UNEP-WCMC Technical Brief
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Advancing understanding of Migratory Connectivity in the Ocean (MiCO)

Illuminating a connected ocean

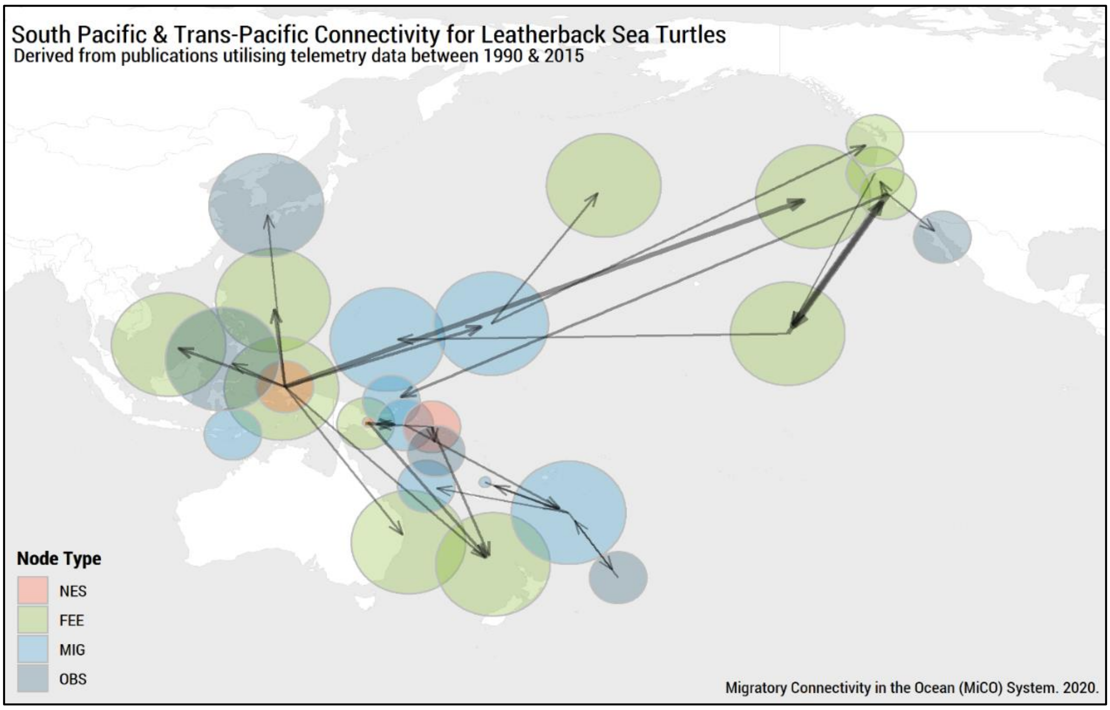

Figure 1: Leatherback sea turtles connect the Pacific through their migrations. Information garnered from the MiCO literature review illustrates north-south connectivity in the western Pacific and trans-Pacific connectivity between Australasia and western North America. Source: MiCO (2020).

Key messages

- Understanding where important areas for marine migratory species are, the routes they take between them, and when certain species are likely to be present in particular locations, is vital for companies to avoid and manage the impacts of their operations. Historically, this data hasn't been readily available in appropriate formats to help inform better corporate decision making on nature.
- The Migratory Connectivity in the Ocean (MiCO) System (mico.eco) is a state-of-the-art product that generates actionable data and information on how marine migratory species—including marine mammals, sea turtles, seabirds and fish—use and connect the ocean. MiCO provides data on the locations of critical migratory cycle stages (e.g. nesting, foraging, migrating, etc.), seasonality of occurrence, and migratory routes that connect these stages.
- With support from UNEP-WCMC and the University of Queensland, work was undertaken to demonstrate the type of products that can be generated from connectivity information in telemetry literature and tracking data to support industry screening processes, strengthen environmental impact assessments and reduce operational risks.
- This work marks an important step toward producing data to support high-level screening for areas of importance to threatened migratory and congregratory species and their key life stages and evolutionary processes – such as identifying areas of critical habitat under the International Finance Corporation's Performance Standard 6.

Introduction

For decades, environmental planning has taken place without knowledge of the distributions and seasonality of marine megafauna migrations. Industry, managers and policy-makers often rely on proxies or expert opinion to broadly describe the distribution of a species. This has drastically limited industry's ability to meaningfully and efficiently generate environmental impact assessments, estimates of operational risk, and appropriate monitoring programs that account for large-scale marine ecosystem connectivity.

One of the main impediments to accessing actionable ecological knowledge has been how it is generated and stored by scientists[1]. Academia incentivizes patents, publication in scientific journals and winning large government funded contracts/grants, rather than knowledge transfer to industry. Applied ecologists who want their knowledge to inform actions, contribute their raw data to repositories, and engage in one or two policy arenas. The knowledge generated by their research (derived from the raw data, but not contributed to repositories) ends up only being accessible by reading publications or talking to researchers directly[2]. This is an incredibly inefficient information flow that cannot meet the needs of industry or support critical conservation efforts in the 21st century.

For example, while the amount of data describing movements of migratory marine species is growing exponentially[2,3], the knowledge generated by the analysis of those data has met the same fate as so many other academic endeavours: death by inaccessibility. **To address this knowledge transfer gap, a consortium of research organisations joined together to develop a system to describe the state of knowledge of Migratory Connectivity in the Ocean (MiCO; mico.eco)[2].**

Marine migratory species matter

… and not just to ecosystems

Ocean basin-scale migrations of sea turtles, marine mammals, seabirds and fish expose them to multiple stressors and governance regimes[4]. Declines of many marine migratory species have resulted from these cumulative stressors, combined with geographical and taxonomic gaps in governance[5, 6], lack of cross-sectoral conservation tools and limited implementation of ecosystem-based approaches to management[7], as well as conservation strategies that focus on individual stages of a species' migratory cycle with little consideration of population connectivity. Many of these

Figure 2: A pair of waved albatrosses nesting in the Galapagos. *c/o D. Dunn*

species are listed as Near Threatened or Threatened (i.e. Vulnerable, Endangered or Critically Endangered) by the IUCN, including:

- 95% of albatrosses[8]
- 87% of assessed migratory sharks[9]
- 63% of sea turtle subpopulations[8]

Similarly, straddling fish stocks (those shared between two or more jurisdictions) and highly migratory fish stocks experience much higher rates of overfishing than those within a single national jurisdiction[10]. Even in the largest, most diffuse open-ocean ecosystem on the planet—the central Pacific ocean—changes in community structure due to the influence of humans have been identified[11, 12].

Migratory species and associated areas important for breeding and feeding are further recognised under the International Finance Corporation's Performance Standard 6 through criteria 3 (Migratory and/or congregatory species) and 5 (Key evolutionary processes).

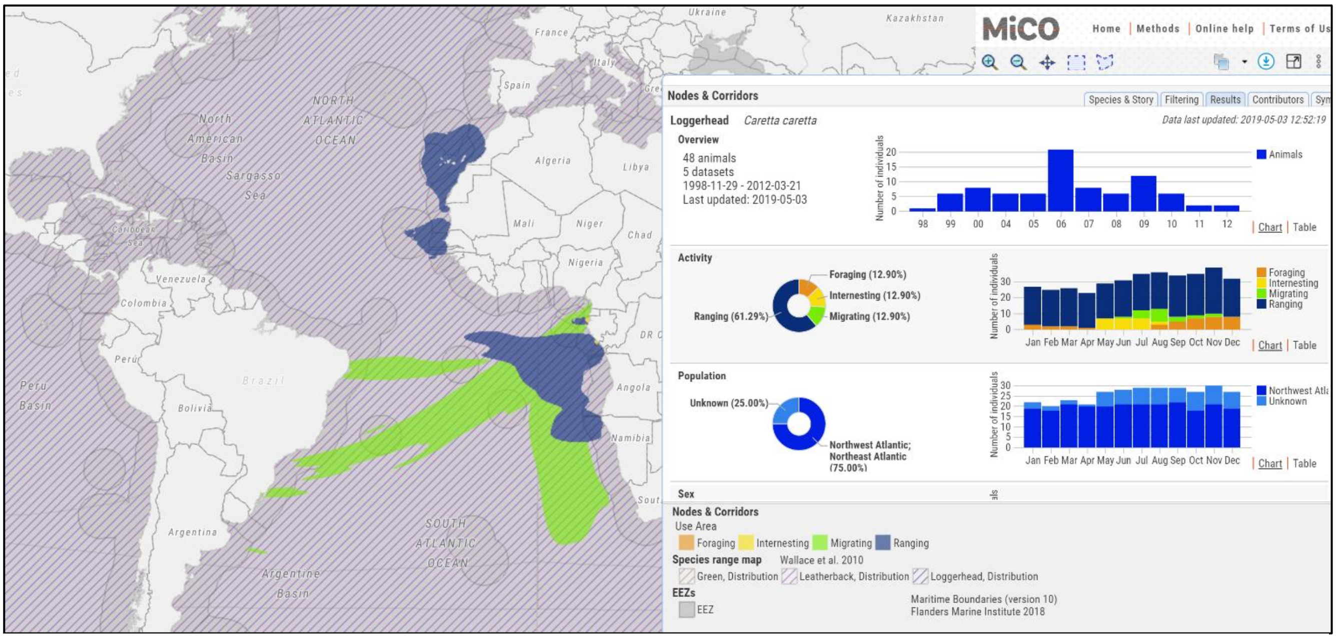

Figure 3: The MiCO System contains models describing area-use by a specific population (e.g. the leatherback sea turtles in the eastern Atlantic shown here), as well as network models as shown in Figure 1. The system transparently describes the tracking data that is used in the area-use models including information on year, month, activity type and, if known, source population and sex. Source: MiCO (2020).

Understanding how migratory species use and connect the oceans, and incorporating that information into management and governance, is crucial for their survival. Moreover, the continued existence of these species is critical to the persistence of whole ecosystems[13, 14].

Species such as blue whales, white sharks, wandering albatrosses, and leatherback sea turtles are also examples of iconic species that form the bedrock of the public's understanding of the ocean[15]. The relationship between the public and these species has generated legal mandates for their protection in many countries, and drives consumer choices. Their conservation by marine industries is a fundamental aspect of corporate licence to operate and profitability.

The MiCO System

A new way forward

Launched in April 2019 at a side event organized by UNEP-WCMC at the UN's Intergovernmental Conference on Marine Biodiversity of Areas Beyond National Jurisdiction, the MiCO System synthesises large quantities of information to generate standardised models of the locations of marine migratory species' routes, important life history stages (e.g. foraging and breeding "nodes") and seasonality of occurrence. The MiCO System represents a state-of-the-art approach to developing fit-for-purpose, actionable knowledge on marine connectivity in the ocean.

This novel approach is contributing to the work of:

- three Regional Seas Organizations
- the UN Food and Agriculture Organization
- the UN Environment Programme
- the Convention on Migratory Species
- the International Seabed Authority
- the negotiations over a new high seas treaty

MiCO has further sought to grow the prototype into a fully fledged system, and expand the user base by identifying industry partners. To this end, the University of Queensland partnered and co-funded a pilot project with UNEP-WCMC to further develop MiCO products and gauge their utility to industry through the Proteus Partnership.

This has involved taking data generated in the review of over 1,200 publications and developing a workflow to produce integrated network models that describe how migratory species connect the ocean. This information can support industry's understanding of operational risks, since impacts and liabilities in the marine realm are not static—the highly connected nature of the ocean means that impacts in one place may influence populations or processes hundreds, thousands or even tens of thousands of kilometers away. This connectivity is not just generated by ocean currents or landscape connectivity, but by migratory marine species[4].

Connecting the networks

Each paper assessed during the MiCO literature review contained information that could be used in a network model: locations of nodes related to migratory cycle stages (e.g. nesting, foraging, migrating, etc.), and connections between nodes. The resulting 27 regional network models were incorporated into single integrated models for the following 11 newly included species (full list of available species outlined in Annex 1):

- Humpback whale
- Great white shark
- Basking shark
- Shortfin mako shark
- Whale shark

Figure 4: Tuna are highly migratory and frequently have basin-wide migrations. Bluefin tuna have a very limited and geographically specific number of spawning areas, making these species vulnerable to over-exploitation and the impacts of industry in, for example, the Gulf of Mexico.

- Black marlin
- Striped marlin
- Southern bluefin tuna
- Leatherback sea turtle
- Arctic tern
- Short-tailed albatross

Area-use models were also developed for:

- Chatham albatross
- Chatham petrel

Maps, data and metadata have been made available, and these models are currently being integrated into the MiCO system.

Next steps

The network models provided describe connectivity both across and between ocean basins, and across hemispheres. They link countries and continents, and provide a strong basis for understanding the potential scope of impacts to migratory marine species.

These models represent 11 of at least 85 species for which the MiCO literature review derived connectivity information. While largely limited to telemetry studies, further information from mark-recapture, acoustic, genetic and stable isotope sampling could also be integrated into these network models to provide broader geographic and taxonomic scope, and fill critical gaps in our knowledge.

Discussions have begun on how to format these products to make them more easily accessible for wider use and programmatic access into industry planning processes. These options are discussed in the inset box on the next page.

Accessing MiCO Products

Actionable knowledge requires an iterative process where industry provides feedback to support the development of products that can feed seamlessly into their workflows.

Various options exist for formatting and delivering MiCO products to inform industry processes. The most basic option is delivery of maps, either interactively through the online system or as static maps downloaded from the system. The MiCO System is the easiest way to quickly visualize and describe the wealth of information being aggregated for a given species, yet such maps are of limited utility to quantiative analysis.

The most widely accepted format for including spatial information on the movements or distributions of species is the ESRI shapefile, or an open-source alternative. The MiCO System allows download of user-generated maps as PDFs, and all area-use models on the website as polygon shapefiles with the appropriate metadata embedded in the shapefile. These products are made available for free, though information about how they are being used is requested upon download to feedback to data contributors and track impact.

While polygon and polyline shapefiles are a feasible output for the network models in the system, they lack the "routing" information that describes the flow of animals and allows for quantitative analysis of the network. Other ESRI file formats are being investigated to identify the industry-standard for communicating relational data described as a network. Internally, MiCO uses R scripts to generate network model objects and those scripts will be made freely available through GitHub to quickly regenerate the network models from data files (two CSV files—one describing the nodes and values associated with each site, and the other laying out the connections between nodes). While these network objects in R would allow for more in-depth analysis of potential related effects between nodes, R is less commonly used by industry analysts.

While downloads of maps or shapefiles are currently done manually via the website, development of programmatic access to MiCO products through an API or web services is being explored to increase the utility of the system.

Conclusions

Access to useful and query-able information in formats that are interoperable with local processes is a shared need of industry, managers and policy-makers across many thematic areas. If environmental outcomes are to be improved and risks to both the environment and industry operations reduced, then access to ecological information must be made more efficient.

Marine migratory species connect the world and can carry the impacts of activities in one location to other distant ecosystems. This has specific implications for how operational risks for activities that may impact migratory species should be evaluated, and for how environmental impact assessments are undertaken.

The MiCO system seeks to provide efficient access to actionable knowledge on how marine migratory species use and connect the world. This work provides evidence of how information in the literature can be integrated into network models that describe connectivity across regions, with implications for planning processes that account for a full understanding of direct and indirect operational and environmental risks. Further efforts are still necessary to ensure that this type of information is not just efficiently stored (i.e. the information from dozens of scientific studies being incorporated into a single network model), but also efficiently delivered in automated, useful formats for industry and other decision-makers.

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Annex 1: Network and Area-Use Models

To illustrate the type of connectivity uncovered by the literature review undertaken by MiCO, this annex depicts the migratory connectivity generated by one species of each of the four taxa found in the MiCO system: a seabird (arctic tern) and marine mammal (humpback whale) listed as Least Concern on the IUCN Red List, an Endangered fish (shortfin mako shark) and a Critically Endangered sea turtle (leatherback). Their journeys are discussed relative to one country (Brazil).

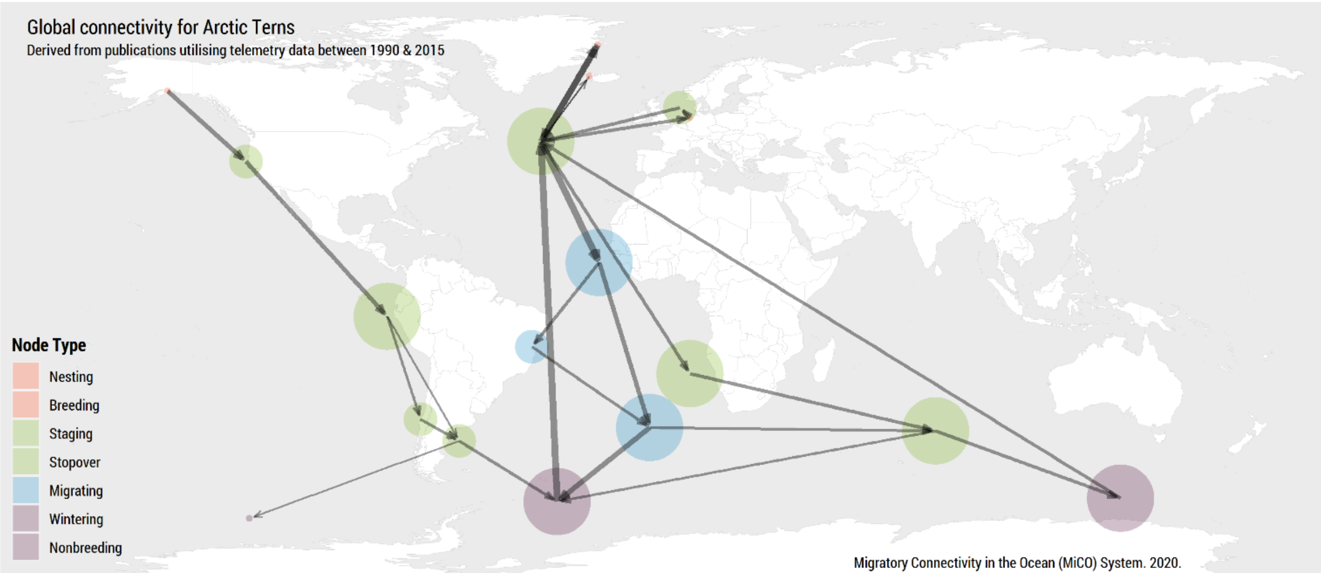

Figure 5: Arctic terns connect the globe above the Arctic Circle to Antarctica. Their immense migrations generate ecological relationships between equatorial countries like Brazil and Mauritania and polar seas. Further examples of how marine migratory species connect Brazil with the rest of the world can be found in Annex 1.

Arctic terns connect the poles in their travels from breeding grounds above the Arctic Circle to foraging grounds in the Southern Ocean (Figure 5). On their post-breeding migration route south from Iceland, arctic terns have been tracked along the coast of Brazil.

Similarly, humpback whales breeding off the central Brazilian coast migrate south to the Southern Ocean to forage (Figure 6a). However, humpback whales seen off the northern coast of Brazil have migrated down from breeding areas in the eastern Caribbean (Figure 6b). Interestingly, humpback whales on the north coast of Brazil have been observed in both the northeast and northwest Atlantic.

Shortfin mako sharks also connect the northern coast of Brazil to the central north Atlantic and mix there with migrants from northwest Atlantic (Figure 6c).

Finally, leatherback sea turtles connect the Atlantic: some populations in the eastern Caribbean migrate southeast toward the central Atlantic passing the northern coast of Brazil, while the southern Brazil population migrates east or northeast to the coast of Africa or the central Atlantic (Figure 6d). Populations from the west coast of Africa also migrate west into the central Atlantic and to the south coast of Brazil.

The connectivity demonstrated by these four species is a small insight into how connected a single exclusive economic zone (here, Brazil) is to other parts of not just the South Atlantic but to the north Atlantic Ocean and polar seas. Other species tie this region to the Pacific and Indian Oceans. This massive, cross-taxa connectivity strongly ties the fate of these populations to their conservation in very disparate places, and to our ability to understand and mitigate cumulative impacts across their migratory cycles. Incorporation of migratory connectivity into environmental impact assessments, strategic environmental planning, risk assessment and siting are critical to the conservation of these iconic species.

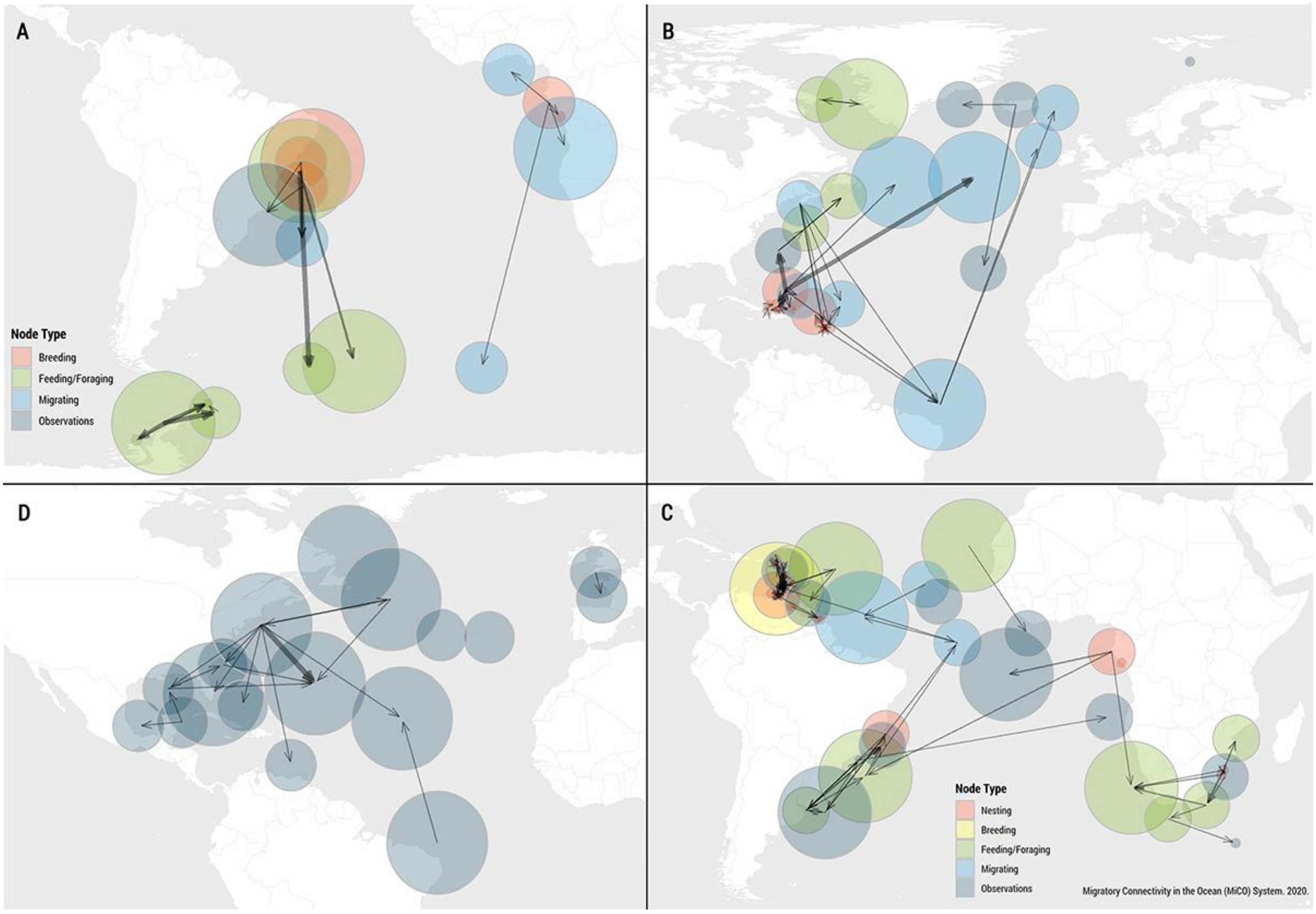

Figure 6: The migrations of humpback whales (a & b), shortfin mako sharks (c) and leatherback sea turtles (d) connect the coast of Brazil to activities and impact throughout the North and South Atlantic and the polar seas.

Network Models Delivered

Mammals

- Humpback whales
    1. Caribbean & North Atlantic
    2. Eastern Pacific
    3. Indian Ocean
    4. North Pacific
    5. South Atlantic
    6. South Pacific

Fish

- Great White Shark
    7. Indian Ocean & the South Pacific
    8. North Pacific
- Basking Shark
    9. Caribbean & North Atlantic
- Black marlin
    10. Australia/SE Asia
- Shortfin mako shark
    11. Global
    12. Caribbean & North Atlantic
    13. South Pacific
- Striped marlin
    14. North Pacific
    15. South Pacific
- Whale shark
    16. Global
    17. Caribbean & N. Atlantic
    18. Eastern & Trans-Pacific
    19. Indian Ocean
- Southern bluefin tuna
    20. Southern Ocean

Sea turtles

- Leatherback
    21. Caribbean & North Atlantic
        i. Inter-Caribbean (zoomed-in)
    22. Eastern Pacific
    23. Indian Ocean
    24. South Atlantic
    25. South & Trans-Pacific

Seabirds

- Arctic Tern
    26. Global
- Short-tailed Albatross
    27. North Pacific

Area-Use Models Delivered

- Chatham albatross
- Chatham petrel

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