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Marine connectivity conservation: Guidance for MPA and MPA network design and management

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ABSTRACT

The importance of considering ecological connectivity in the design of marine protected areas (MPAs) and ecologically coherent networks of protected areas across coasts and oceans has risen in prominence with the 2022 Kunming-Montreal Global Biodiversity Framework. This short communication highlights key messages emerging from a specialist conference session on marine connectivity by members of the IUCN-WCPA Marine Connectivity Working Group at the Fifth International Marine Protected Areas Congress (IMPAC5) in Vancouver in 2023. We consider the importance of spatial and temporal scale, knowledge and data gaps and some of the technological and scientific advances that are generating insights into species movements that can inform the ecologically meaningful design of protected areas for effective conservation of ecosystem integrity, biodiversity and the flow of ecosystem services.

1. Introduction

The importance of considering ecological connectivity in the design of marine protected areas (MPAs) and ecologically coherent networks of protected areas across coasts and oceans has risen in prominence with the 2022 Kunming-Montreal Global Biodiversity Framework. This short communication highlights key messages emerging from a specialist conference session on marine connectivity by members of the IUCN-WCPA Marine Connectivity Working Group at the Fifth International Marine Protected Areas Congress (IMPAC5) in Vancouver in 2023. This IMPAC5 session (no. LCS-1464) consisted of two parts. First, the session participants were provided with an introduction to marine and ecological connectivity, and to the IUCN-WCPA Marine Connectivity Working Group (MCWG), which was created in 2019 to advance global science and policy collaboration in marine connectivity. This introduction included support for the Convention on Biological Diversity (CBD) Global Biodiversity Framework goals and targets to increase global coverage of MPAs and natural ecosystem protection taking into account connectivity [1]. Secondly, presentations were made by five international experts covering marine connectivity with respect to the deep sea, migratory sharks, seascape ecology, marine genetics, and North American MPA collaborations. This 'Short Communication' highlights key messages from the session, which is largely based on 'rules of thumb' for MPA network design e.g., [2] as developed in a recent IUCN publication (see [3]).[1]

We offer the analysis and insights below as a snapshot of how scientists and managers are advancing knowledge and practice in design and implementation of marine connectivity for MPAs and networks. Scientific knowledge and practice in this field are at early stages of development with many more unknowns than for terrestrial connectivity. As highlighted here marine connectivity presents unique on-site challenges with such issues as scale, defining connectivity objectives, data limitations, capacity and policy inadequacies, and transdisciplinary and technology needs. Formal generic guidelines on ecological connectivity provide essential baseline. But knowledge specific to marine connectivity application is still an early 'work in progress' and what is presented below provides insights for what might be called 'rules of thumb' to help inform ongoing science and policy work in this critical

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[1] "When science has gaps, uncertainties, and as yet significantly unexplored domains, as is the case with connectivity in the marine environment, practical 'rules of thumb' can provide basic guidance for planning and management" [2]. Because of ongoing scientific gaps and uncertainty, 'Rules of thumb' have been prepared by the IUCN-WCPA Marine Connectivity Working Group [4] to help guide connectivity design [3].

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Table 1
Differences in the role of protected areas, OECMs and ecological corridors (taken from Hilty et al. 2020).

	Protected areas	OECMs	Ecological corridors
MUST conserve *in situ* biodiversity	•	•	
MAY conserve *in situ* biodiversity			•
MUST conserve connectivity			•
MAY conserve connectivity	•	•	

area of marine biodiversity conservation (Table 1).

Marine biodiversity is decreasing due to many stressors, particularly overfishing, habitat loss, and climate change [5,6]. Marine Protected Areas (MPAs) and MPA networks are widely used as place-based protective measures for marine biodiversity (e.g., genetic, species, functional groups) and ecological functions (e.g., population and ecosystem productivity). Ecological connectivity underpins community recovery from disturbance, as well as the functions and performance of MPAs; thus, it is essential to identify and build connectivity into the decision-making for the design and management of MPAs and MPA networks [7,8]. Although almost every coastal country has at least one marine and coastal protected area [9,10] information gaps exist on the critical role of connectivity for sustaining marine biodiversity. It is recognized that connectivity promotes resilience to disturbance and enhances recovery potential of impacted ecosystems [11]. Despite this importance, connectivity is among the most infrequently and ineffectively applied ecological criteria in MPA network design, management, and evaluation [8,12,13], often because it is difficult to measure [8,14]. Considering connectivity in MPA design will advance efforts to mitigate threats, ensure that marine populations have access to the locations they need to thrive and to maintain biodiversity and ecosystem services [15–18].

IUCN Guidance. The importance of considering ecological connectivity in conservation has been framed by the 2020 *IUCN Guidelines for Conserving Connectivity through Ecological Networks and Corridors*[2] (the 'Guidelines'). In this document, from an ecological perspective, connectivity has been defined as "The movement of organisms, including their genes, gametes and propagules, between populations, communities and ecosystems, as well as that of non-living material from one location to another" [19]. From a conservation policy perspective, ecological connectivity has been defined as the "unimpeded movement of species and the flow of natural processes that sustain life on Earth" [20]. The Guidelines also include other key terms, and differentiate the role of protected areas and other conservation categories for conserving biodiversity:

- Ecological network of protected areas for conservation – A system of core habitats (protected areas, OECMs and other intact natural areas), connected by ecological corridors, which is established, restored as needed and maintained to conserve biological diversity in systems that have been fragmented see [21,22].
- OECMs (other effective area-based conservation measures) – geographically defined areas other than protected areas, governed and managed to achieve positive and sustained long-term outcomes for the *in situ* conservation of biodiversity [4].
- Ecological Corridor – A clearly defined geographical space that is governed and managed over the long-term to maintain or restore effective ecological connectivity.

[2] Download Guidelines through: https://portals.iucn.org/library/node/49061

2. Specific points for consideration

2.1. Scale

The spatial and temporal scales over which connectivity operates differ among individuals, life stages and species, and are also system-specific, being a function of the life-history and traits of the organisms, and the dynamic patterns and processes in the surroundings. In seascape ecology, the spatial composition and configuration of patches influences connectivity, where patch mosaics (e.g., reefs, vegetated corridors) and gradients in the seascape (e.g., channels, slopes, temperature) can form corridors and stepping stones that influence how species move through their environment [23]. Understanding how different life-history stages utilize different habitat types is critically important in designing effective MPA networks given that larvae, juveniles and adults of a single species may have different habitat requirements to meet their needs for feeding and refuge during ontogenetic shifts, daily and seasonal migrations or reproductive migrations [16,24,25].

Considerations of connectivity are most effective if they are multi-scale in space and time, and for MPA design if they are relevant both within and between focal areas. This is because multi-scale considerations of connectivity should reflect the dispersal patterns and ability of all species in an ecosystem, However, this is rarely, if ever, achievable in practice because of pronounced differences among taxa in dispersal capability based on differences in mode of reproduction, larval behaviors, habitat preferences, etc. [24,26]. For broad-ranging species, conservation of connectivity corridors is most likely to yield the desired conservation outcomes at broad scales and will likely require transnational collaboration, for example, the North American Marine Protected Areas Network (NAMPAN – Canada, USA, Mexico – http://nampan.org/) or the South Pacific Regional Fisheries Management Organisation (SPRFMO – New Zealand, Australia and other South Pacific states - https://www.sprfmo.int/). There is increasing evidence of the importance of inter-jurisdictional and transboundary connections for many marine species from studies of physical oceanography [27–30], genetic connectivity [26,31] and tracking of individual movements [24,32,33]. Understanding offshore and coastal species' transboundary distributions and connections, including land-sea and freshwater-marine connections [34–36], is critically important to help determine whether existing MPA networks are fulfilling the expected conservation role.

Whilst bigger MPAs are usually better than smaller MPAs for conservation outcomes and when including the spatial scales of connectivity for many species [37,38], conservation design must also consider temporal scales of connectivity. Thus, to understand the influence of MPAs on connectivity, multi-site and multi-year baseline data before MPA establishment are useful, as well as monitoring data after establishment [39–41]. However, often such pre-establishment data do not exist and although the monitoring of post-establishment MPAs is informative for connectivity (and other metrics), the interpretation of such data may be confounded by other factors, esuch as climate change [42,43]. This highlights the challenges presented by data limitation (see subsequent section) in evidence-based MPA network design and may require proxies or surrogate data to address knowledge gaps [44].

2.2. Defining success for connectivity objectives

There is no 'one size fits all' approach for MPA success. Successful MPA networks must consider species-specific biological (e.g., genetic structure, life history, behavioral and reproductive) differences and responses to protection. An example is the conservation of groups such as coastal and oceanic species of sharks [45]. Many shark species are resident at the scale of the reef (at a spatial scale much larger than for invertebrates such as lobsters and conch, and territorial fish species) but many are also highly migratory, with many transoceanic migrations having now been recorded by tagging and tracking studies [46,47].

Thus, for highly migratory species such as sharks, rays, turtles and whales, the connectivity conservation benefits of MPAs are likely to be greatest when the placement and the size and shape of MPAs considers reproductive and breeding areas, nursery areas, migratory routes, resting areas, and foraging areas [16,48–50]. Progress is being made with global recognition of 'swimways' that span multiple nations - a concept analogous to flyways for birds [51] and with mapping designations such as Important Marine Mammal Areas (IMMAs), Important Bird Areas (IBAs) and the new Important Shark and Ray Areas (ISRAs). Having clearly identified measurable objectives against which to measure MPA performance may be one way in which policy makers and managers can estimate success or failure, identify regions or habitats or taxa that are not protected, and modify management practice to enhance overall performance [52–54].

2.3. Getting around lack of data

The lack of data availability on the distribution of habitat types, species dependencies and key ecosystem processes may hinder the establishment of new MPAs. Similarly, a lack of capacity (skilled personnel) in many countries may hinder the collection of appropriate data. For example, in coastal areas, an absence of sufficient data about life-history traits of taxa, seasonal catches of targeted species, or how different life-history stages use different habitat types during the species' life cycle may be a challenge to decision making about MPA location, size, siting, and management. In the deep sea (depth greater than 200 m), little is known about reproductive cycles and the timing and duration of dispersal for many species [27,30]. Practitioners are therefore often forced to construct theoretical scenarios based on limited knowledge or by comparison to other related species or genera from different regions or depths, to estimate connectivity. The absence of direct functional connectivity data (e.g., tracking with telemetry) combined with a lack of understanding of relevant interpretations of the data that do exist impede MPA design and implementation in many regions. In these instances, spatially explicit mathematical models can help define relevant spatial and temporal scales at which connectivity operates [8,29,30]. However, because these models require human and computational resources, frequently not readily available, methodologies of intermediate complexity may suffice in certain contexts [55]. In some instances, local ecological knowledge has provided the most reliable information on ecological connectivity such as from fishers' knowledge [56].

Habitat suitability modelling [57], joint species distribution modelling [58] and graph theoretic models [59] may be used where there are limited data on spatial distributions of target species, communities, or ecosystems to develop scenarios that can provide information on habitat linkages and species dynamism. Structural connectivity (i.e., patch structure or spatial gradients) may serve as a spatial proxy for connectivity models and can form predictors in habitat suitability modeling to support improved spatial management where data are lacking [59,60] and may inform deep-sea fisheries management (closure) decisions [61].

2.4. Barriers to implementation

While a lack of data is in many instances a key impediment to conservation success (i.e., establishment of a network of MPAs), it is not the only limiting factor. Lack of capacity and lack of communication of relevant scientific evidence to conservation can lead to an absence of implementation [8]. Lack of capacity and/or funding along with inadequate policy support to implement science-based advances, to recruit personnel, to conduct MPA network monitoring and to police (enforce) the MPA rules are oft-cited problems hindering design and management of MPAs for connectivity [22,38]. Opposition to the establishment of an MPA network from local users is also an oft-cited problem [62,63], which sometimes may be solved by marine spatial planning that takes into account the histories, present and futures needs of all users [64].

2.5. Connectivity informed by transdisciplinary research

Identifying rates and routes of species-specific connectivity is critical in the planning of MPA networks, although rarely used [15]. Understanding where recruits come from (source populations) and whether a population makes little or no contribution to the network connectivity (sink populations) is key. Typically, the aim is to protect source populations whereas sink populations may not receive protection unless they act as an important stepping-stone population within a network. Molecular markers may be used to identify spatially explicit genetic variation and source populations [26,27,30,31,65] to better protect both coastal and deep-sea species.

Studies are increasingly taking transdisciplinary approaches to quantifying connectivity. For example, estimates of genetic connectivity may be tested against oceanographic (particle tracking) models to determine if the known or the most likely physical oceanographic conditions (e.g., current direction, rate of flow, seasonality) explain observed genetic connectivity [29,30,66,67]. Whilst most studies report a high degree of correlation between physical oceanographic and genetic connectivity, there are exceptions that still need to be better understood. Transdisciplinary approaches will help inform MPA placement in the future, but more region-specific physical oceanographic models need to be developed and validated before this technique can be widely used.

2.6. Technological advances needed to support MPA design and well-connected MPA networks

Advances in connectivity modeling and habitat suitability modeling, together with data from Earth observation satellites, pattern recognition algorithms, satellite and acoustic telemetry, soundscapes, chemical signatures and metabarcoding (eDNA) are rapidly breaking down the barriers to identifying ocean corridors [68–71]. Accelerated global seafloor mapping projects such as Seabed 2030 (https://seabed2030.org/) and local-scale nearshore mapping initiatives [72] will inform international and national management decisions about where to place new MPAs, how many, and what size they ought to be, to achieve conservation outcomes, as well as supporting the evaluation of existing MPAs, in coastal zones and the deep sea.

Increasingly, multi-variable environmental data sets are available for use at different spatial scales. For example, EEZs of several different countries have now been mapped for a range of key environmental variables including depth, substrate type, temperature, salinity, dissolved oxygen concentrations, calcite, aragonite and silicate concentrations. An ability to understand genetic connectivity in terms of environmental variation [30,73] will play a key role in the establishment of new offshore MPAs, and such an approach may be applied wherever the necessary environmental data exist. However, for most countries these data are still lacking, and the technologies are often unavailable in developing countries , placing them in an inequitable position to develop and report progress on MPA connectivity.

3. Conclusion

Urgent action is needed to better understand, conserve, restore and leverage the critical ecological connectivity of marine and coastal areas. Unimpeded exchanges of individuals (larvae, juveniles, adults) are central to biodiversity, ecosystem functioning and resilience to stressors (e.g., climate change, urbanisation, habitat loss), and underpin the many contributions to human well-being particularly for coastal communities. However, ecological connectivity is a relatively abstract concept and setting targets for it presents a challenge. In particular, translating high-level conservation goals to actionable goals with quantitative objectives and meaningful indicators that require specific actions to be met is non-trivial with respect to connectivity. Additionally, specific actions will require different types of data and different approaches for obtaining these data, and depending on the focal system (e.g., deep sea benthos versus migratory sharks). It is because of these complexities that all disciplines working in marine conservation have a role in advancing understanding, designing action, and advising on supportive polices for conserving areas important for connectivity.

CRediT authorship contribution statement

Barbara Lausche: Conceptualization, Writing – review & editing. **Jonathan P.A. Gardner:** Writing – original draft, Writing – review & editing. **Simon J. Pittman:** Writing – review & editing. **Anna Metaxas:** Writing – review & editing.

Data Availability

No data were used for the research described in the article.

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