DOSI
DEEP-OCEAN STEWARDSHIP INITIATIVE

POLICY BRIEF
FEBRUARY 2020

Ecological Connectivity:
Implications for Ocean Governance

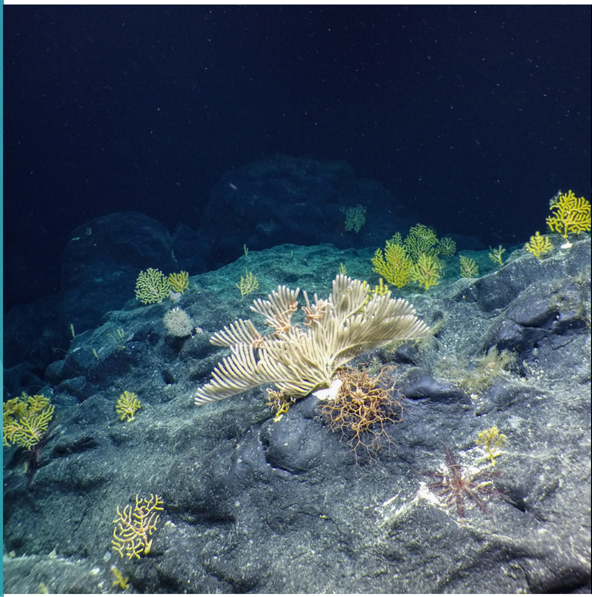

Fig 1 *A mixed invertebrate assemblage on Jarvis Seamount #2 (central Pacific) at 1463m.*
Photo credit: Ocean Exploration Trust.

Fig 2 *The only pelagic shrimp known to inhabit the Canada Basin – Beaufort Sea, Alaska.*
Photo credit: Hidden Ocean

The ocean is dynamic and interconnected, from the surface to the seafloor and from the coasts to the high seas. This connectivity plays a critical role in healthy ocean functions. Connectivity can be measured or estimated in different ways and is an important consideration for the design and implementation of area-based management tools, environmental impact assessments and strategic environmental assessments.

Ocean policy practitioners utilize various area-based management tools to support conservation and sustainable ocean use. Increasingly, practitioners recognize that **linking the use of such tools across habitats or regions can help achieve conservation goals for a given location or species.** Protecting ecological connectivity (including the movement of individuals, nutrients, and food) among conservation areas can reduce the long-term impact of human activities on the species that live there. The resultant increased resilience may provide insurance by mitigating some risks from other environmental stressors, including the longer-term effects of climate change and sudden catastrophic events, such as storm surges or oil spills. Many international agreements and corresponding commitments can provide a basis to preserve these linkages with well-connected networks of Marine Protected Areas [e.g. through the Aichi Targets or the 2030 Global Biodiversity Framework under the Convention of Biological Diversity, the emerging new international legally binding instrument for the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction under the UN Convention on the Law of the Sea, and Areas of Particular Environmental Interest (APEIs) through the International Seabed Authority].

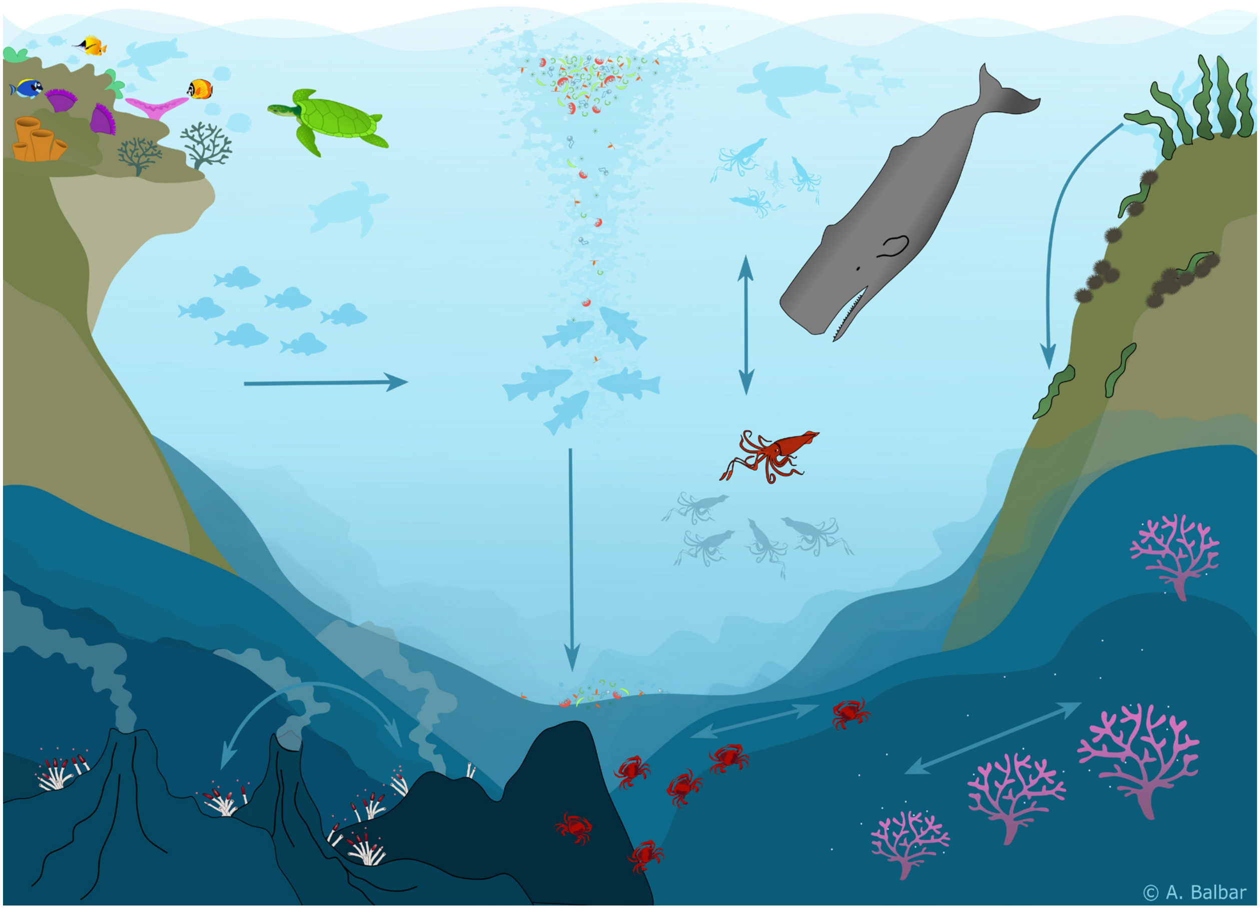

Fig 3 *The ocean is dynamic and interconnected, from the surface to the seafloor and from the coasts to the high seas through the movement of plants, animals, their propagules and their food. Arrows indicate some of these connections.*

Why is connectivity important?

Connectivity can ultimately determine the success or failure of area-based management approaches *Fig 3*. The best-intentioned policy measures may not help conserve a species or maintain ecosystem function if the only source of recruits is from adjacent, unprotected locations, which may be compromised by human pressures. Similarly, if a species in a protected area depends on food or other resources from unprotected locations, conservation efforts may falter. Therefore, careful consideration should be given to the size and spacing of a protected area, along with knowledge of whether there is a source of recruits for a species within that area. Some geographic locations represent "sources" of energy, nutrients or organisms that conservation efforts should prioritize. The identification of pathways of connectivity, including of these sources, should form a core consideration in management interventions such as individual and networks of protected areas, as well as strategic environmental assessments and environmental impacts assessments.

What is connectivity?

Connectivity describes the ecological linkages between locations and habitats, individual organisms and the resources they require. In the highly dynamic and diverse marine realm, plants and animals interact with the physical environment and with each other across scales of centimetres to thousands of kilometres, from the surface of the ocean to the seabed, and from the land-sea interface to the great ocean depths. Connectivity affects the capacity of species to migrate and maintain ecosystem function, and determines the timing, magnitude, and direction of linkages between species and their habitat. The movement of water, tracers (e.g. temperature, nutrients, pollutants) and particles (e.g. egg, larval, and adult stages of different species, or dead plants and animals) establishes, maintains and affects the connections, which may vary over time. For example, temperature, salinity and pressure can limit migration of different species in terms of both latitude and depth as a result of their tolerance to certain conditions. Human activities may further limit connectivity by interfering with the exchange of individuals between populations and the resources they rely on.

Examples of connectivity

The sinking of a plankton bloom, the resuspension of sediments during a benthic storm, or the sinking of cold water at high latitudes are examples of vertical processes which connect the surface of the ocean to the seabed that may be thousands of meters below. Ocean currents create lateral connectivity by transporting warm water from the coast to the high seas, or from low to high latitudes. Biological movements can be passive, such as in weak-swimming larval stages with their movements largely defined by dominant currents, or active, as in strong-swimming adult fish, marine mammals, turtles, and birds, many of which swim across the water basins of the high seas to the coast to spawn. There are also mass daily migrations of species which move towards the sea surface in the night-time to feed and move towards the seafloor in the daytime to avoid being eaten. These biological and physical connections play a critical role in maintaining ocean health – by recycling nutrients, regulating temperature, sequestering carbon to the deep ocean, and enabling species to be in the right place at the right time for their life cycle. Conversely, connectivity can exacerbate harmful effects caused by human activities – such as the spread of a pollutant through a food web or ecosystem or the spread of invasive species.

What are the types of connectivity?

Species are often associated with particular habitats, such as hydrothermal vents, deep-water corals, the twilight zone or productive coastal waters. Patches of similar habitats may be separated by large distances or inhospitable conditions. For example, animals from hydrothermal vents may not have the capability to disperse between two vent fields that are far apart, and animals may not be able to traverse a canyon if the concentration of oxygen is too low. Connectivity may be defined by:

- ***Structural connections*** which are measured based on distances, arrangement and conditions between patches of similar habitats of a particular species, or
- ***Functional connections*** which are measured by the movement of individuals, species, energy, or materials (e.g. larval dispersal can connect populations of a single species in geographically separated patches; food energy in the form of detritus can connect ecosystems across ocean space).

Estimating connectivity for ocean management applications

Connectivity can be measured in several ways depending on the information that is available for a region or a species. Measurements of connectivity identify different habitats and populations and the strength and direction of movement between them (e.g. what subset of a population links specific nesting and foraging areas or how will a pollutant disperse). Ways to estimate connectivity depend on the type and amount of available data (*Box 1*):

- If direct measurements of connectivity (for a particular species, habitat and location) are not available, general 'rules of thumb' can be used, e.g. define the minimum size for areas to contain self-sustaining populations and the maximum distance that individuals could disperse between different locations
- Measurements of structural or landscape connectivity can identify potential pathways of movement among patches of suitable habitats for particular species based on the distribution of these patches
- Measurements of functional connectivity can identify locations that are connected through animal movements or through the flow of energy and materials.

At present, it is difficult and expensive to measure connectivity, however, tools and approaches that are being developed will improve our capability to do so. In areas of poor data availability, such as the open ocean and the deep sea, a combination of tools and approaches should be used to estimate connectivity.

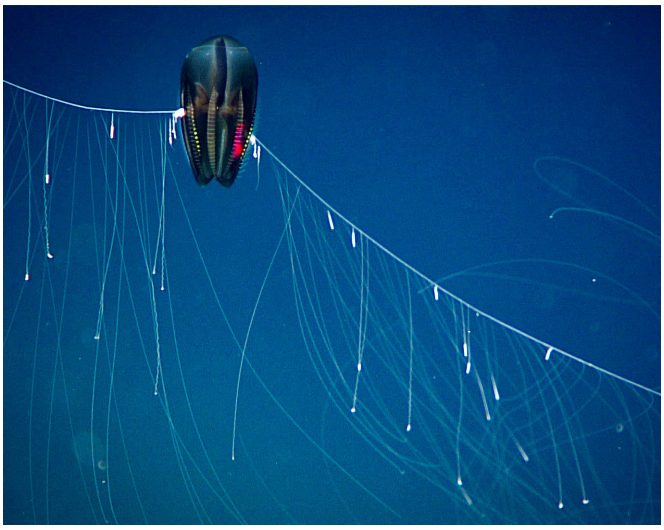

Fig 4 *Dark ctenophore observed with its tentacles fully extended at approximately 1,460m deep, Gulf of Mexico.*
Photo credit: NOAA Office of Ocean Exploration and Research

BOX 1

Options for estimating connectivity for ocean management

1) RULES OF THUMB

Management application	Science input	Data	Advantages	Shortcomings	Examples
Define minimum size for areas to contain self-sustaining populations and maximum distance that individuals could disperse between areas	Identify range of distances of movement based on an "average" species and determine whether one location can theoretically be reached from another	Timing, duration, average speed, and direction of movement of an animal or species (determined through basic knowledge of ocean currents and species biology, ecology, and swimming speed and not by direct measurements in the area of interest)	Simplest way to estimate connectivity	Often, estimates based on past studies, but lack of specificity can limit utility at a new location	Network of Areas of Particular Environmental Interest in the Clarion Clipperton Zone, a region targeted for deep seabed mining

2) STRUCTURAL (ALSO KNOWN AS LANDSCAPE) CONNECTIVITY

Management application	Science input	Data	Advantages	Shortcomings	Examples
Identify potential pathways of movement among patches of suitable habitats for particular species	Locations of patches of suitable habitat and the shortest distances between them	Map of habitats in three-dimensional space, either through direct observations or based on predictive models (e.g. habitat distribution models)	Maps are often the first data to become available from a particular location	Mapping is expensive and in need of further technological development to augment rate of data collection	Most come from terrestrial systems

3a) FUNCTIONAL CONNECTIVITY – AMONG POPULATIONS OF A SPECIES

Management application	Science input	Data	Advantages	Shortcomings	Examples
Identify locations that are connected through animal movement	Probability that an animal (and its genes) moves from a particular location or population to another (and survives to reproduce) based on (i) genetic or (ii) demographic approaches	**Genetic approaches** Genetic structure of individual animals sampled at different locations/ populations **Demographic approaches** i. Trajectories of larvae modelled as "virtual particles" following ocean currents; models combine data on ocean circulation with information about the characteristics of a species (e.g. timing of spawning, duration of travel) ii. Tracks of individuals from telemetry tags and acoustics, or more traditional mark/ recapture methods (e.g. rings around birds' legs, or whale scars); indirect measures of chemicals in the animal that describe the different environments in which an animal has lived	**Genetic approaches** Estimates actual connectivity (including survival and reproduction at new location) **Demographic approaches** i. Estimates probability that individual larvae will reach a location (i.e., potential connectivity) ii. Tracking data provide direct measurements of movement and connections	**Genetic approaches** Coarse nature of available knowledge of genetic structure of most species, and relatively high cost **Demographic approaches** i. Does not estimate the probability that an animal will actually survive and reproduce at that location (i.e. actual connectivity) ii. Expensive and difficult to tag many individuals	**Genetic approaches** Few, used in area-based management tools in coastal environments **Demographic approaches** i. Used widely to estimate "connectivity" on mid-ocean ridges, among seamounts and from coastal EEZs to the high seas ii. Migratory pathways used by Regional Fisheries Management Organizations to manage fish stocks

i. For animals that depend on passive movement such as drifting (e.g. weak swimming larvae of sedentary animals such as worms, mussels or shrimp)

ii. For animals that depend on active movement such as swimming (e.g. fishes, marine mammals, birds and reptiles)

3b) FUNCTIONAL CONNECTIVITY – AMONG ECOSYSTEMS

Management application	Science input
Identify ecosystems that are connected through the flow of energy and materials	Formalized measurements to quantify these connections are only now becoming possible

The way forward

Given its importance in maintaining healthy and resilient ecosystems, management interventions should always consider connectivity alongside other design features such as representation or replication. Protection of connectivity should help ensure the survival of a species or the functions of an ecosystem through maintaining self-recruitment, migratory pathways, feeding, spawning, mating grounds, maintaining the flow of energy and materials. Management interventions can be designed to promote connectivity even in the absence of direct measurements for a particular species.

For example, rules of thumb can help determine appropriate MPA size and spacing or protect known larval source populations. In instances where connectivity exacerbates harmful effects of human activities, understanding these connections can inform management measures, such as avoiding new pathways for invasive species (e.g. ship hulls) or using booms to limit spread of oil spills. Measuring connectivity can be useful for strategic environmental assessments environmental impact assessments and play an important role in informed decision-making. Appropriate use of connectivity in management requires clear objectives that properly align with overarching societal goals.

Additional reading

- *Balbar A, Metaxas A* (2019) The current application of ecological connectivity in the design of marine protected areas. Global Ecology and Conservation 17: e00569
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- *Gaines SD, Gaylord B, Gerber LR, Hastings A, Kinlan BP* (2007) Connecting places: the ecological consequences of dispersal in the sea. Oceanography 20: 90-99
- *Hilario A, Metaxas A, Gaudron S, Howell K, Mercier A, Mestre N, Ross R, Thurnherr A, Young C* (2015) Estimating dispersal distance in the deep sea: Challenges and applications to marine reserves. Frontiers in Marine Science 2: 6: doi:10.3389/fmars.2015.00006

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ABOUT DOSI

The Deep-Ocean Stewardship Initiative seeks to integrate science, technology, policy, law and economics to advise on ecosystem-based management of resource use in the deep ocean and strategies to maintain the integrity of deep-ocean ecosystems within and beyond national jurisdiction.

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Fig 5 *Deep-sea assemblage.*
Credit Stephen Long, Zoological Society of London, UK