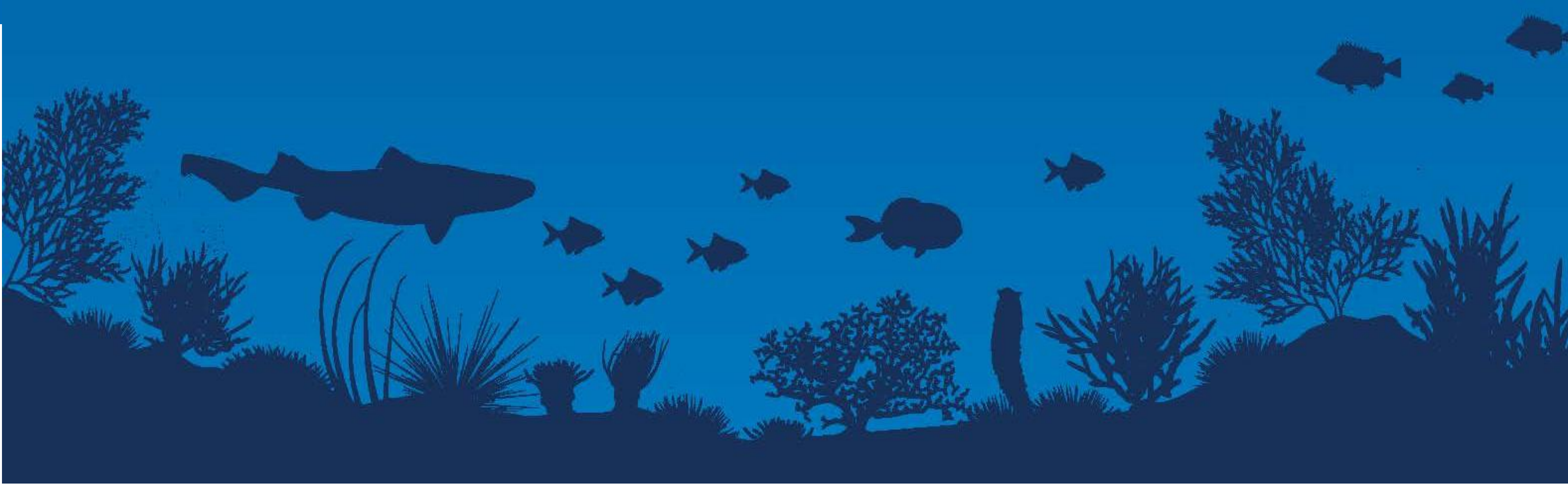
MARINE CONNECTIVITY ACROSS JURISDICTIONAL BOUNDARIES:
AN INTRODUCTION



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Marine connectivity across jurisdictional boundaries: An introduction

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The UN Environment World Conservation Monitoring Centre (UNEP-WCMC) is the specialist biodiversity assessment centre of the United Nations Environment Programme (UNEP), the world's foremost intergovernmental environmental organisation. The Centre has been in operation for over 30 years, combining scientific research with practical policy advice.

INTRODUCTION

The ocean provides human societies with valuable and diverse goods and services, including food (from fisheries and aquaculture), coastal protection, tourism, transportation and energy (Harris and Tuhumwire, 2016). Together, these are of significant economic, social and cultural importance. Marine ecosystems and biodiversity are, however, negatively impacted by human activities. Such activities, in turn, threaten the very processes and resources that support these goods and services (Halpern et al. 2012; Eassom et al. 2016). Furthermore, the anticipated effects of climate change will fundamentally reorganize marine communities (Pinsky et al. 2013). As human uses of the ocean continue to grow at a rapid pace (Halpern et al. 2015), including in the deep seas (e.g., deep-ocean fishing and seafloor mining) (Ramirez-Llodra et al. 2011), the need for better and more integrated management of the use of the marine space and its resources is growing (Baker et al. 2016; Carneiro et al. 2017). **Such efforts come with significant challenges given that human management of the seas is based on administrative and jurisdictional delineations (i.e. national waters of countries), while ecological processes do not respect such boundaries.**

Species range boundaries do not necessarily align with national waters of countries, or other political, economic and human-derived boundaries (e.g. shipping lanes, marine protected areas (MPAs), industry-licensed areas). Furthermore, boundaries can change seasonally, due to a variety of processes such as migration, or longer term due to climate change. The marine environment is fluid and dynamic by nature, meaning that impacts to it can also move and affect areas far distant from the initial event. Similarly, species, including fish stocks and other exploited taxa, range through this highly connected, in space and time, medium (Jönsson and Watson, 2016; Baustian et al. 2014). Species further connect multiple disparate administrative boundaries, including Areas Beyond National Jurisdiction (ABNJ). Strong evidence exists for the value of connectivity in maintaining the integrity and functionality of ecosystems and services derived from them (Olds et al. 2016). **It is important, therefore, to account for connectivity in marine area-based planning processes, including those that may take place in ABNJ.**

CONTEXT

ECOSYSTEM APPROACH IN AREAS BEYOND NATIONAL JURISDICTION

The Sustainable Fisheries Management and Biodiversity Conservation of Deep Sea Living Resources in Areas Beyond National Jurisdiction Project (ABNJ Deep Seas Project for short) is a five-year multi-partner project with the objective *“to enhance sustainability in the use of deep-sea living resources and biodiversity conservation in the Areas Beyond National Jurisdiction (ABNJ) through the systematic application of an ecosystem approach”*. One component of the project aims to develop and test a methodology for area-based planning in two pilot regions: the Western Indian Ocean and the South East Pacific (Figure 1). These regions incorporate the boundaries of two Regional Seas Organisations, the Nairobi Convention[1] and the Comisión Permanente del Pacífico Sur (CPPS)[2], along with a portion of ABNJ located beyond the Exclusive Economic Zones, and hence the national waters, of states.

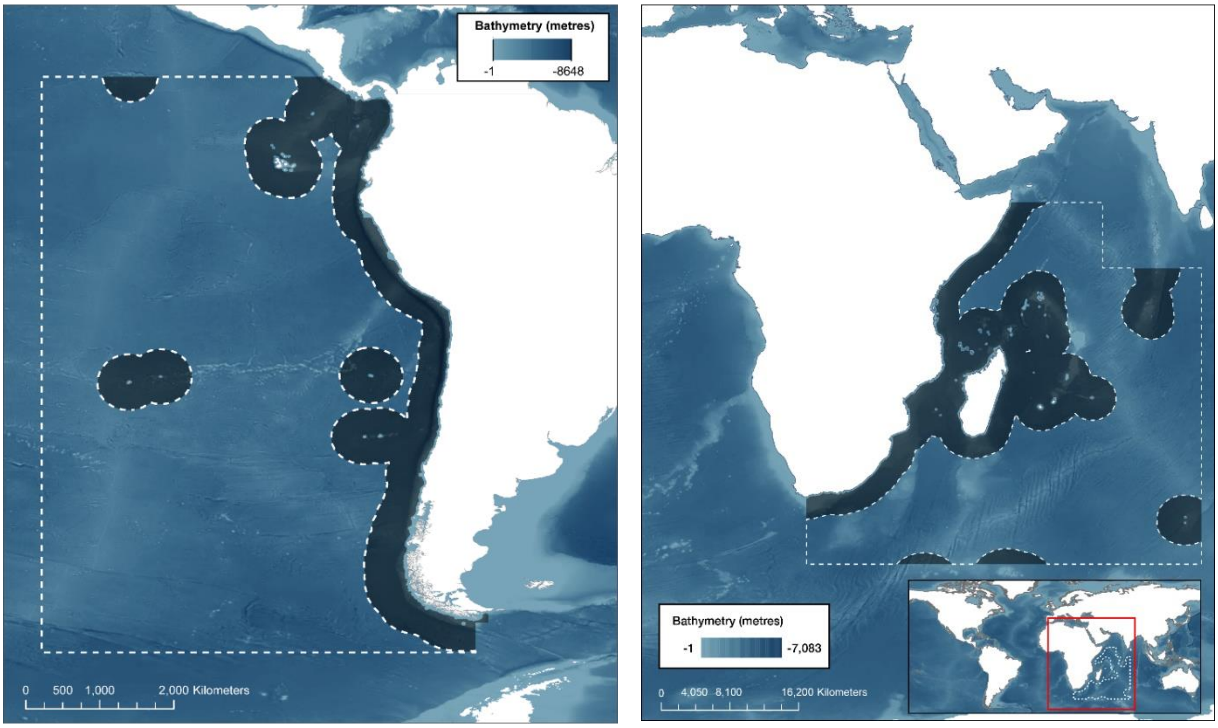

Figure 1 *Maps showing the illustrative boundaries of the two pilot regions, the South East Pacific Ocean (left) and the Western Indian Ocean (right) (Source: Weatherdon et al. 2016a and 2016b).*

CONNECTIVITY AND PLANNING

Connectivity can be defined as the physical or ecological conditions that allow living organisms and non-living material to move between, or influence, habitats, species populations or assemblages that are intermittently isolated in space or time. This document

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[1] http://web.unep.org/nairobiconvention///

[2] http://www.cpps-int.org/; Permanent Commission for the South Pacific

provides an introduction to two forms of connectivity, functional and structural, and discusses these in terms of transboundary considerations. There are a number of other forms of connectivity, such as genetic connectivity, all of which are interlinked within the ocean system and can be transboundary in nature and vary in scale across the ocean. This presents an important challenges to planning (and management) processes, including regional-scale planning processes such as Regional Sea Programmes. **This document therefore provides an introduction to connectivity in the marine environment in a spatial planning context.** Through this, the first steps are taken in terms of in helping states assess the relevance of the ABNJ in their planning processes.

AN ADMINISTRATIVE AND LEGAL PERSPECTIVE OF THE OCEAN

The 1982 **United Nations Convention on the Law of the Sea** (UNCLOS) is the principal legislation pertaining to ocean governance and its territorial zonation (United Nations General Assembly 1982[3]). Maritime zonation is shown in Figure 2, illustrating the complexity of sovereignty matters at sea. National waters of countries generally extend up to 200 nautical miles (nm) from the baseline (UNCLOS Article 55[4]), and are referred to as the country's "Exclusive Economic Zone" (EEZ); beyond EEZ boundaries the High Seas begin. Also of note, countries may claim jurisdiction beyond the 200 nm boundary, but only over the seabed[5] of the continental shelf, and not the pelagic waters above. Beyond national jurisdiction on the seafloor, a benthic zone known as 'the Area' begins.

The marine realm is the largest ecosystem on planet Earth, representing 99% of the biosphere by volume (Angel, 1993), yet only approximately 36% of it is under the jurisdiction of any single country. Within their jurisdiction, countries have the mandate to establish and enforce national laws to manage marine resources, living or not. Beyond national waters, the ocean becomes a "common resource" for which no single country or body has a regulatory mandate for managing resources (Warner, 2014).

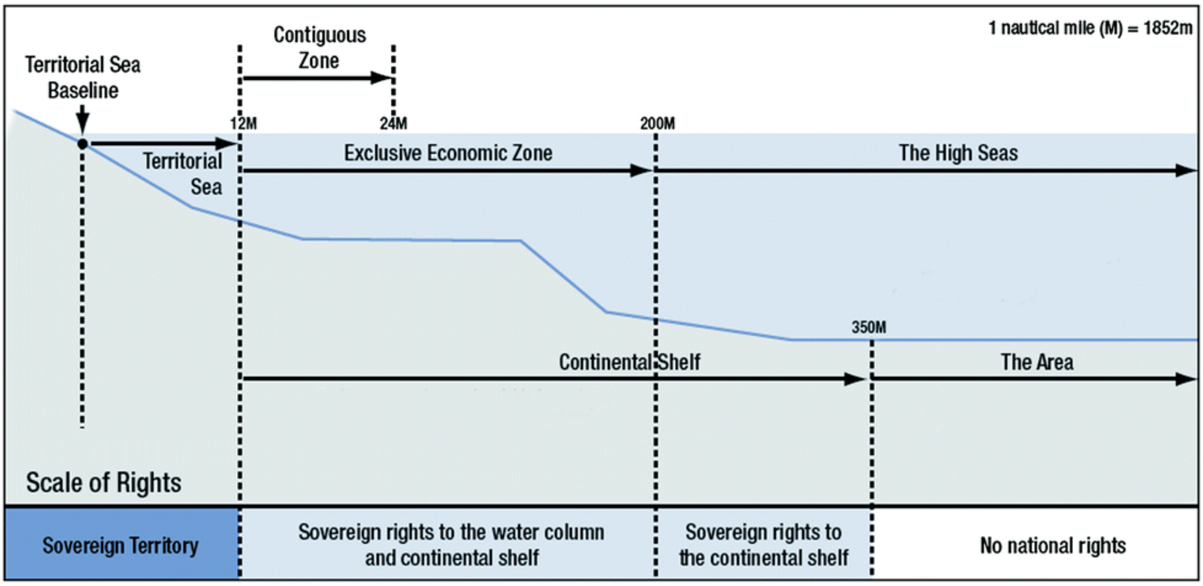

Figure 2 *Maritime zones as described by the United Nations Convention on the Law of the Sea, UNCLOS (Source: Lallier et al. 2014).*

However, a number of sectoral organisations have regulatory mandates in specific sectors and specific spatial areas of the High Seas. For instance, **Regional Fisheries Management**

[3] http://www.un.org/depts/los/convention_agreements/convention_overview_convention.htm
[4] http://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf
[5] Including ocean floor, subsoil and their mineral resources.

Organisations (RFMOs) are composed of states having fishing interests in the same area, with a mandate to manage and give advice on fish stocks, sometimes focusing on specific stocks (e.g. tunas). **Regional Seas Organisations, created as part of** the Regional Seas Programme, are composed of neighboring states, with the purpose of protecting their shared marine environment. Some Regional Seas Organisations, such as the OSPAR[6] Commission for the Northeast Atlantic, have a mandate to act in Areas Beyond National Jurisdiction on particular topics, although many others do not. Some specific sectors are managed by specialized bodies, such as the International Maritime Organization (shipping) and the International Seabed Authority (seabed resources). Finally, there is a multilateral Environmental Agreement (MEA) that is particularly relevant to connectivity in the marine realm: the 1979 Convention on Migratory Species (CMS), which includes species that move across international and national waters. Additionally, the Convention on Biological diversity (CBD), with a specific mandate from Conference of the Parties (CoP) 8, is tasked with providing scientific and technical advice on ABNJ issues. The original convention articles directly address ABNJ: *"In the case of processes and activities, regardless of where their effects occur, carried out under its jurisdiction or control, within the area of its national jurisdiction or beyond the limits of national jurisdiction"*[7].

For a detailed analysis of the legal and governance situation in the two pilot regions for the project, please see: *Governance of areas beyond national jurisdiction for biodiversity conservation and sustainable use: Institutional arrangements and cross-sectoral cooperation in the Western Indian Ocean and South East Pacific*[8].

[6] Convention for the Protection of the Marine Environment of the North-East Atlantic.
[7] https://www.cbd.int/convention/articles/default.shtml?a=cbd-04
[8] https://www.unep-wcmc.org/resources-and-data/governance-of-abnj

AN INTRODUCTION TO TWO FORMS OF CONNECTIVITY

Marine connectivity encompasses a range of interlinked forms, including genetic, functional and structural. The following explores marine connectivity across jurisdictional boundaries through functional and structural connectivity and discusses the importance to ABNJ. **Functional connectivity** relates to the movement of organisms (and the organic matter derived from them) through the ocean as a result of their ecological characteristics, such as habitat preference and dispersal ability (Olds et al. 2016). These movements often underpin ecosystem functioning, and hence the health and resilience of species, populations, and ecosystems. In contrast, **structural connectivity** relates to the physical characteristics of the ocean that allow for movement, for instance, oceanographic features such as eddies, currents and fronts, or benthic (seafloor) structure (Wells et al. 2008). Focus is place upon these specific forms of connectivity due to the impact across jurisdictional boundaries. For example, the movement of marine species between EEZ and ABNJ provides economic benefits due to the ecosystem services provided, such as fisheries and tourism. Barriers to such connectivity could affect such economic dependencies. Additionally, oceanographic characteristics, such as currents and gyres, are cross-boundary in nature and provide significant connectivity which could be altered under climate change. It is important to note that forms of connectivity are interlinked and should be considered in combination.

FUNCTIONAL CONNECTIVITY

Traditionally, areas of the ocean have been defined according to discrete zones, often subdivided by depth (e.g. pelagic or benthic) or distance from the shore (e.g. coastal or oceanic) (Figure 3). Whilst some species are characteristic of certain zones, increasingly species have been found to be more dynamic in space and time than previously thought and may conform less to such zones (Costa et al. 2012). For example, clearly delineating communities by depth appears to be overly simplistic, with many organisms found to regularly move between the various depth divisions (Sutton, 2013). Similar findings are being made for species considered to be coastal or oceanic, such as the great white shark (*Carcharodon carcharias*), once considered a coastal predator, is now thought of as an oceanic shark which regularly moves inshore to feed (Bonfil et al. 2005).

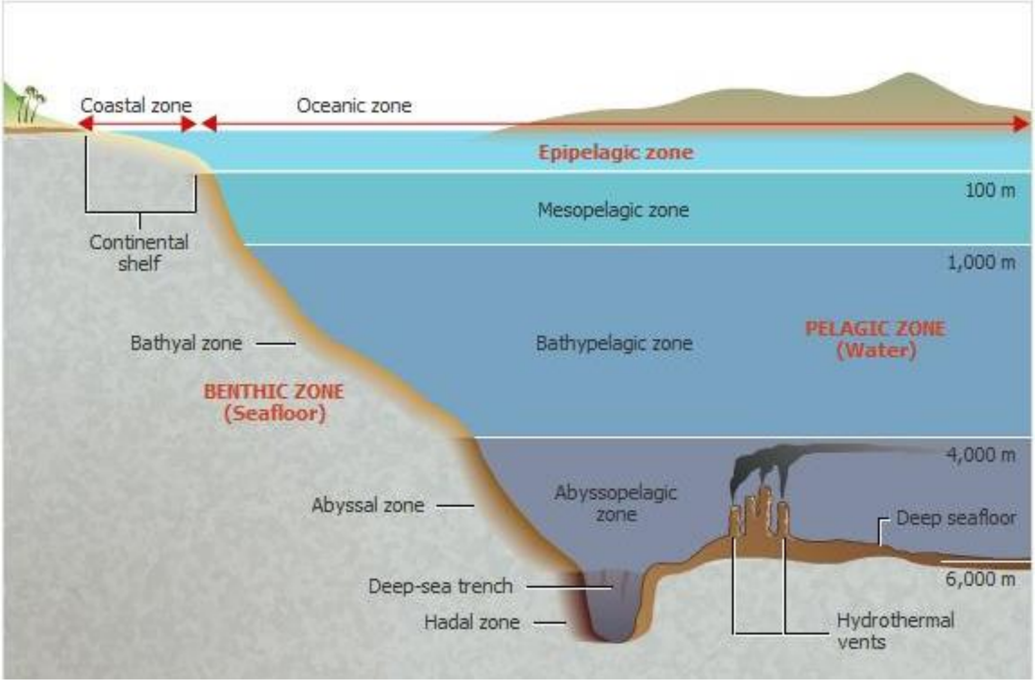

Figure 3 *The depth zones in the ocean (Source: Anyadiegwu and Uwaezuoke, 2015).*

The movement of species plays an important role in shaping the structure, functioning and productivity of ecosystems. Actions in one region, such as unsustainable fishing practices, can have profound impacts on another, such as fisheries within a specific EEZ, an example of a teleconnected impact (Liu et al. 2015). When issues occur on land that result in impacts across a boundary, they can be taken to an International Court of Justice as "Transboundary Harm Disputes". To avoid impacts occurring across boundaries, it is important to consider connectivity. In some deep sea areas, there are extreme environments which, by their isolated nature, contain distinctive species. It may be that the lack of connectivity, and very specific environmental conditions, results in a unique area (e.g. Van Dover et al. 2018). Accounting and planning for unique marine habitats, organism movements and their importance in maintaining the provision of services, is essential in developing robust and ecologically appropriate spatial plans and should be considered in area based planning efforts (Baco et al. 2016).

Age Based Movement of Organisms

Species movement patterns, influenced by factors such as resource availability, predation risk and social interactions, can change over an animal's life span. Marine species typically exhibit complex life histories with differing dispersal capacities and habitat utilization at different stages of their development.

Larval Dispersal

Understanding of larval dispersal is important in connectivity and conservation planning, with examples of larval dispersal models used in MSP exercises such as the design and configuration of MPA networks (Sala et al. 2002), area-based management of deep-sea mining (Dunn et al. accepted), and management and conservation of marine habitats (Gormley et al. 2015).

Larvae can be passively moved (carried by currents and wind; rafting on floating objects and hitchhiking in ballast) or actively swim for weeks or months. Estimating and predicting the spatial scale of larval dispersal is challenging. Larvae have been tracked individually (Almany et al., 2007) but the majority of estimates are derived from computer simulations (Figure 4) and population genetic approaches. Genetic evidence suggests mean dispersal distances of marine invertebrate and fish species are in the order of ten to hundreds of kilometers (e.g. Planes et al. 2009). Similar larval dispersal distances have been identified for deep-sea invertebrates and fishes (Baco et al. 2016).

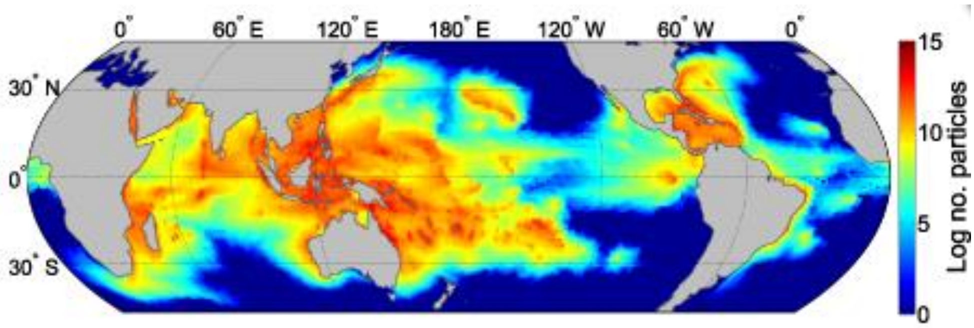

Figure 4 *Map of simulated coral 'larvae' trajectories aggregated over an 8-year model period (2003–11). The color scale shows the log number of individual particles passing through each cell on a 1 × 1° grid (Source: Wood et al. 2014).*

Dispersal is a complex biophysical process. Biological factors influence offspring production, growth, development (e.g., some species disperse during the larval stage, others have no planktonic life stage or spend only hours to days in this phase), and survival. Physical processes determine water circulation, and biophysical processes determine interactions between larval traits and physical environment properties. For example, headlands and embayments off the Chilean coast result in the formation of distinct subpopulations of the marine gastropod *Concholepas concholepas* with minimal levels of connectivity between them despite dispersal distances of over 100 kilometers (Poulin et al. 2002). In the deep-sea, limited knowledge regarding species ecology and ocean circulation have hindered our capacity to understand dispersal and connectivity. Hilário et al. (2015) reviewed existing studies and found that the *range* of time (e.g. durations) spent dispersing was similar in deep seas to shallow seas (10-315 days in deep sea vs. 0.17-293 days in shallow). However, the *average* amount of time spent in the deep sea was longer (97 in deep sea vs. 28 days in shallow seas).

Juvenile Dispersal

Whilst larval dispersal is the focus of many connectivity studies, many species also have a juvenile life stage during which they have the capacity to disperse. Some invertebrate species, following settlement into/on the seabed, actively re-suspend themselves and move into the water column to further disperse. Reduced vulnerability to predation, increased competition and greater resource requirements may all prompt individuals to leave natal grounds for new locations. Many species settle in nearshore coastal habitats such as mangroves, seagrass beds and estuaries before heading out to sea as adults (UNEP, 2014). Species including turtles and some coral reef organisms exhibit natal homing, in which juveniles return to the region in which they were spawned. Therefore, understanding the habitats of juveniles, migration patterns between them – potentially across administrative boundaries - and how these may change over an organism's lifespan is fundamental in MSP efforts to assure the sustainable use and conservation of economically and intrinsically important marine species alike.

Adult Migrations

Many species, such as turtles and sharks, and some demersal (e.g. hake, cod), pelagic and coral reef fish, exhibit migratory behavior in which they move in search of favorable feeding and/or spawning zones in response to temporal and/or environmental changes (e.g. seasonal migrations of tuna from cold feeding grounds to warm spawning grounds). Movements can range from a few hundred meters to thousands of kilometers, and can occur over short timescales and small spatial scales or be temporally infrequent over long distances (Sequiera et al. 2018). Through migrations, surface waters are linked to deep oceans and coastal waters to the High Seas.

Zooplankton move in the water column through diel (daily) vertical migration (DVM), transporting nutrients from the deeper ocean to the pelagic zone in the process. The vertical migration of zooplankton is considered the largest in terms of biomass and most frequent migratory movement on the planet. It has significant impacts on the functioning and productivity of both benthic and pelagic ecosystems, and also the distribution and abundance of organisms all along the food chain. Crustaceans (copepods and krill), squid and fish also migrate vertically to feed on zooplankton or their predators. DVM is also common amongst large pelagic species in the open ocean, reported in some tuna, swordfish, rays and sharks (for example, West and Stevens, 2001; Sims et al. 2006). Hypotheses include feeding and the use of sub-surface currents to assist migration, reproduction and predator avoidance.

A number of species travel long-distances spanning entire ocean basins, moving between foraging grounds or suitable breeding areas (Figure 5). Many such movements have long been known and documented, with 17th century whalers' logbooks describing the movement of humpback whales in the Southeast Pacific from their breeding sites in the tropics to feeding sites in Antarctic waters. In the last twenty years the known locations of breeding and feeding sites of baleen whales have been refined, with breeding areas shown to extend from the waters off the north of Peru (5° S) to central Costa Rica (12° N) and feeding areas located mainly west of the Antarctic Peninsula and southern Chile. Along this journey, populations use a mixture of both coastal and offshore routes, and although the precise reasons for their routes are unknown, it has been suggested to be related to predator avoidance or the potential for feeding in coastal upwelling areas off Peru and Chile.

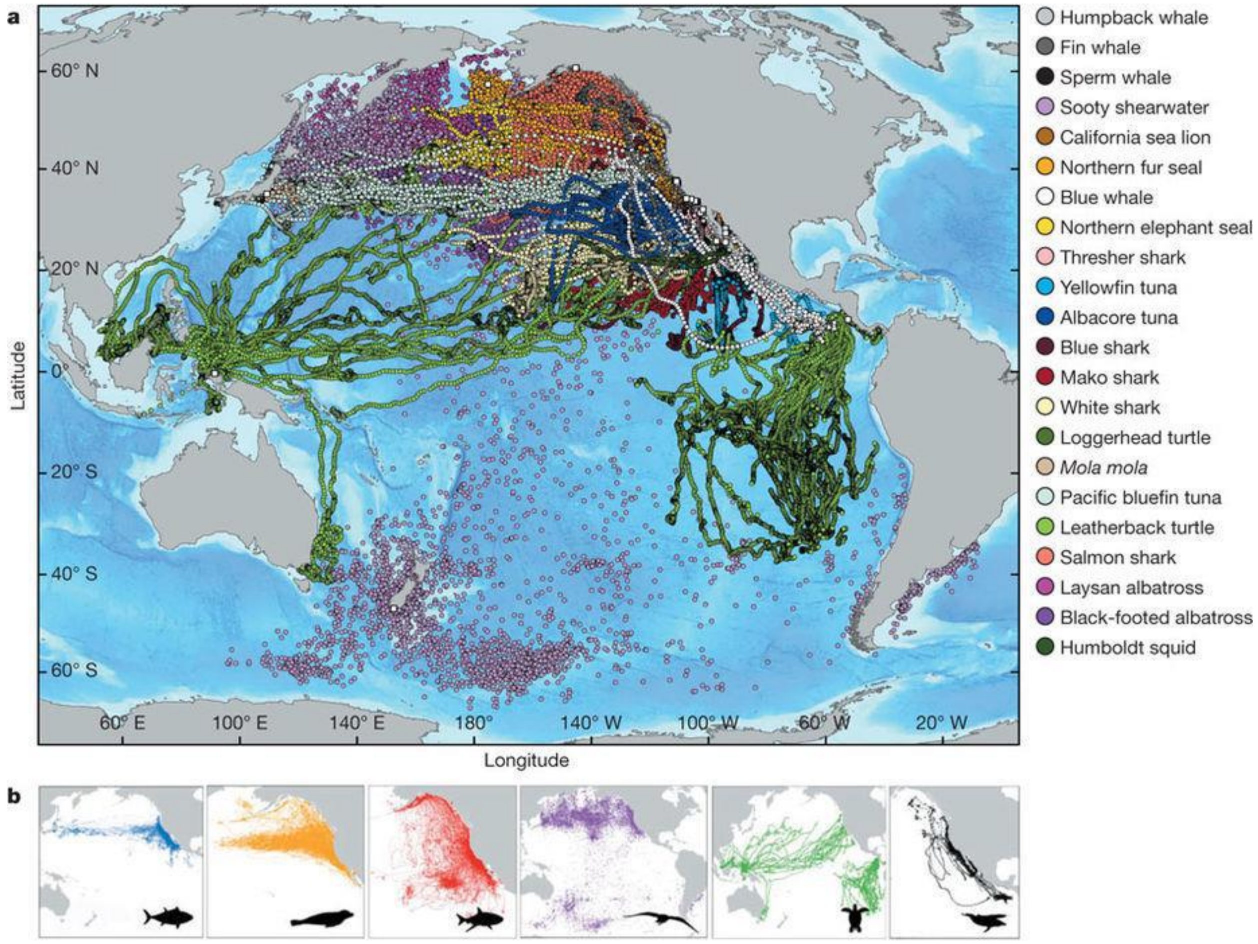

Figure 5 *Migration routes of multiple species: (a) as labelled, following daily tracked position estimates (circles) of tagged species; (b) following daily tracked position estimates of from left: tunas; seals and sea lions; sharks; seabirds; sea turtles; and whales (Source: Block et al. 2011).*

Several turtle species travel seasonally for foraging and also, as adults, periodically between nesting sites and feeding grounds, sometimes thousands of kilometers apart (Figure 5). The total distances travelled by green turtles (*Chelonia mydas*) and loggerheads (*Caretta caretta*) exceeds tens of thousands of kilometers in their lifetime, and provide cross-basin connections in the Pacific, Atlantic and Indian Oceans.

Economically valuable species including swordfish, sharks and tuna can be highly migratory, generally moving during all phases of their life history. Atlantic Bluefin tuna (*Thunnus thynnus*) perform long, seasonal reproductive migrations between feeding areas in the Atlantic Ocean and spawning grounds in the Gulf of Mexico or the Mediterranean Sea. Highly migratory and straddling stocks (those that migrate through, or occur in, more than one EEZ) account for 67% of the total global catch and 72% of the total landed value associated with global commercial fisheries (Sumaila et al. 2015). Long-distance migrations pose a challenge to fisheries management, as actions taken on a regional scale can be undermined elsewhere in the migratory pathway, and migratory and straddling stocks are targeted by fisheries in multiple EEZs and in ABNJ, increasing susceptibility to overfishing (Ortuño Crespo and Dunn, 2017). Straddling and highly migratory fish stocks are overfished at twice the rate of those within a single national jurisdiction (64% vs. 28.8%; FAO, 2014).

ABNJ management can influence coastal economies and societies, and the integrity, health and functionality of ecosystems and habitats in ABNJ can have impacts on reproduction and development of migratory species, and as such impact coastal ecosystem services, such as fishing or tourism. Movement of migratory species between coastal waters and ABNJ also has ecological consequences on food-web linkages and the transport of biological material between the two (e.g. Palko et al. 1982).

STRUCTURAL CONNECTIVITY

A number of **structural connectivity** characteristics are worthy of consideration in understanding of connectivity and planning purposes.

Movement of organic matter and nutrients

The distribution of marine nutrients and patterns of biological production are controlled by the interplay of biogeochemical and physical processes. Transport of nutrients by physical processes (currents, upwelling, etc.) is a vital mechanism in sustaining primary productivity in coastal environments and in shaping ecological patterns.

Pelagic and benthic habitats are connected via a range of mechanisms operating over multiple spatial and temporal scales including movement and cycling of nitrogen, phosphorus, carbon, oxygen and animal excretion and organism decomposition. The matter and nutrients required to maintain deep-water pelagic and benthic ecosystems are derived from sinking organic matter produced by phytoplankton in the upper water column. The export of material from surface waters has been shown to be a key source of energy that helps maintain deep sea species diversity and maintains ecosystems. Various species play vital roles, transforming the falling material for uptake by other organisms.

The movement of species also plays a role in translocating organic matter and nutrients; an organism may feed in the surface water and excrete nutrients lower in the water column and vice versa. Marine mammals that feed at depth and then move to surface and coastal waters have been found to support primary production (Roman and McCarthy, 2010). The combined functional connectivity through the movement of marine species and structural connectivity through ocean currents demonstrates the interlinked nature of connectivity an strengthens the case for considerations to explore all forms of connectivity.

Oceanographic transport

Physical processes such as current flows and upwellings play a vital role in transporting, redistributing and mixing nutrients spatially and within the water column but the processes are complex and occur across multiple spatial and temporal scales.

Globally, a system of currents called the thermohaline circulation (or the “global conveyor belt”) moves warm surface waters downward and forces cold, nutrient-rich waters upward (Figure 6). This circulation is a vital component of the global ocean nutrient and carbon dioxide cycles. Warm surface waters are depleted of nutrients, but are enriched as deep or bottom layers. This process, along with other factors such as seasonal temperature changes, is fundamental to life in the oceans as the base of the marine food chain depends on the cool, nutrient-rich waters that support the growth of algae and seaweed. As can be seen from Figure 6, these global currents are by nature global, cross national boundaries, and travel through ABNJ.

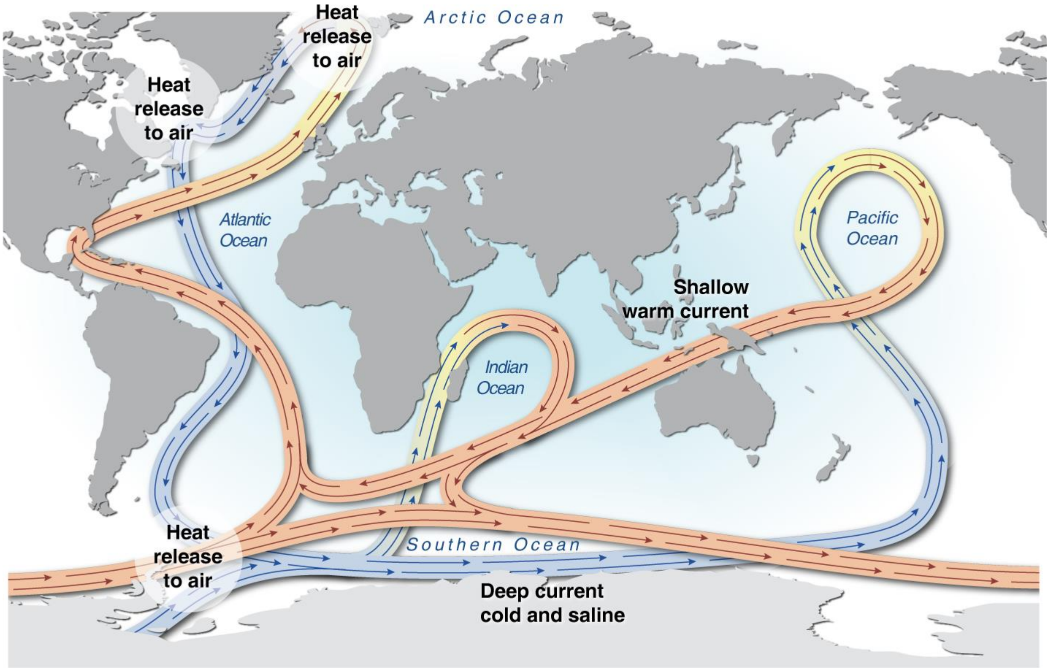

Figure 6 *The Thermohaline circulation (Source: GRID Arendal, n.d.).*

At a regional scale, winds blowing across the ocean surface push water away from the coast leading to an upwelling of deeper water (Figure 7). This water is generally richer in nutrients and stimulates the growth of phytoplankton which in turn supports other marine life. Coastal upwelling is most prevalent in the eastern boundaries of the Atlantic and Pacific Oceans, some of the most biologically productive regions, covering less than 1% of the ocean's area but providing up to 20% of the world's wild capture fisheries. These systems - the California, Humboldt, Canary/Iberian, and Benguela Currents - provide ecosystem, economic and recreational services to about 80 million people living along their coasts.

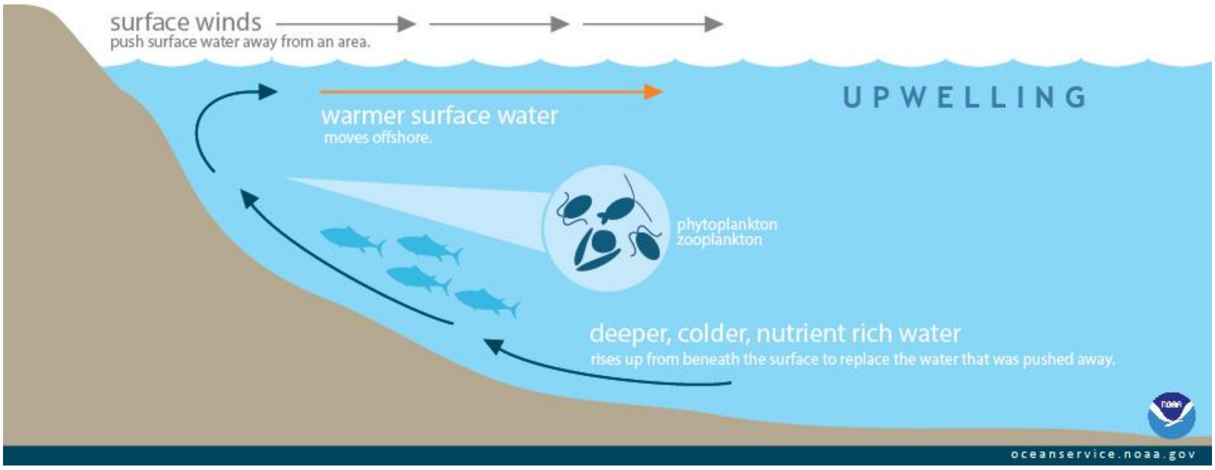

Figure 7 *The upwelling mechanism (Source: NOAA, 2017)*

At a more local scale, processes involving gyres, eddies and fronts transport and mix materials within and between ocean basins. For example, hotspots of predatory fish diversity (tuna, billfish) are associated with fronts within warm waters (25 °C) across the major ocean basins. In the Mozambique Channel, eddies formed from the Somali Current transport nutrients off the continental shelf making them available to pelagic ecosystems and contributing to the high productivity of the channel.

Area-based planning can ensure effective identification of important, highly productive marine areas, such as upwelling zones, all the more important in light of climate change impacts which may shift marine circulation patterns (IPCC, 2014). The recognition of these areas may be relevant for management and therefore their integration into a planning process can be useful.

BARRIERS TO CONNECTIVITY

Accounting for connectivity in planning is complicated by the fact that connectivity differs among closely related species and from region to region. This is due in part to geological features and other processes which restrict and/or enhance dispersal and connectivity. In marine environments barriers may not be evident as on land. However, it has been established that features such as land bridges, currents or eddies, and environmental limitations or distance between habitat patches can all be barriers. Some are hard - presence of land - and others are soft, semipermeable, transient or infrequent.

Abrupt breaks in the distributions of marine organisms with potentially high dispersal abilities have been identified. One potential explanation is historical changes in sea level and glacial episodes which have significantly altered coastal topology, thus creating effective barriers to dispersal (Bowen et al. 2106). Genetic separation for coastal taxa can coincide with disruptions in species ranges which lead to genetic differences in isolated populations, including along and in the south eastern Australian coast, the strait of Gibraltar, Southern Florida Transition Zone and the California Transition Zone.

A second explanatory factor is oceanographic features like eddies, currents and fronts which can limit mixing and diffusion of pelagic larvae, meaning that two adjacent sites on different sides of a front may rarely exchange migrants. Steep environmental gradients (water temperature, salinity and nutrients) and habitat discontinuities can act as additional breaks that impede dispersal and connectivity. For example, near Cape St Lucia in south-eastern Africa, in the north the warm Agulhas Current flows close to the coast but in the south it flows further away from the coast reducing its influence and the resultant difference in surface temperature and other hydrological differences result in different species compositions either side of Cape St Lucia (Figure 8).

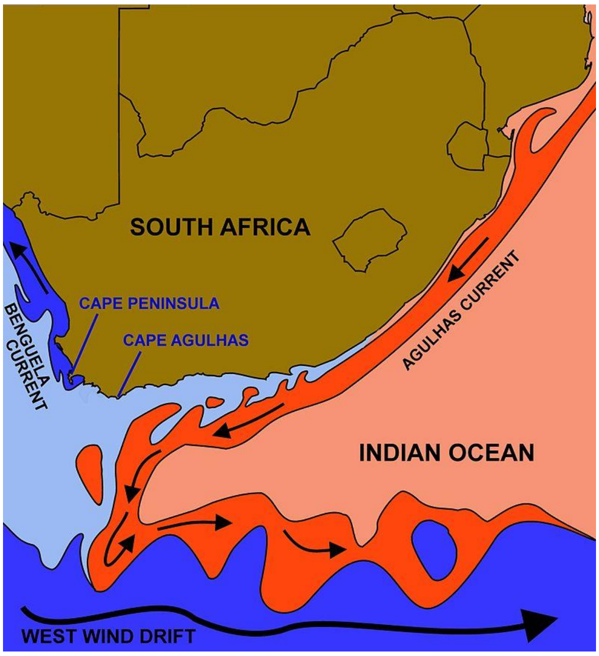

Figure 8 *The position of the warm Agulhas Current in relation to the South African Coast (Source: Oggmus, 2015).*

Certain features and barriers may impact some but not all species. The thermal profile around the Cape of Good Hope and the Benguela Barrier are topographically and hydrologically complex and reduce connectivity and movement in a number of large, migratory species. However, other species including tuna (Graves et al. 1984; Ely et al. 2005) and dolphinfish (Palko et al. 1982; Diaz-Jaimes et al. 2010) cross the region.

The majority of barriers to dispersal and connectivity have been identified within coastal regions, with species inhabiting the open ocean generally having or assumed to have broader distributional ranges. However, large, localised genetic differences have been found within circum-global species of deep-sea fish (e.g. Gaither et al. 2018), and retentive circulation of subtropical gyres contributes to extensive genetic differentiation of populations of an oceanic copepod throughout its distribution in subtropical and tropical waters (Goetze, 2003; Goetze, 2005; Andrews et al. 2014).

Understanding where and when barriers to dispersal and connectivity exist and the species likely impacted is a vital step in developing effective spatial plans which account for and seek to maintain ecosystem health and functioning. In addition, understanding if a number of populations of the same species are mixing, or if they are genetically distinct, is important for fisheries management. The treatment of these populations in stock assessments would be different depending on how they interrelate.

MAINTAINING CONNECTIVITY

Habitat health, diversity and connectivity are important components of healthy marine ecosystems. The role of habitats in facilitating movement and connectivity in organisms is well known. The area, quality and spatial arrangement of habitat are key determinants of the distribution, movement, growth and survival of organisms.

The importance of well-connected habitats has been documented for some fish and crustaceans, which move among different habitats to spawn and forage. Near-shore, shallow-water habitats, such as mangroves and seagrasses, have been shown to support a high abundance of juvenile fishes and invertebrates, and many commercially and ecologically important coral reef fishes use mangroves and seagrass beds as juvenile nursery areas before migrating to coral reefs as adults (Figure 9). A number of studies demonstrate a strong relationship between the presence of coastal wetlands and offshore fish abundance and fisheries yield. For example, the biomass of several commercially important species on Caribbean coral reefs more than doubled when the adult habitat was connected to mangroves (Mumby et al. 2004).

Similarly, in the Gulf of California, fisheries landings are positively related to the local abundance of mangroves and, in particular, the mangrove–water fringe used as nursery and/or feeding grounds by many species; it has been estimated that the annual economic median value of these fisheries is US $37,500 per hectare of mangrove fringe. In some situations, larvae and juveniles may aggregate in areas that are relatively safe and offer optimal oceanographic conditions, such as South Australian sardines aggregate at the mouths of gulfs and straits before moving offshore when older. Within these organism migrations, a substantial transfer of organic matter, nutrients and energy takes place.

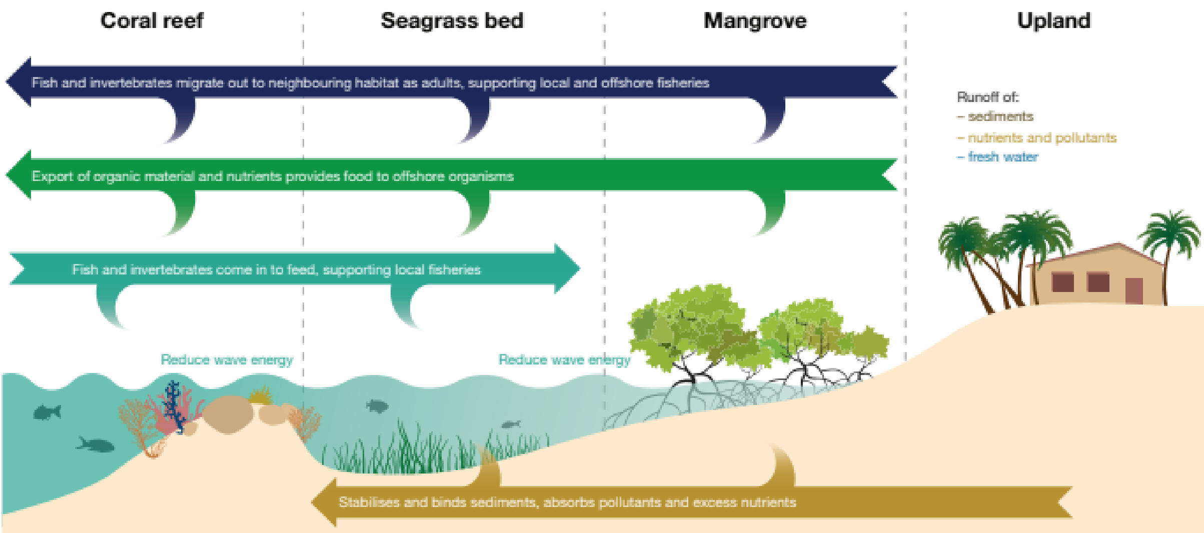

Figure 9 *Illustrating connectivity between seagrass beds, mangroves, and coral reefs which can affect the size and density of fish. (Source: UNEP, 2014).*

Upwelling circulation along eastern margins of the world's ocean basins brings nutrient-rich water from the deep ocean to nearshore surface waters, fuelling high levels of primary production that form the base of species-rich and productive nearshore food webs. Many animals visit these regions seasonally and form feeding, breeding, and aggregation habitats that only exist for a limited time each year. The development and persistence of these upwelling fronts are essential to the functioning of nearshore marine communities and changes can have significant effects on the survival of adults and successful rearing of young. The Benguela upwelling ecosystem off the south west coast of Africa supports a high abundance of life: nutrient-rich upwelled water boosts growth of large-celled phytoplankton, a food source for zooplankton, which in turn are eaten by pelagic fish such as anchovies and sardines. The high abundance of these pelagic fishes is of economic importance and attracts a vast community of predatory fish, seabirds and marine mammals. Similarly, in the Humboldt Current system off Peru, one of the most productive coastal upwelling systems where large numbers of small pelagic fish aggregate to feed on phytoplankton, the world's largest tonnage fishery for anchoveta (*Engraulis ringens*) is supported. This abundance is thought to be linked to El Niño Southern Oscillation events and decadal-length regime shifts. Thus upwelling regions form a natural connection between deeper offshore and surface nearshore waters.

Currents can play a significant role in enhancing dispersal of larvae and juveniles and increasing connectivity between patches of suitable habitat. Models of ocean circulation are used to explore dispersal, and estimate connectivity, and have demonstrated its influence on community structure and dispersal distance. In deep water, whale falls, seamounts, cold seeps and hydrothermal vents may act as stepping-stones for trans-oceanic dispersal of benthic invertebrate and fish species (Wilson and Kaufman, 1987; Leal and Bouchet, 1991; Rouse et al. 2004). For example, within the Tropical Pacific, the Marshall Islands, Fiji, French Polynesia and New Caledonia were identified as potential pathways across the equatorial currents of the region (Treml et al. 2007). Population genetic studies show complex connectivity among seamounts and suggest genetically homogeneous populations of some fish species on seamount chains within ocean basins (Miller et al. 2010).

Conserving connectivity requires identifying, maintaining and possibly enhancing linkages between suitable habitat in the ocean and area-based planning can play a fundamental role in achieving this. Area-based planning could provide the framework to manage habitats throughout the water column such as coral reefs and mangroves; transient features such as upwellings, and deep sea habitats such as seamounts.

ANTHROPOGENIC IMPACTS AND CONNECTIVITY RELEVANCE

The waters within ABNJ experience a vast array of anthropogenic impacts, both direct and indirect. Three specific types of impacts are explored below as illustrative examples: invasive species, plastic pollution and climate change. It is important to note that these are not exhaustive and anthropogenic impacts should be a key area for consideration within any planning exercise.

INVASIVE SPECIES

Increased global trade and trade routes, as well as climate change, habitat conversion and a highly mobile fishing industry play a role in connectivity and transporting marine organisms in the oceans. Such factors can transport non-indigenous species (NIS) outside their natural environment, and if the organisms find adequate conditions to survive, reproduce, and spread, they can cause widespread harm to biodiversity and human livelihoods. Shipping is the main source of invasive marine species introductions (ibid). Ballast waters have often been transported over thousands of miles from their origin before they are discharged, potentially containing millions of microscopic organisms and larvae (Miller et al. 2011). This transplantation allows exotic species to be introduced into both pelagic and coastal habitats. Ship hulls and anchors provide a substrate for many sessile and mobile marine species which can thus also be transported over extensive distances (Schultz et al. 2011). Additionally, man-made structures such as coastal protections and artificial reefs are known to favor small-scale spread of NIS (Glasby et al., 2007). These structures can serve as stepping stones for sessile organisms, especially early successional species, which can then invade further.

While no single legislation addresses marine invasions directly, several are of relevance. UNCLOS Article 196 requires states to cooperate to prevent, reduce and control the pollution of the marine environment - including the introduction of NIS. The Conventions on Migratory Species (CMS) and on Biological Diversity (CBD) require states to address and protect their diversity. Additionally, the International Maritime Organization (IMO) has taken steps to reduce introductions through ballast waters through the 1991 adoption of international guidelines for preventing the introduction of unwanted organisms and pathogens from ship ballast water (Resolution MEPC.50 (31)[9]). This resulted in the adoption of the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention) in 2004 (IMO, 2004[10]) which requires ships to implement a ballast water management plan. The treaty, as of February 2016, was ratified by 47 States, representing less than 35% of the world's tonnage, and entered into force in September 2017[11]. The treaty

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[9] http://www.imo.org/en/KnowledgeCentre/IndexofIMOResolutions/Marine-Environment-Protection-Committee-(MEPC)/Documents/MEPC.50(31).pdf

[10] http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Control-and-Management-of-Ships'-Ballast-Water-and-Sediments-(BWM).aspx

[11] http://www.imo.org/en/OurWork/Environment/BallastWaterManagement/Pages/Default.aspx

does not extend to leisure vessels which is another issue. Biofouling is another issue, where living organisms attach themselves to the hull of a ship, and are transported across oceans. Biofouling control can be a double-edged sword: Tributyl tin (TBT) coating of hulls has been traditionally used to prevent biofouling. However, TBT is toxic to all marine organisms and in 2008 the IMO decided on a complete ban of its application. In 2011, the IMO prepared guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species (Resolution MEPC.207 (62)[12]).

PLASTIC POLLUTION

It is important to note that whilst passive connectivity and movement via ocean currents aids the distribution of key biodiversity, such as larval or planktonic dispersal, connectivity also encompasses the transport and distribution of anthropogenic impacts, such as pollutants (Dunn et al. 2017). Plastics are ubiquitous within the marine environment and have been recorded at depths greater than 6000m (Chiba et al. 2018) and found in seawater and sediments (Ng and Obbard, 2006;), in open-ocean and shoreline stranding (Barnes, 2002). Plastic pollution accounts for 60-80% of marine litter (Moore, 2008) and has a significant impact on biodiversity. More than 260 species of marine organisms, including large migratory species, are known to have been affected by plastic debris (Moore, 2008). Movements of plastics within the marine environment has been recorded to affect species dispersal, with an estimated doubling of the opportunities for organisms to disperse in the tropics (Barnes, 2002). Furthermore, species such as dinoflagellate algae (Maso et al. 2003) and iguanas (Censky et al. 1998) have been observed rafting on rubbish in the Atlantic.

CLIMATE CHANGE

There are known implications for changes to environment properties to migration patterns. For example, Burrows et al. (2014) investigated the direct and indirect effects of climate change on migratory species. This study examined changes to temperature, rising sea levels, changes in ocean currents, decrease in sea-ice cover, changes in salinity, amongst others. It concluded that *"the greatest threat to marine mammals probably comes from changes in their food resources as a result of climate change"* and called for management measures to take into account changes of species ranges. There are also known links between larval connectivity and changes to environmental properties, such as ocean temperature. Recent studies have shown that larval connectivity is likely to be significantly reduced due to potential reductions in life expectancy during the planktonic larval stage which is associated with ocean warming (Kleypas et al. 2016; Alzarez-Romero et al. 2017). Consequently, area-based planning will need to take such changes to physical processes and environmental properties into account.

[12] http://www.imo.org/en/OurWork/Environment/Biofouling/Documents/RESOLUTION%20MEPC.207[62].pdf

POLICY RELEVANCE

Ocean currents and processes and the movement of species and organic material, including from the deep waters to the surface, provide connectivity in the marine environment. In addition, some deep water areas are unique because of the low levels of connectivity experienced by these environments. Such local, regional and global ecological and environmental processes have links to policy making processes. This section details why connectivity is relevant to policy making processes.

The natural environment provides us with many resources, which are dependent on the functioning ecosystems, which in turn is dependent on connectivity. The resources found within the marine environment are beneficial for our economy and society. A global recognition of the value of ecosystems is through the Sustainable Development Goals, and in particular, Goal 14 on Life Below Water. Healthy ecosystems, sustainable use and the importance of sustainable fisheries all feature in the Targets associated with this Goal[13]. One clear example of this is both the economic value of fisheries sector, and its provision of fish as a nutritional food. Of relevance to the connectivity question, many species of fish are migratory, and are of nutritional and economic value. Oil-rich fish such as salmon are an important source of micro-nutrients; cod, sardines, and mackerel likewise have nutritional and economic importance. Tuna fisheries are extremely valuable. At a policy level, the value economically of the species and the support they provide to the fishing industry, is therefore dependent on connectivity. It is also dependent on transboundary considerations in relation to management as has been recognized by the fact that UNCLOS has an implementing agreement focused on highly migratory fish stocks[14].

Fishing is not the only economic activity which benefits from a healthy connected ocean. The movement of organisms can be a very visible form of connectivity. Many species of seabirds, sea turtles, whales and other marine mammals, and fish are visible at the coastline but also travel many miles between countries and out into ABNJ. These visible charismatic species are important for the tourism industry, another economically valuable activity. For example whale watching is often a key attraction for visitors to some countries. It is estimated that whale watching provides an annual global income of over $1 billion per year, and occurs in over 119 countries (O'Connor et al. 2009). Consideration of the importance of whales, and other charismatic species, to planning processes would provide benefits if securing long term sustainability of these species and the industries that they support.

In addition to the economic value of fisheries and tourism, cultural connections to the environment can be very important for society, and can be considered an enabler of sustainable development[15]. Although, from a cultural perspective the value of ABNJ is often not recognized. However, making the link between the species that are culturally important, and the lifecycles of these species which takes them into ABNJ, brings into focus the relevance of these distant marine areas for coastal communities. Indigenous People and

[13] https://sustainabledevelopment.un.org/sdg14
[14] http://www.un.org/depts/los/convention_agreements/convention_overview_fish_stocks.htm
[15] http://www.un.org/millenniumgoals/pdf/Think%20Pieces/2_culture.pdf

local communities can be reliant on migratory species for identity and other needs such as nutrition. They can be negatively affected if these species decline (Dunn et al. 2017). Whales, albatross, turtles and species of fish can be found in many parts of the world, crossing the divides between nations and navigating entire ocean basins as part of their lifecycles. They provide a "'living thread" crossing the earth (UNEP/CMS/ Conf.10.22/Rev.1[16]). For example, in the Pacific, sea turtles have been part of the cultural fabric of society for hundreds of years and have a religious significance or some groups (Rudrud, 2010). Whales feature in many legends and are sometimes seen as spiritual guardians on voyages and symbols of wealth for the Maori of New Zealand. An important example of a cultural dependence is the reliance on salmon for some North American indigenous peoples: this fish is a key subsistence food and cultural systems developed around it over hundreds of years in order to sustainably manage the harvest (Ames, 2003). The large–ranging migratory routes of albatross mean the species have strong connections within coastal communities in both the northern and southern hemisphere, serving as sources of food, raw material for tools and clothing as well as significance within religious activities (Beckwith, 1940; Rogers, 2017; Ginsberg, 2018). These and many other species are migratory and at various stages in the life cycle will cross national borders and travel through ABNJ. The importance of Indigenous Knowledge, and links with the environment, was recognized through the CBD in article 8j. This article gives nations the responsibility, as far as possible, to "*respect, preserve and maintain knowledge, innovations and practices of indigenous and local communities*"[17].

Connectivity is not just about the positive benefits that species which travel vast distances provide us with when they reach our shores. The marine environment is also under threat from our activities, such as plastic pollution which has reached the deep ocean. It is important to consider connectivity in terms of policy needs to mitigate anthropogenic impacts. The Secretariat for the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities, hosted by UN Environment[18], has been working since 2012 to address the issue of land-based sources of marine pollution on an international scale. Global movements such as the CleanSeas campaign[19] and commitments by governments, businesses and civil society organizations to beat pollution[20] have actively encouraged engagement, supporting calls to combine legislation with enhanced ecological consciousness through education (Derraik, 2002). With an estimated 80% of marine pollution originates from land, action to address land-based sources of pollution has advantageous effects on the marine environment, supporting the need for integrated efforts with multi-stakeholder partnerships.

In an example of where lack of connectivity is a key feature, some deep water species are unique and potentially provide materials that could be of use for medical research (e.g. O'Hanlon, 2005; Haefner, 2003). Species that live in extreme environments, such as around deep water hydrothermal vents, have been found to have novel life history patterns and

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[16] http://www.cms.int/sites/default/files/document/Doc_22rev_Updated%20Strategic_Plan_2006_2014_e.pdf
[17] https://www.cbd.int/convention/articles/default.shtml?a=cbd-08
[18] https://www.unenvironment.org/explore-topics/oceans-seas/what-we-do/addressing-land-based-pollution
[19] http://www.cleanseas.org/
[20] http://web.unep.org/environmentassembly/act-now

unique mechanisms for gaining food. Their isolation, and ability to live in these difficult environments, gives them potential to have novel genes and therefore hold the possibility for new scientific solutions.

In the examples above, the potential to receive benefits from species which transit between different jurisdictions depends on not just one nation. Planning for lifecycles and movements and the connectivity across many jurisdictions, including ABNJ, is becoming increasingly relevant as the marine environment and biodiversity come under greater threat. In order to benefit from important species, those species must be sustainably managed both within nations' waters, and in the waters they travel through. Not only that, but function ecosystems are also often dependent on these species. In addition, anthropogenic impacts have reached the deepest ocean trenches and climate change could have severe impacts on the deep seas, demonstrating that connections to our actions still occur, despite some of these ecosystems being isolated and unique. Therefore connectivity and planning of ABNJ is increasingly relevant to economic, social and environmental benefits received by people at the coast. Our collective responsibilities for the health of the marine environment as a whole is also important.

NEXT STEPS

There are a number of topics that this review has highlighted as potentially useful to take forward. As part of the ABNJ deep seas project the following items will be evaluated for relevance to the project, and some will be selected for further research. These have been broken down into specific case studies and assessments that would be useful in order to better understand area based planning in ABNJ.

Case studies focused on the following areas:

- Analysis of economic value of selected transboundary species to the pilot regions. For example, where there are chains of seamounts and associated biodiversity which cross the EEZ boundary into ABNJ within pilot region(s), there may be relevance for connectivity across the boundary, and also between deep and surface waters, related to planning processes;
- Review of existing information on deep sea processes, connectivity and isolation. Considerations of structural, functional and genetic connectivity will be given where possible. Identify the gaps in knowledge, and how these deep sea areas are important to us;
- Identify how primary productivity and oceanographic processes of regional significance in the pilot regions; and
- Identification of culturally relevant species in both pilot regions which spend a significant portion of their lifecycle in ABNJ, with particular emphasis on deep sea species.

Assessments relevant to spatial planning processes:

- Assessment on how connectivity can be incorporated into spatial planning approaches in ABNJ using pilot regions; and
- Regional analyses of climate trajectories and potential impacts on connectivity across ocean regions.

SUMMARY

The ocean provides human societies with a wealth of valuable and diverse goods and services of significant economic, social and cultural importance. Threats from human activities and effects of climate change have the potential to fundamentally reorganize marine communities leading to an increasing need for better and more integrated planning of the marine environment and resources. Such efforts, however, come with significant challenges given that planning of the seas is based on administrative and jurisdictional delineations, while ecological processes do not respect such boundaries. It is important, therefore, to account for connectivity within marine planning processes, including those that may take place in areas beyond national jurisdiction (ABNJ).

This document provides an introduction to connectivity in the marine environment from a spatial planning context, whilst discussing the relevance to areas beyond national jurisdiction (ABNJ). Many species which transit through ABNJ, or spend significant portions of their lifecycle there, also have economic and cultural relevance to coastal states. The potential to receive benefits from species which transit between different jurisdictions requires transnational coordination, including considerations for ABNJ. The deep sea is currently being impacted by anthropogenic activities illustrated through the discovery of single use plastics in the deepest ocean trenches. Connectivity therefore has significant importance within policy making processes. Area based planning can help provide solutions to some management challenges. Identification of how planning on a regional scale in ABNJ could be undertaken is one possible solution to be explored. Considerations within spatial planning are given to contextual factors of connectivity such as depth, hydrographic barriers and species ecology and institutional context such as mandate. In addition, international conventions potentially have a significant role to play. Next steps in the ABNJ Deep Seas project are to explore some of these aspects, with a specific focus on the deep sea, and identify if area-based planning in ABNJ can provide some of the solutions.

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ABNJ DEEP SEAS PROJECT

The Sustainable Fisheries Management and Biodiversity Conservation of Deep Sea Living Resources in Areas Beyond National Jurisdiction Project (ABNJ Deep Seas Project for short) is a five year project supported by the Global Environment Facility, and implemented jointly by the Food and Agriculture Organization of the United Nations, and the United Nations Environment Programme. The UNEP project component is executed though the UNEP World Conservation and Monitoring Centre.

The Project is designed to enhance sustainability in the use of deep-sea living resources and biodiversity conservation in the ABNJ through the systematic application of an ecosystem approach. It brings together over 20 partners who work on deep-sea fisheries and conservation issues in the ABNJ globally. The partnership includes regional organizations responsible for the management of deep-sea fisheries, Regional Seas Programmes, the fishing industry and international organizations.

The Project aims to:

- Strengthen policy and legal frameworks for sustainable fisheries and biodiversity conservation in the ABNJ deep seas;
- Reduce adverse impacts on VMEs and enhanced conservation and management of components of EBSAs; and
- Improve planning and adaptive management for deep sea fisheries in ABNJ; and develop and test methods for area-based planning.

The ABNJ Deep Seas Project started in September 2015 and is one of four projects under the **GEF Common Oceans Programme**.

More information is available from **www.commonoceans.org**