the choice of appropriate spatial management. Overall, MPAs and other spatial management tools based on SCP principles are an essential component of MSP to enhance conservation and sustainable management in open oceans.

Combinations of spatial and temporal closures could be designed by identifying parts of the ocean that are important at particular times for a variety of species of interest. Where space and time closures are focused on species not targeted for harvest, closures could be further specified to operate only when a trigger limit of bycatch species has been reached (e.g., Australian fishery managers close areas to the gillnet fishery off the coast of South Australia if Australian sea lions are caught) [112]. Such more complicated management procedures (e.g., within-season changes to fishing areas or quotas) require greater monitoring and enforcement effort, although modern technologies including vessel monitoring systems and cameras can assist in providing suitable monitoring coverage for reduced effort and cost.

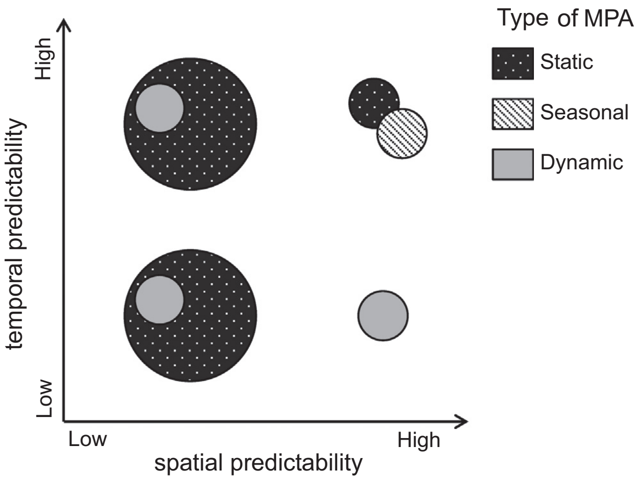

Fig. 3. MPA design in relation to spatial and temporal predictability of features of conservation interest. Predictability refers to the degree that a correct forecast of a system's state can be made either qualitatively or quantitatively. Features with high spatial predictability are usually static or regularly recurring in the same location. Spatial predictability is scale-dependent [21] so referred to as nominal spatial scales of 1–200 km, corresponding to the sizes of most marine protected areas. Features with high temporal predictability are either permanent or regularly (e.g., seasonally) recurring. Nominal temporal scales are considered to be up to 20 years. Examples: top right, persistent or seasonal hydrographic features and spawning aggregations related to physical structures such as seamounts [24,120,121]; bottom right, irregular spawning aggregations and occasional hydrographic phenomena related to physical structures [24]; top left, persistent hydrographic features such as currents and frontal systems that vary spatially [24,122]; bottom left, ephemeral hydrographic features such as eddies and fronts [24,110]. Sizes of circles indicate relative sizes of MPAs required. Superimposed circles indicate optional sizes of different types of MPAs (see legend).

4.2. *Precautionary and adaptive management in the open ocean*

There are many uncertainties about open ocean systems and their linkages, about the effects of human activities on them, and about the effectiveness of management tools. Precautionary and adaptive approaches to resource management are designed to allow decision-making to proceed despite significant scientific uncertainty, and are therefore relevant for open ocean management. The precautionary approach as used in biodiversity conservation suggests that a lack of full scientific certainty should not be used as a reason for postponing conservation action [113]. Given increasing evidence of degradation in open ocean ecosystems and the higher vulnerability of many open ocean species and ecosystems, a precautionary approach to prevent further harm despite a paucity of data is an essential component of effective management. However, as acknowledged in the original Rio Declaration [114], appeal to the precautionary principle does not negate the need to assess strategies, actions and the trade-offs attached to them. One approach to achieve this assessment of alternative management actions while not postponing conservation actions is through adaptive management.

Adaptive management is a well-described process of learning while doing [115]. Adaptive management focuses on deliberate learning from currently applied management actions in order to improve future iterations of the same management decision. The emphasis in adaptive management is on reducing uncertainty around which management action will best achieve the stated objectives. As such, it makes a natural pairing for precautionary management. Although adaptive management is challenging in complex systems (lacking any central control) such as the open ocean [116], its effectiveness will be improved with planning approaches that are integrated across the different sectors operating in the open ocean.

4.3. *A combined approach for the open ocean*

Integrating MSP, the precautionary approach and adaptive management into the SCP framework could provide the best option for managing the open ocean, as each has advantages that are beneficial in the complex open ocean system. The integration of these tools can be initiated by incorporating the following considerations.

First, in addition to spatial management, non-spatial tools need to be included as complementary measures for protecting open ocean ecosystems (Table 1). These non-spatial tools might include catch or bycatch limits in fisheries, limited entry systems for mining or fisheries, or ballast water and discharge regulations for shipping.

Second, goals and objectives that are ecologically appropriate for the open ocean should be established. These need to include considerations of the coupling between benthic and pelagic ecosystems, the dynamic nature of much of the open ocean, and the contrasting stability of deep benthic systems. The limited data that exist for much of the open oceans should not justify inaction but rather require making the most of those data combined with expert knowledge in a precautionary and adaptive management framework, and preferably an active one. Expert knowledge has been effectively applied in a number of planning processes, including describing areas that meet the criteria for ecologically and biologically significant areas (EBSAs) for the CBD and Priority Conservation Areas from Baja California to the Bering Sea for the Commission for Environmental Cooperation [117,118].

Third, a combined scientific approach requires supporting policies be developed. Even though the 1992 Rio Principles and the 1995 UN Fish Stocks Agreement [119], inter alia mandate precaution, this is not always reflected in the constitutions, rules and procedures of the sectoral management bodies. In most organizations, harm still has to be demonstrated before conservation measures will be considered. For example, in response to the United Nations General Assembly resolutions [119] to protect vulnerable marine ecosystems (VMEs), Regional Fisheries Management Organizations and Arrangements (RFMO/As) often “freeze the fishing footprint” (i.e. lock in the status quo) rather than opening only those areas that have been surveyed and found to be free of VMEs. While most organizations will over time revise their management measures in an ad hoc fashion, there is seldom an explicit process that systematically takes an adaptive approach.

Fourth, the clear need for monitoring and evaluation to achieve successful management of this area that remains largely unknown, demands the global coordination of monitoring methods, data analysis, interpretation and archiving of data in accessible databases. At present, significant limitations exist for monitoring open ocean ecosystems and managers will have to be realistic about what can be monitored and what conclusions can be drawn from monitoring [78]. Surface ecosystems are easier and cheaper to monitor compared to the deeper water column and deep benthic ecosystems; thus the development of surface proxies for deeper regions could be developed from increased understanding of the coupling between surface ecosystems and sub-surface environment. Global organizations currently involved in oceanographic monitoring (e.g., Intergovernmental Oceanographic Commission's Global Ocean Observing System, IOC-GOOS), and biological data collation (e.g. the Ocean Biogeographic Information System) would need support through adequate funding including capacity building to provide additional coverage specific to the requirements of pelagic protected areas, linked to the objectives and goals of their management plans [87].

5. Special considerations for areas beyond national jurisdiction

Applying MSP, SCP and adaptive management in ABNJ has some implications for new governance arrangements currently being debated at the United Nations' “Ad Hoc Open-ended Informal Working Group to study issues relating to the conservation and sustainable use of marine biological diversity beyond areas of national jurisdiction”. SCP requires explicit goals, objectives, and targets, as well as structured stakeholder consultation to be successful, while adaptive management requires a process of iteration that provides for the re-evaluation of these objectives and goals, using monitoring information as it becomes available. This suggests that a forum is required that would bring bodies together on a regular basis including at least those concerned with fisheries, conservation, shipping and mining [123]. These sectors are currently represented through several different international arrangements including the UN Food and Agriculture Organization, Convention on Biological Diversity, International Maritime Organization, and International Seabed Authority, respectively. Regarding conservation, to this list could be added several others, such as the Convention on Migratory Species, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), the World Heritage Convention, and Regional Seas Agreements. Regarding fisheries, the most active RFMO/As operate autonomously and would likely represent themselves in any new international forum, as would the Commission for the Conservation of Marine Living Resources and the International Whaling Commission. Some of these bodies are to some extent increasing their collaboration, for example through memorandums of understanding.

Nonetheless, the number and variety of relevant marine conservation agreements and maritime management arrangements strongly suggests that much greater cooperation, ideally through a more formal arrangement, will be required for long-term integrated MSP. Managing the half of this planet that is beyond national jurisdictions requires a clear international commitment, supported by scientific knowledge [87]. The interconnected nature of the open oceans should be reflected in governance structures by better interlinking of single-sector authorities and incorporating a common conservation mandate. An international agreement enabling a dedicated MSP forum that is systematic, precautionary, and adaptive, would signify that the countries of the world are willing to take on this challenge.

6. Conclusion

Many vertical and horizontal ecological linkages exist in open oceans, and a range of activities are already affecting – and have the potential to further affect – these linkages. Thus, it is essential to manage open oceans in such a way as to explicitly consider these linkages. Integrating the best of marine spatial planning, systematic conservation planning, and adaptive management provides a structured approach to planning that would greatly benefit management efforts in the open oceans, and would provide a policy mechanism by which to consider vertical and horizontal linkages. Some of the management tools commonly used elsewhere would have to be adapted to the open ocean, expanded to encompass the diversity of habitats and scales of movements of organisms and account for vertical and horizontal linkages. In particular, for this integrated approach to succeed, we suggest that (1) spatial tools are essential, and more emphasis is needed on integrating spatial and established non-spatial tools, (2) goals and objectives that are ecologically appropriate for the open ocean need to be established, (3) supporting policies need to be developed if a scientific approach is to be used in managing the open oceans; and (4) monitoring and evaluation are crucial to achieve successful management, and demands the global coordination of monitoring methods, data analysis, interpretation and archiving of data in accessible databases. Furthermore, SCP and MSP have to date been predominantly two-dimensional, yet the open ocean demands expansion of dimensions – depth, and time – to capture the volume and spatial dynamics to be managed. Thus, because knowledge of the open ocean is patchy and limited, there is a strong need for managers and decision makers within and beyond national jurisdictions to apply the precautionary approach in managing open ocean ecosystems and resources.

International targets for ocean conservation have already been agreed to by many States, and there is momentum to increase protection and work towards sustainable use. One of the outcomes of Rio+20 was a commitment by States to work towards improving the conservation and sustainable use of marine biodiversity in ABNJ, including through a possible new international instrument. A new international instrument is a logical mechanism to put the structured approach advocated here in place. The challenge now is to make the best of this momentum, both in the short-term using and linking existing structures, and in the longer-term through new arrangements; in particular, for benthic and pelagic systems, to operationalize the international targets and commitments, and work towards achieving them by integrating MSP, SCP, and adaptive management.

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