Data Report:
Produced as a background document for the Workshop on the Regional Environmental Management Plan for the Area of the Northwest Pacific Ocean, with a focus on management assessment

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18 – 21 May 2026

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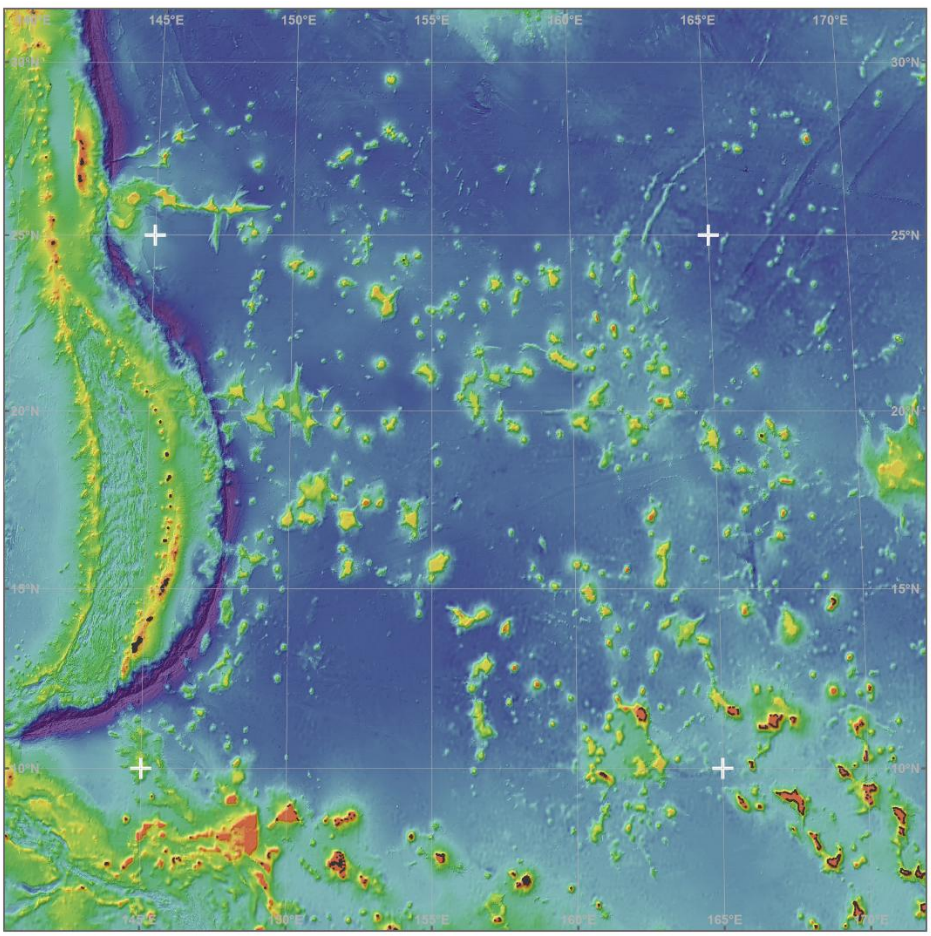

The preparation of this report was financially supported through the commissioning of a consultancy by the ISA secretariat.

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Citation:
DeLand, S., J. Cleary, E. Menini, P.N. Halpin (2026) "Data Report: Workshop on the Regional Environmental Management Plan for the Area of the Northwestern Pacific, with a focus on management assessment", 170 pp.

Maps
Digital versions of individual maps herein are also available online at
https://duke.box.com/s/s4bmkjk4aq3yp9i8d1qf6x8w7a5tnx4y

Table of Contents

Figures

1 Context

The Marine Geospatial Ecology Lab at Duke University was contracted to provide data discovery and mapping support for experts attending the “Workshop on the Regional Environmental Management Plan for the Area of the Northwest Pacific Ocean, with a focus on management assessment” (Busan, Republic of Korea, from 18 - 21 May 2026). This workshop is convened by the International Seabed Authority Secretariat in collaboration with the Ministry of Oceans and Fisheries of the Republic of Korea and the Korea Institute of Ocean Science and Technology. The preparation of this report was financially supported through the commissioning of a consultancy by the ISA secretariat. This data report provides minor updates to the version that was produced for a workshop in February of 2024 in Tokyo, Japan, for the same area of interest. These updates focus on ensuring the most recent versions of management areas are being reflected in mapping, including Exclusive Economic Zones, Extended Continental Shelf Submissions, and ISA contract areas.

As part of this support, a large number of datasets and analyses pertaining to the region of ISA interest the Area of the Northwest Pacific have been collected and mapped. These datasets and supporting references have been compiled into this data report, an annotated catalog of available spatial data and selected publications to brief workshop participants and aid with data discovery.

The datasets described herein will be available during the workshop supported by live GIS and mapping capabilities. Workshop participants will be able to request simple map overlays and analyses be performed during the workshop that will aid in their discussions. The results of the mapping work performed at the workshop will be included in the subsequent ISA Workshop Report.

1.1 Geographical area to be addressed in this report

For the purposes of this data report on the Area of the Northwest Pacific, data were collected or generated for areas between 40°N and 1°N and 132°E to 179°E. The area to be included in the draft REMP will be discussed in the ISA workshop and will not necessarily coincide with the area covered by this data report. This map is illustrative only and does not delineate the boundaries of the REMP or of any management measures established by the ISA.

EEZ Data Source - VLIZ v12, http://www.marineregions.org/eez.php
ECS Data Source – VLIZ v2, https://doi.org/10.14284/697

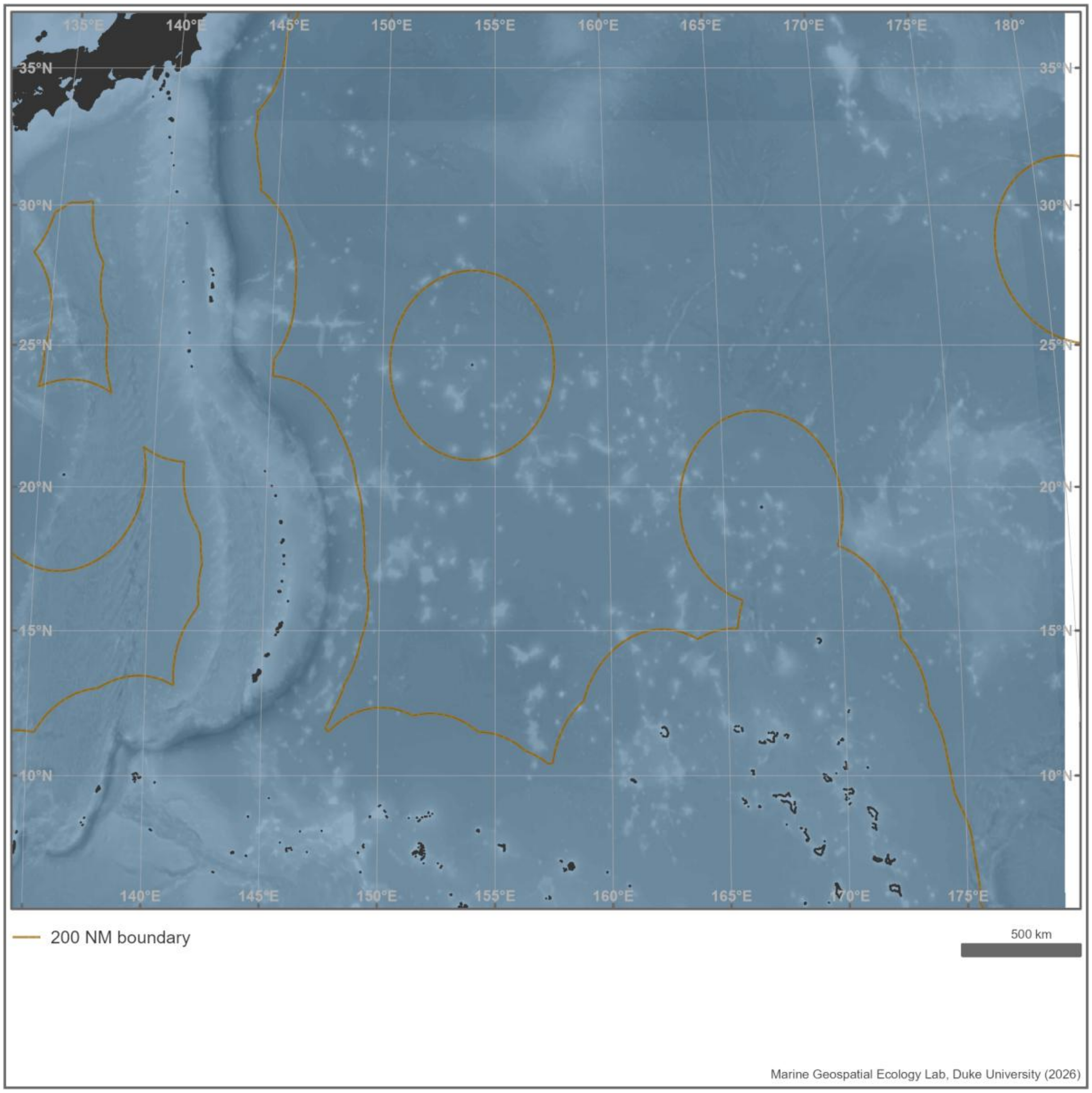


Figure 1.1-1 Data collection scope and boundary context

2 Environmental Data

2.1 GEBCO Bathymetry

GEBCO's gridded bathymetric data set, the GEBCO_2023 grid, is a global terrain model for ocean and land at 15 arc-second intervals. The GEBCO_2023 Grid is the latest global bathymetric product released by the General Bathymetric Chart of the Oceans (GEBCO) and has been developed through the Nippon Foundation-GEBCO Seabed 2030 Project.

The complete GEBCO_2023 data set provides global coverage, spanning 89° 59' 52.5''N, 179° 59' 52.5''W to 89° 59' 52.5''S, 179° 59' 52.5''E on a 15 arc-second geographic latitude and longitude grid. It consists of 43200 rows x 86400 columns, giving 3,732,480,000 data points. The data values are pixel-centre registered i.e. they refer to elevations, in meters, at the centre of grid cells.

Source:
https://www.gebco.net/data_and_products/gridded_bathymetry_data/gebco_2023/

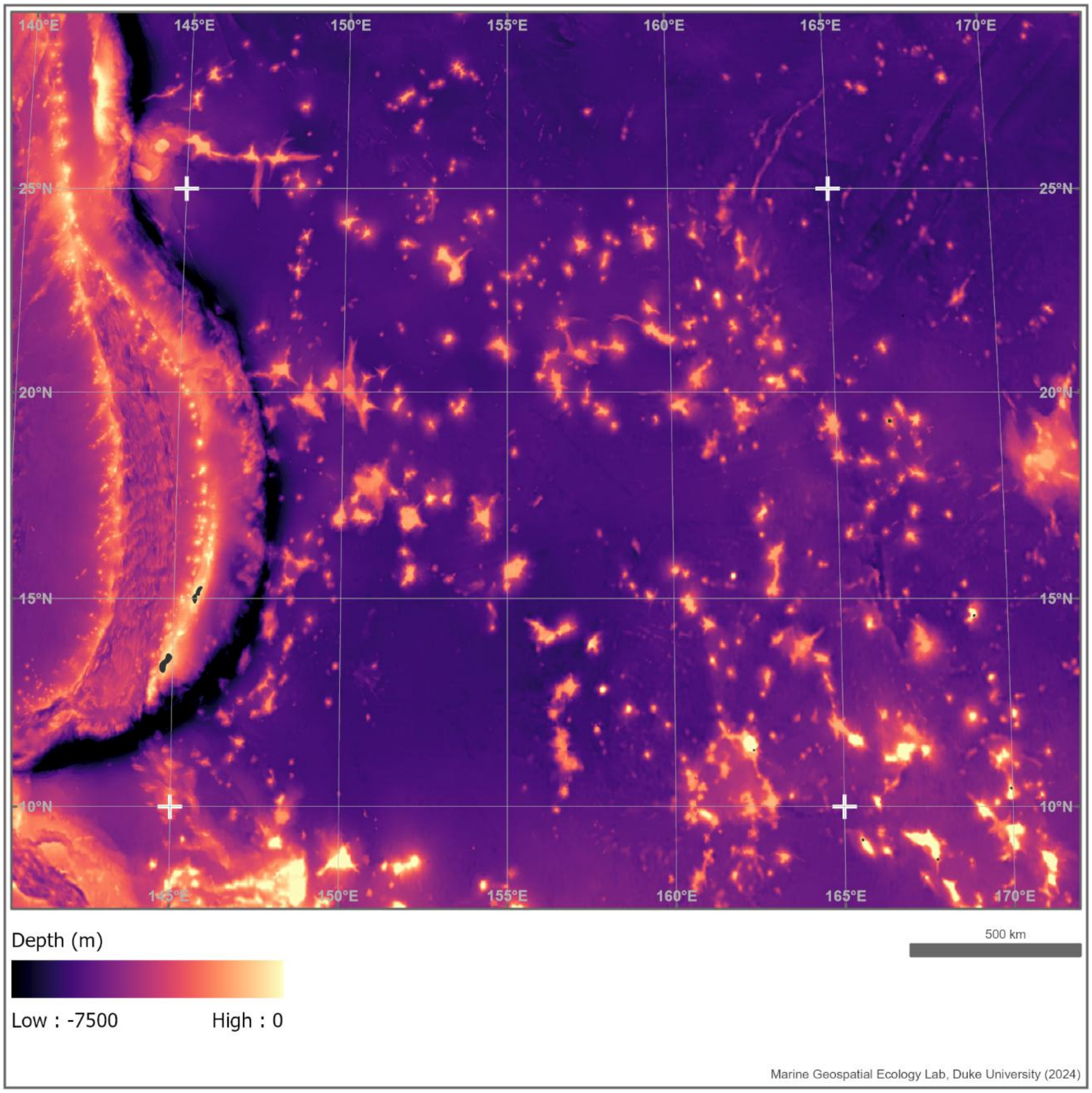


Figure 2.1-1 GEBCO Bathymetry

2.2 Benthic Terrain Model

During the previous northwest Pacific REMP workshop, a benthic terrain characterization was performed to help workshop attendees assess the coverage of large benthic features , such as seamounts and guyots, within exploration areas, workshop described areas, and the broader workshop region. This analysis was performed using the ESRI Benthic Terrain Modeler (BTM, Walbridge et al. 2018). The terrain forms from the BTM analysis were aggregated at two levels for workshop attendees to review. A broad aggregation included the crest, upper-slope, mid-slope and lower-slope terrain forms. A narrow aggregation included the crest and upper-slope terrain forms. Attendees reviewed both the broad aggregation and the narrow aggregation during the description of areas. The statistics below represent area and coverage calculations for the narrow aggregation of benthic terrain forms. These results from the BTM tool were filtered to focus on large features with areas greater than 50km^2.

Subsequent GIS geoprocessing was used to summarize the identified features within several zones of interest. Three levels of spatial overlap were mapped and summarized:

1. Large benthic features within workshop described areas
2. Large benthic features within CFC lease and exploration areas
3. Large benthic features that did not overlap with CFC areas or workshop described areas

An additional summary of depth zone representation within exploration areas, workshop described areas, and the broader workshop region was also performed. Depth was calculated using the GEBCO 2019 bathymetry dataset (GEBCO Compilation Group 2019). For this analysis, area calculations were performed using the Mollweide projection, with the central meridian set to 155 E longitude. Area calculations were made using 2D GIS features.

Walbridge, S.; Slocum, N.; Pobuda, M.; Wright, D.J. (2018) Unified Geomorphological Analysis Workflows with Benthic Terrain Modeler. Geosciences 8, 94. doi:10.3390/geosciences8030094

GEBCO Compilation Group (2019) GEBCO 2019 Grid (doi:10.5285/836f016a-33be-6ddc-e053-6c86abc0788e)

For more information on how this dataset was developed and applied during the 2020 REMP workshop, see Annex V of the Northwest Pacific REMP Report: https://www.isa.org.jm/wp-content/uploads/2022/10/NWP_REMP_workshop_report.pdf

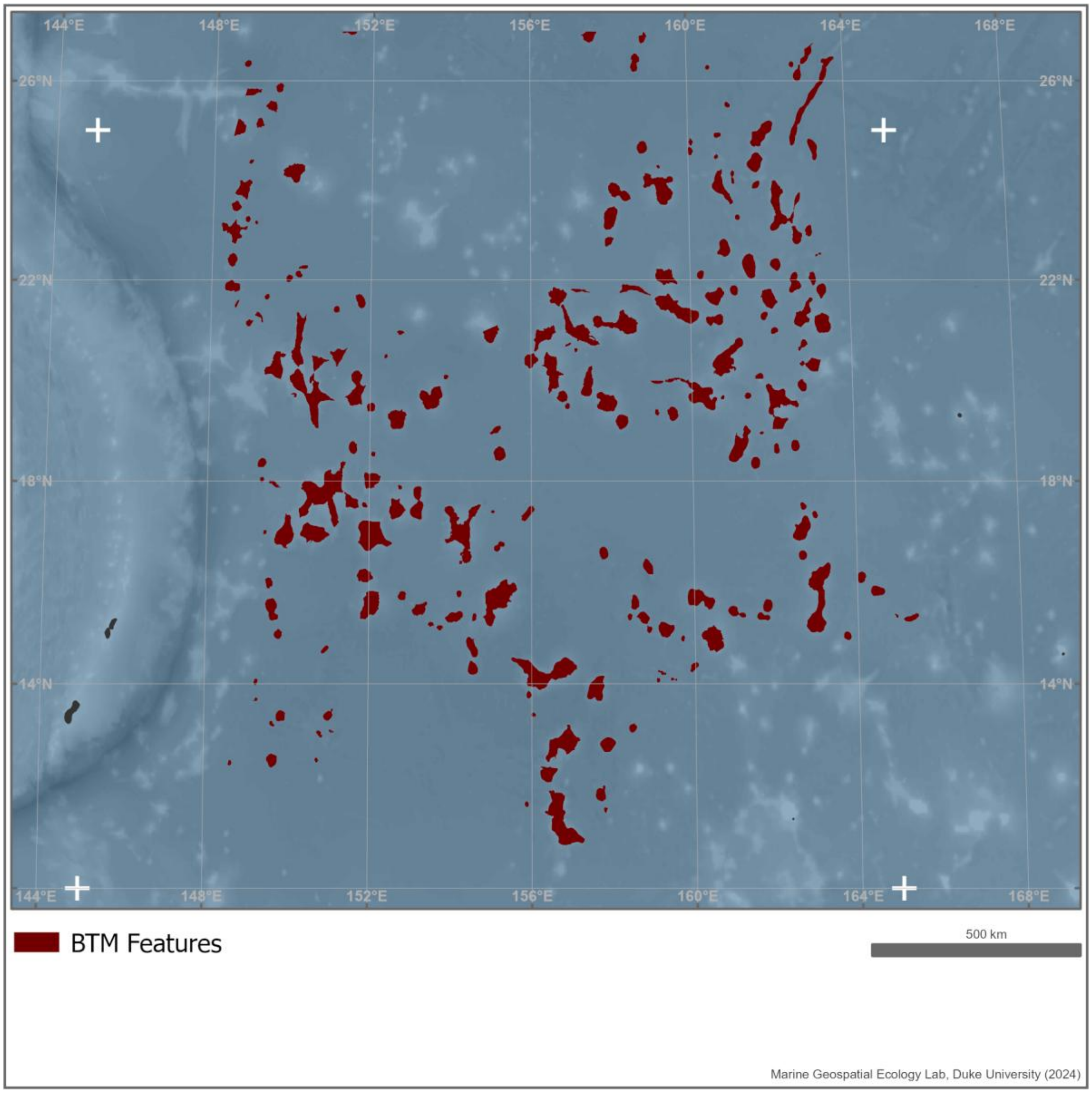


Figure 2.2-1 Features identified using benthic terrain modelling during the 2020 REMP workshop

2.3 Geomorphon Landforms

Abstract (Jasiewicz & Stepinski 2013):
"We introduce a novel method for classification and mapping of landform elements from a DEM based on the principle of pattern recognition rather than differential geometry. At the core of the method is the concept of geomorphon (geomorphologic phonotypes) — a simple ternary pattern that serves as an archetype of a particular terrain morphology. A finite number of 498 geomorphons constitute a comprehensive and exhaustive set of all possible morphological terrain types including standard elements of landscape, as well as unfamiliar forms rarely found in natural terrestrial surfaces. A single scan of a DEM assigns an appropriate geomorphon to every cell in the raster using a procedure that self-adapts to identify the most suitable spatial scale at each location. As a result, the method classifies landform elements at a range of different spatial scales with unprecedented computational efficiency. A general purpose geomorphometric map — an interpreted map of topography — is obtained by generalizing allgeomorphons to a small number of the most common landform elements. Due to the robustness and high computational efficiency of the method high resolution geomorphometric maps having continental and even global extents can be generated from giga-cell DEMs. Such maps are a valuable new resource for both manual and automated geomorphometric analyses. In order to demonstrate a practical application of this new method, a 30 m cell− 1 geomorphometric map of the entire country of Poland is generated and the features and potential usage of this map are briefly discussed. The computer implementation of the method is outlined. The code is available in the public domain."

Reference:
Jasiewicz, J., and Stepinski, T. F. (2013). Geomorphons — a pattern recognition approach to classification and mapping of landforms. Geomorphology 182, 147–156. doi: 10.1016/j.geomorph.2012.11.005

The landforms mapped below were generated using the Geomorphon Landforms tool in ArcGIS Pro on the 2023 GEBCO bathymetry. For more information on the tool and its use, see the information below. Alternative inputs can be used during the workshop in Tokyo and participants' discretion.
https://pro.arcgis.com/en/pro-app/3.1/tool-reference/spatial-analyst/geomorphon-landforms.htm
https://www.esri.com/arcgis-blog/products/spatial-analyst/analytics/classify-terrain-with-the-new-geomorphon-landforms-tool/

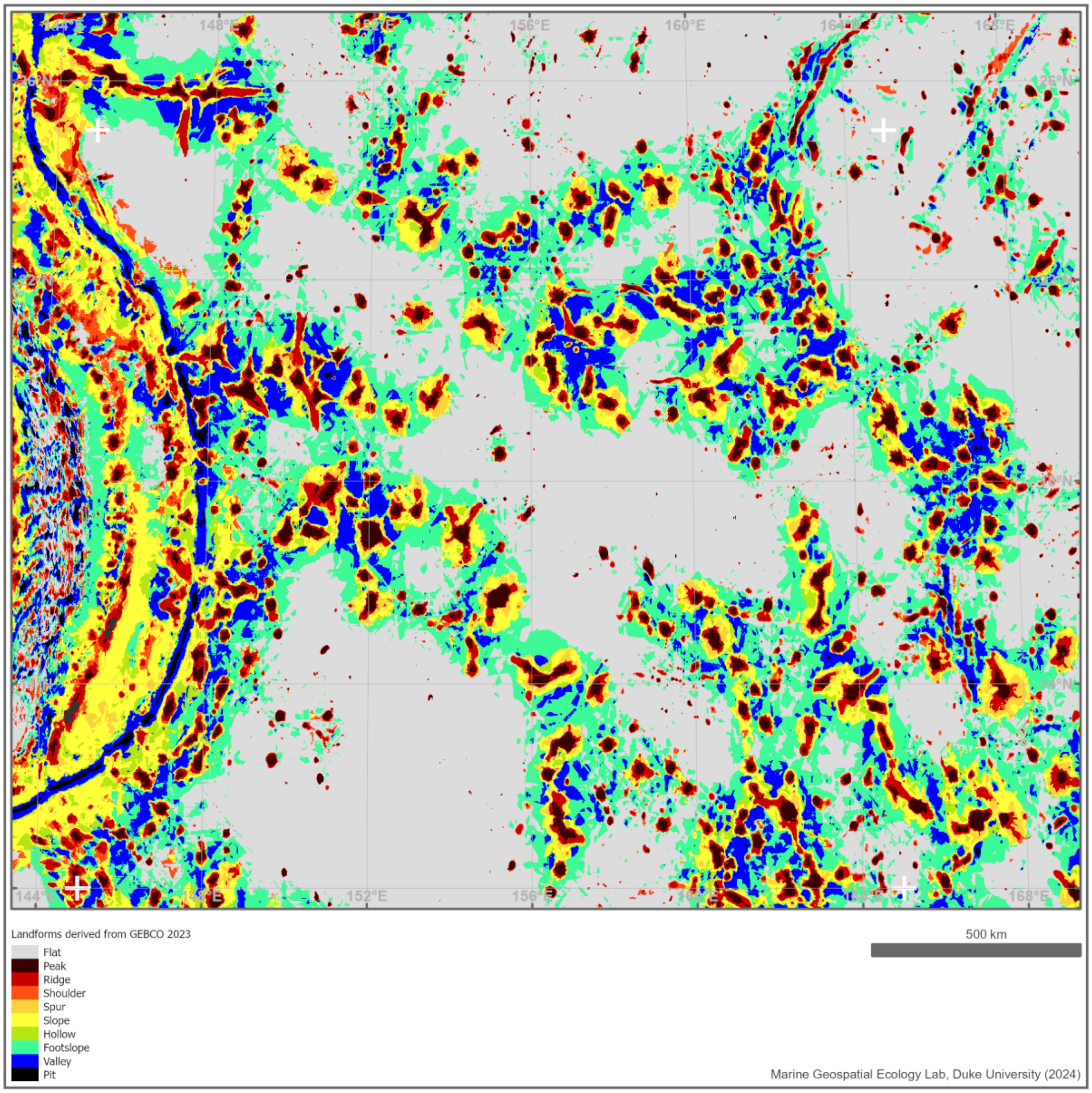


Figure 2.3-1 Landforms derived from GEBCO 2023

2.4 Global Multi-Resolution Topography (GMRT), Version 4.2

"The Global Multi-Resolution Topography (GMRT) synthesis is a multi-resolution gridded compilation of edited multibeam sonar bathymetry data from the global and polar oceans, merged with terrestrial and lower resolution ocean data from GEBCO. Seafloor bathymetric data acquired with multibeam sonars are used for a wide range of fundamental research applications (e.g. on active seafloor geologic processes, bottom water circulation, biological habitats), as well as for more applied needs (e.g. marine resource management, tsunami inundation, submarine navigation). However these data have been acquired for only a small fraction of the oceans and typically require specialist knowledge to process. The GMRT is the only global-scale multi-resolution compilation of these data, providing access to grids and images to the full native resolution of the data, as well as attribution to the original data sources and is intended for broad use for research and education. The GMRT also serves the terrestrial community by providing easy access to images or grids from NASA's ASTER terrestrial elevation data (30-m resolution) for the globe and the USGS National Elevation Dataset (NED) (10-m resolution) for portions of the US. New source swath sonar data are obtained from NOAA's NGDC and other sources, and are evaluated, cleaned, edited, and then merged into the multi-resolution DEM. The GMRT synthesis is provided with funding from the U.S. National Science Foundation. Collaboration with Google has resulted in publication of the GMRT multibeam content in Google Earth, and GMRT content has routinely been contributed to GEBCO since 2014. Further details on the architecture of the GMRT are available in Ryan et al. (2009) and from: https://gmrt.org/about/"

Link: https://www.gmrt.org/about/index.php
Web Services: https://www.gmrt.org/services/index.php

Reference:
Ryan, William B. F., Suzanne M. Carbotte, Justin O. Coplan, Suzanne O'Hara, Andrew Melkonian, Robert Arko, Rose Anne Weissel, et al. 2009. "Global Multi-Resolution Topography Synthesis." Geochemistry, Geophysics, Geosystems 10 (3). https://doi.org/10.1029/2008GC002332.

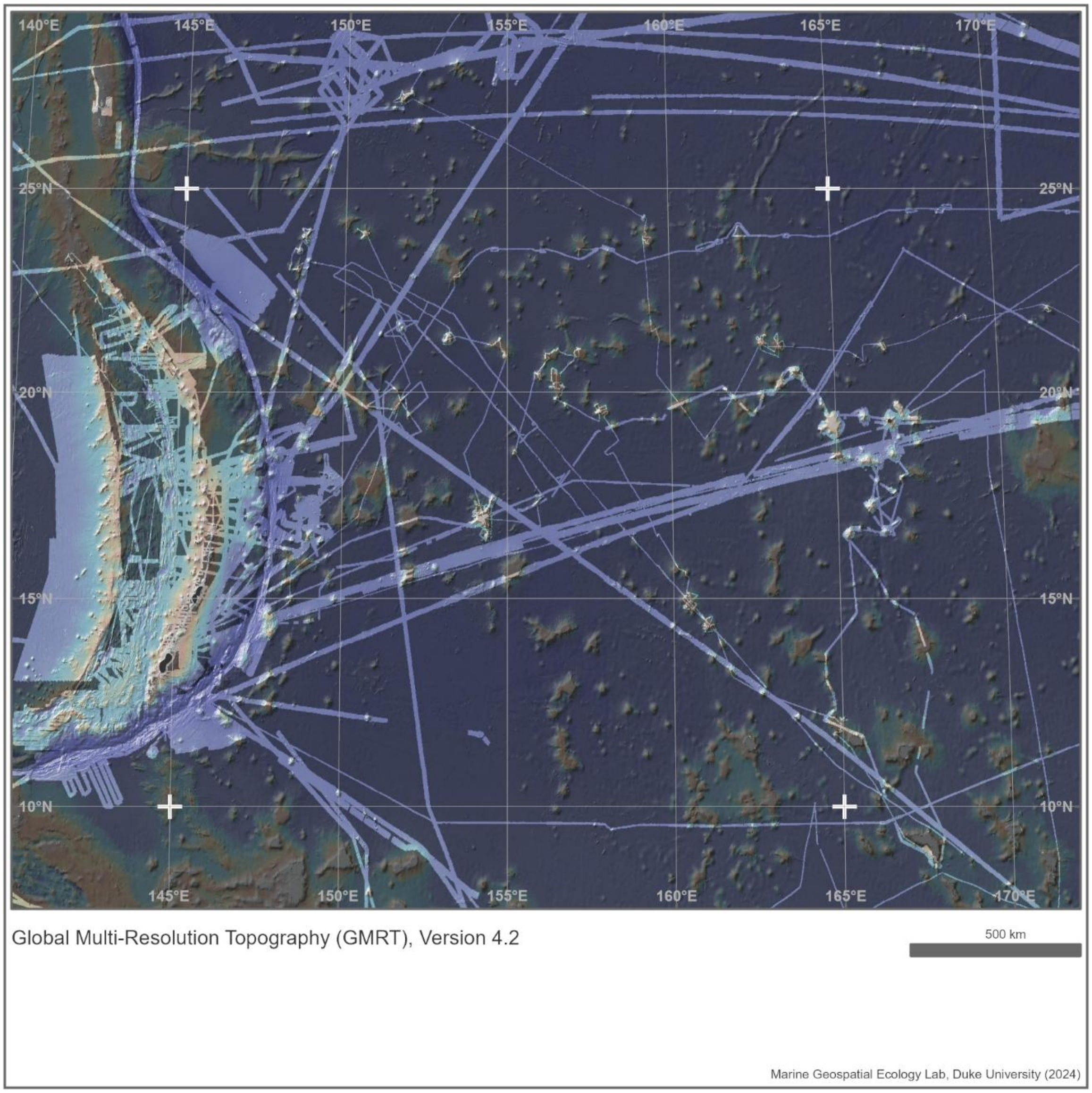


Figure 2.4-1 Global multi-resolution topography

2.5 Multibeam Bathymetric Survey Tracklines

"The Multibeam Bathymetry Database (MBBDB) at NCEI collects and archives multibeam data from the earliest commercial installations (circa 1980) through today's modern high-resolution collections. Data are acquired from both U.S. and international government and academic sources (see individual cruise metadata records for source information) and consist of the raw (as collected) sonar data files. Datasets may also include processed or edited versions of the sonar data, ancillary data (i.e., sound velocity data), derived products (i.e., grids), and/or metadata for the data collection. The MBBDB provides data that span the globe and are discoverable and accessible via map interface or text-only search options. This map service shows ship tracks for multibeam bathymetric surveys archived at NCEI."
Source: https://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html

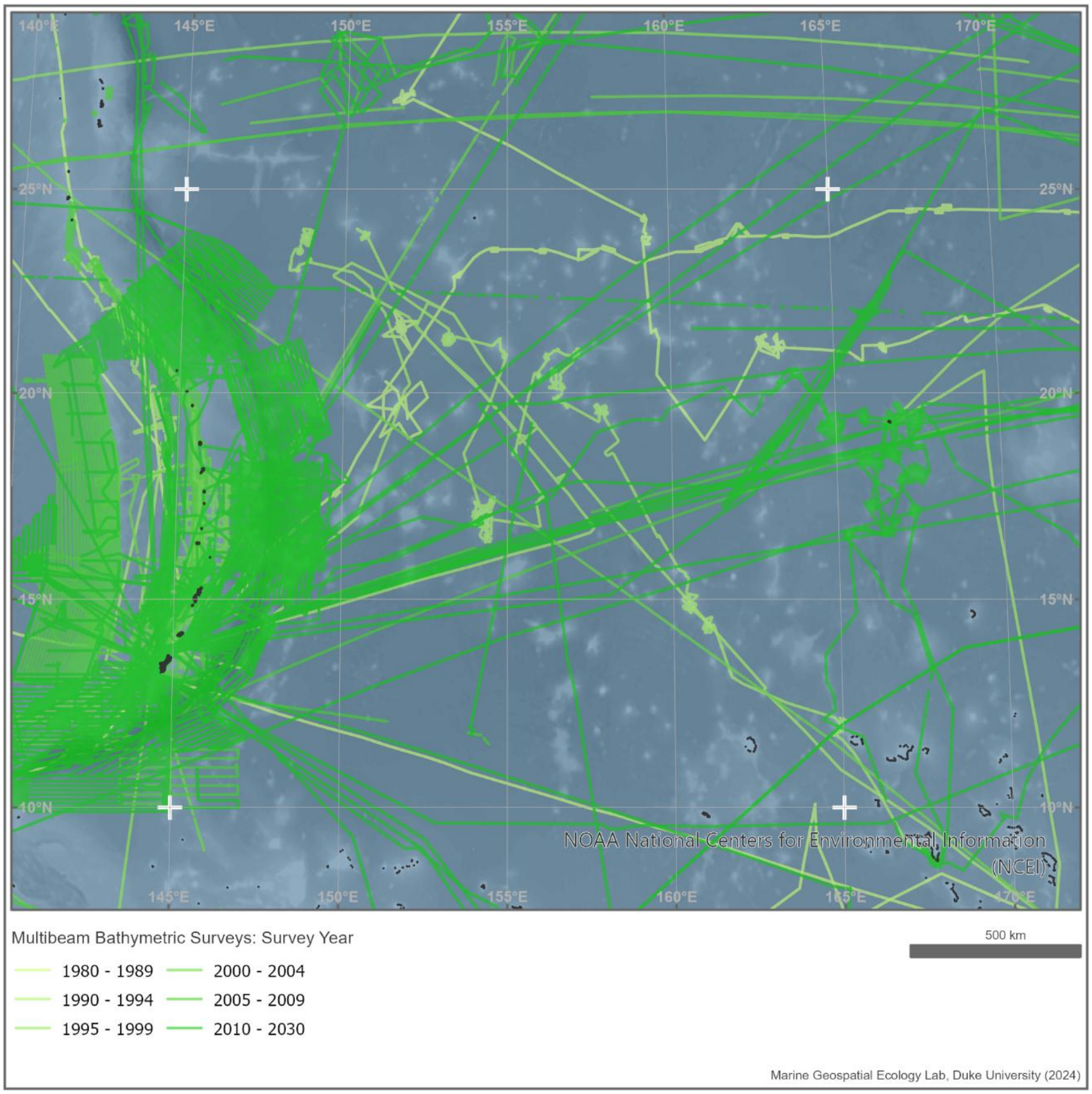


Figure 2.5-1 Multibeam bathymetry survey tracklines

2.6 InterRidge Vents Database

“The InterRidge Global Database of Active Submarine Hydrothermal Vent Fields, hereafter referred to as the InterRidge Vents Database, is available online as the authoritative source for locations of hydrothermal vent fields worldwide (linked to InterRidge homepage: http://www.interridge.org). The InterRidge Vents Database was developed to provide a comprehensive list of active submarine hydrothermal vent fields for use in academic research and education.”

Source: http://vents-data.interridge.org/, database version 3.4

Reference:

Beaulieu, S. E., E. T. Baker, C. R. German, and A. Maffei (2013), An authoritative global database for active submarine hydrothermal vent fields, Geochem. Geophys. Geosys., 14, 4892–4905, doi:10.1002/2013GC004998.

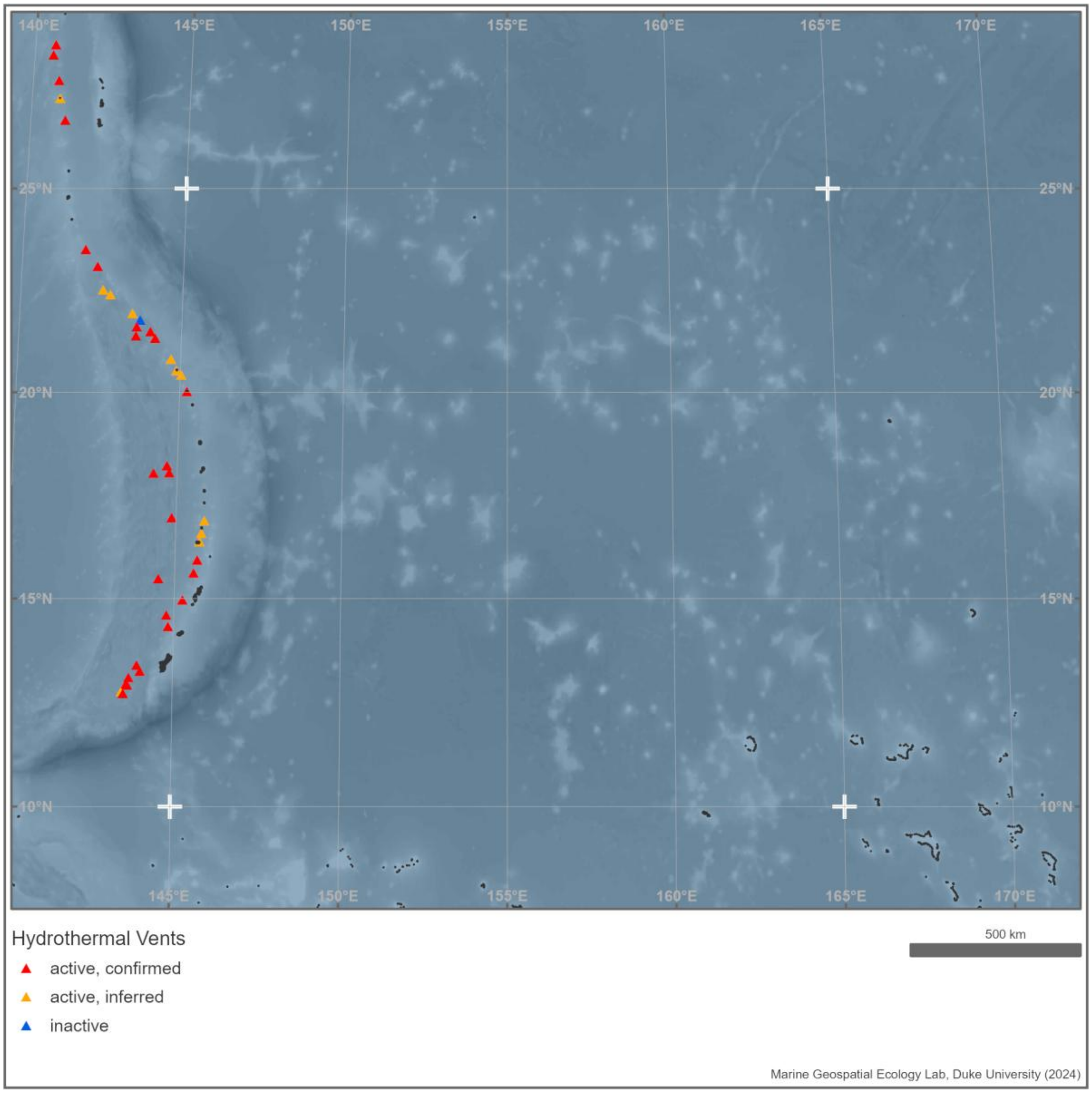


Figure 2.6-1 Hydrothermal vents

2.7 GEBCO Undersea Features Gazetteer

"The GEBCO Sub-Committee on Undersea Feature Names (SCUFN) maintains and makes available a digital gazetteer of the names, generic feature type and geographic position of features on the seafloor.

The gazetteer is available to view and download via a web map application, hosted by the International Hydrographic Organization Data Centre for Digital Bathymetry (IHO DCDB) co-located with the US National Centers for Environmental Information (NCEI).

The data are available in a number of formats including spreadsheet and shapefile.

Name proposals can be submitted to SCUFN for consideration for inclusion in the gazetteer."

Source: https://www.gebco.net/data_and_products/undersea_feature_names/

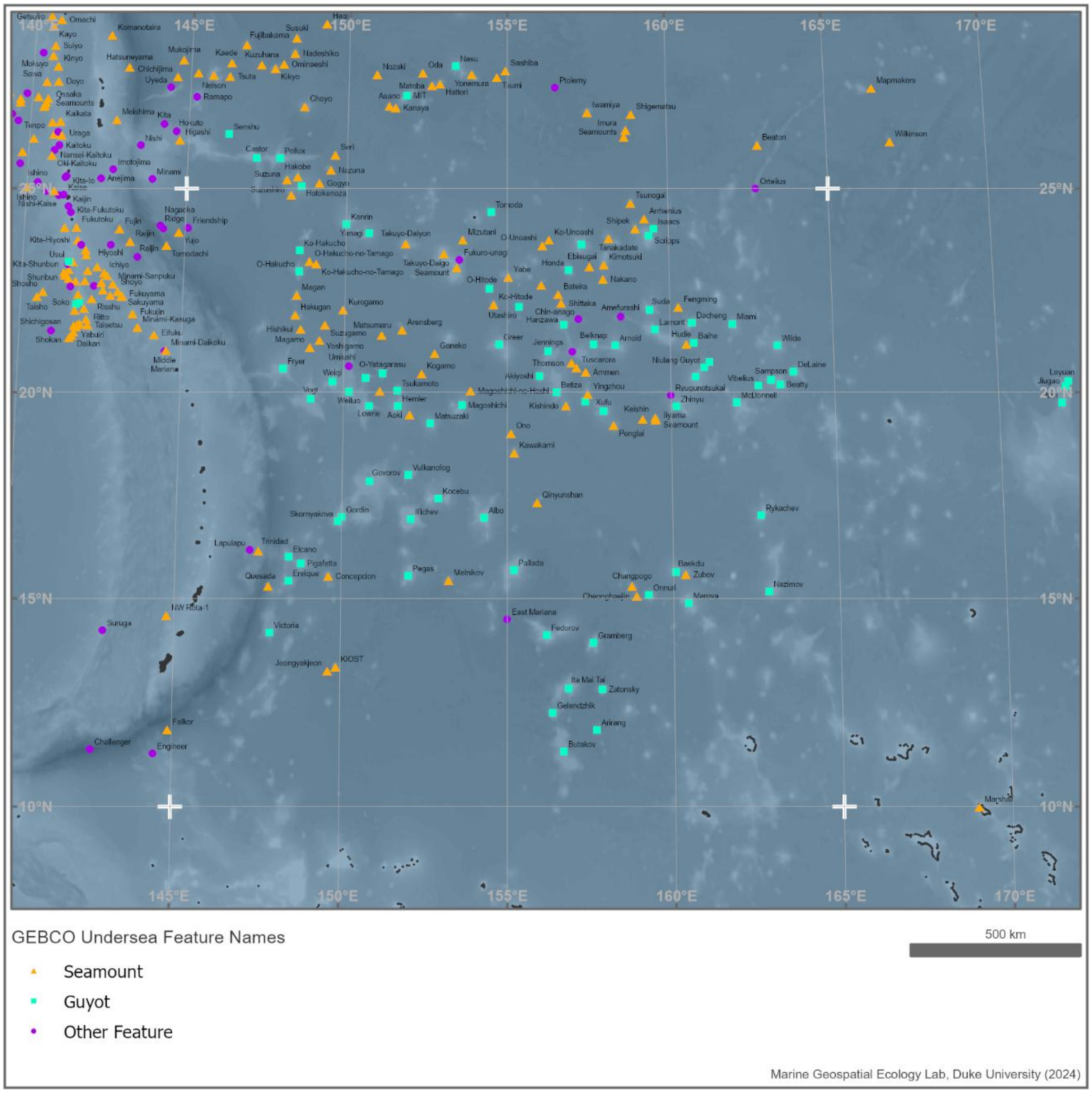


Figure 2.7-1 Undersea features names

2.8 Seafloor Geomorphic Features

Abstract (Harris et al. 2014):
"We present the first digital seafloor geomorphic features map (GSFM) of the global ocean. The GSFM includes 131,192 separate polygons in 29 geomorphic feature categories, used here to assess differences between passive and active continental margins as well as between 8 major ocean regions (the Arctic, Indian, North Atlantic, North Pacific, South Atlantic, South Pacific and the Southern Oceans and the Mediterranean and Black Seas). The GSFM provides quantitative assessments of differences between passive and active margins: continental shelf width of passive margins (88 km) is nearly three times that of active margins (31 km); the average width of active slopes (36 km) is less than the average width of passive margin slopes (46 km); active margin slopes contain an area of 3.4 million km2 where the gradient exceeds 5°, compared with 1.3 million km2 on passive margin slopes; the continental rise covers 27 million km2 adjacent to passive margins and less than 2.3 million km2 adjacent to active margins. Examples of specific applications of the GSFM are presented to show that: 1) larger rift valley segments are generally associated with slow-spreading rates and smaller rift valley segments are associated with fast spreading; 2) polar submarine canyons are twice the average size of non-polar canyons and abyssal polar regions exhibit lower seafloor roughness than non-polar regions, expressed as spatially extensive fan, rise and abyssal plain sediment deposits — all of which are attributed here to the effects of continental glaciations; and 3) recognition of seamounts as a separate category of feature from ridges results in a lower estimate of seamount number compared with estimates of previous workers."

Reference:
Harris PT, Macmillan-Lawler M, Rupp J, Baker EK (2014), Geomorphology of the oceans. Marine Geology. doi: 10.1016/j.margeo.2014.01.011

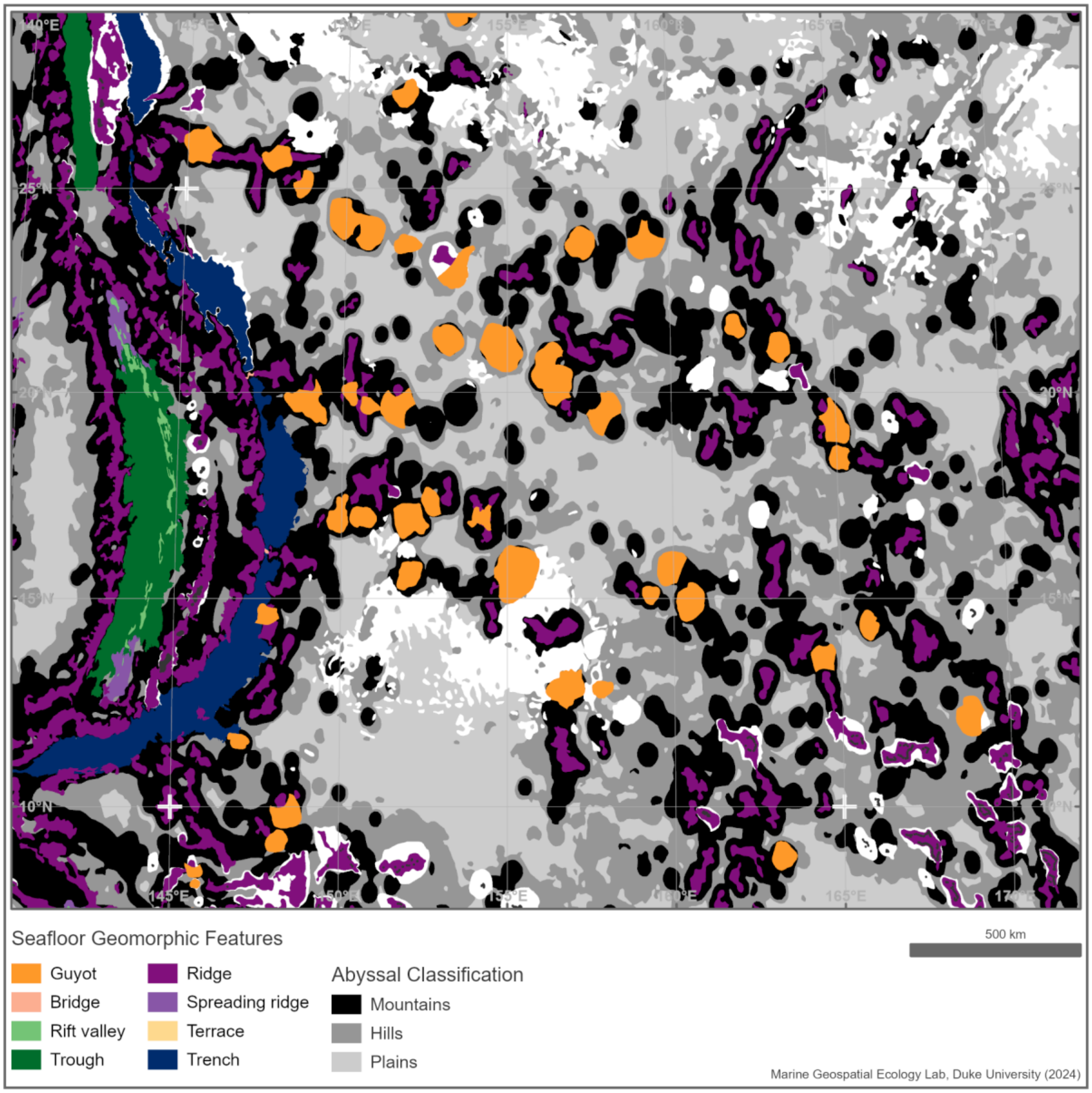


Figure 2.8-1 Seafloor geomorphic features

2.9 Global Distribution of Seamounts

Abstract (Yesson et al. 2011):
"Seamounts and knolls are 'undersea mountains', the former rising more than 1000 m from the seafloor. These features provide important habitats for aquatic predators, demersal deep-sea fish and benthic invertebrates. However most seamounts have not been surveyed and their numbers and locations are not well known. Previous efforts to locate and quantify seamounts have used relatively coarse bathymetry grids. Here we use global bathymetric data at 30 arc-second resolution to identify seamounts and knolls. We identify 33,452 seamounts and 138,412 knolls, representing the largest global set of identified seamounts and knolls to date. We compare estimated seamount numbers, locations, and depths with validation sets of seamount data from New Zealand and Azores. This comparison indicates the method we apply finds 94% of seamounts, but may overestimate seamount numbers along ridges and in areas where faulting and seafloor spreading creates highly complex topography. The seamounts and knolls identified herein are significantly geographically biased towards areas surveyed with ship-based soundings. As only 6.5% of the ocean floor has been surveyed with soundings it is likely that new seamounts will be uncovered as surveying improves. Seamount habitats constitute approximately 4.7% of the ocean floor, whilst knolls cover 16.3%. Regional distribution of these features is examined, and we find a disproportionate number of productive knolls, with a summit depth of o1.5 km, located in the Southern Ocean. Less than 2% of seamounts are within marine protected areas and the majority of these are located within exclusive economic zones with few on the High Seas. The database of seamounts and knolls resulting from this study will be a useful resource for researchers and conservation planners."

Reference:
Yesson, C., Clark, M. R., Taylor, M. L., & Rogers, A. D. (2011). The global distribution of seamounts based on 30 arc seconds bathymetry data. Deep Sea Research Part I: Oceanographic Research Papers, 58(4), 442-453. doi: 10.1016/j.dsr.2011.02.004

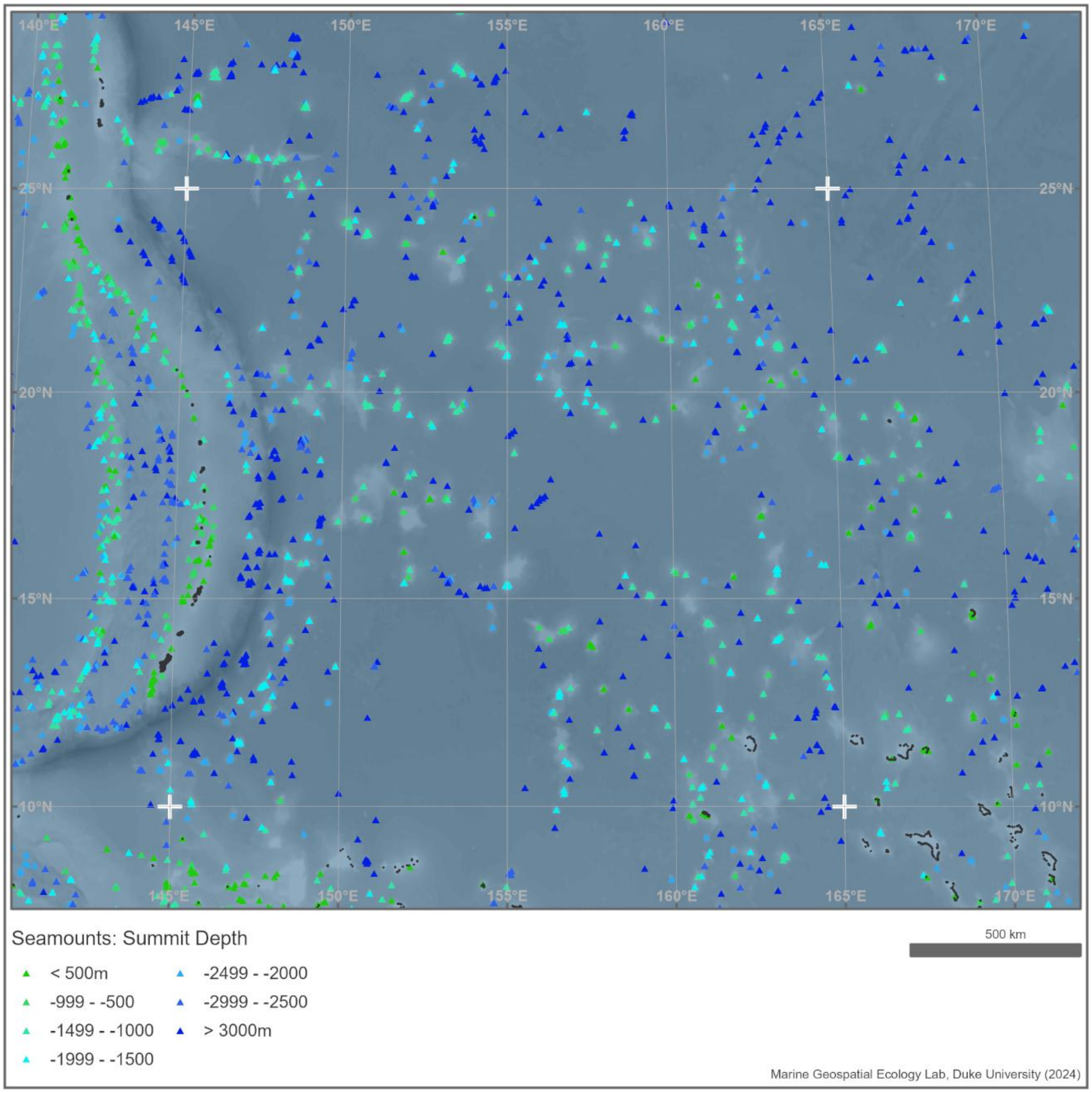


Figure 2.9-1 Seamount summit depths

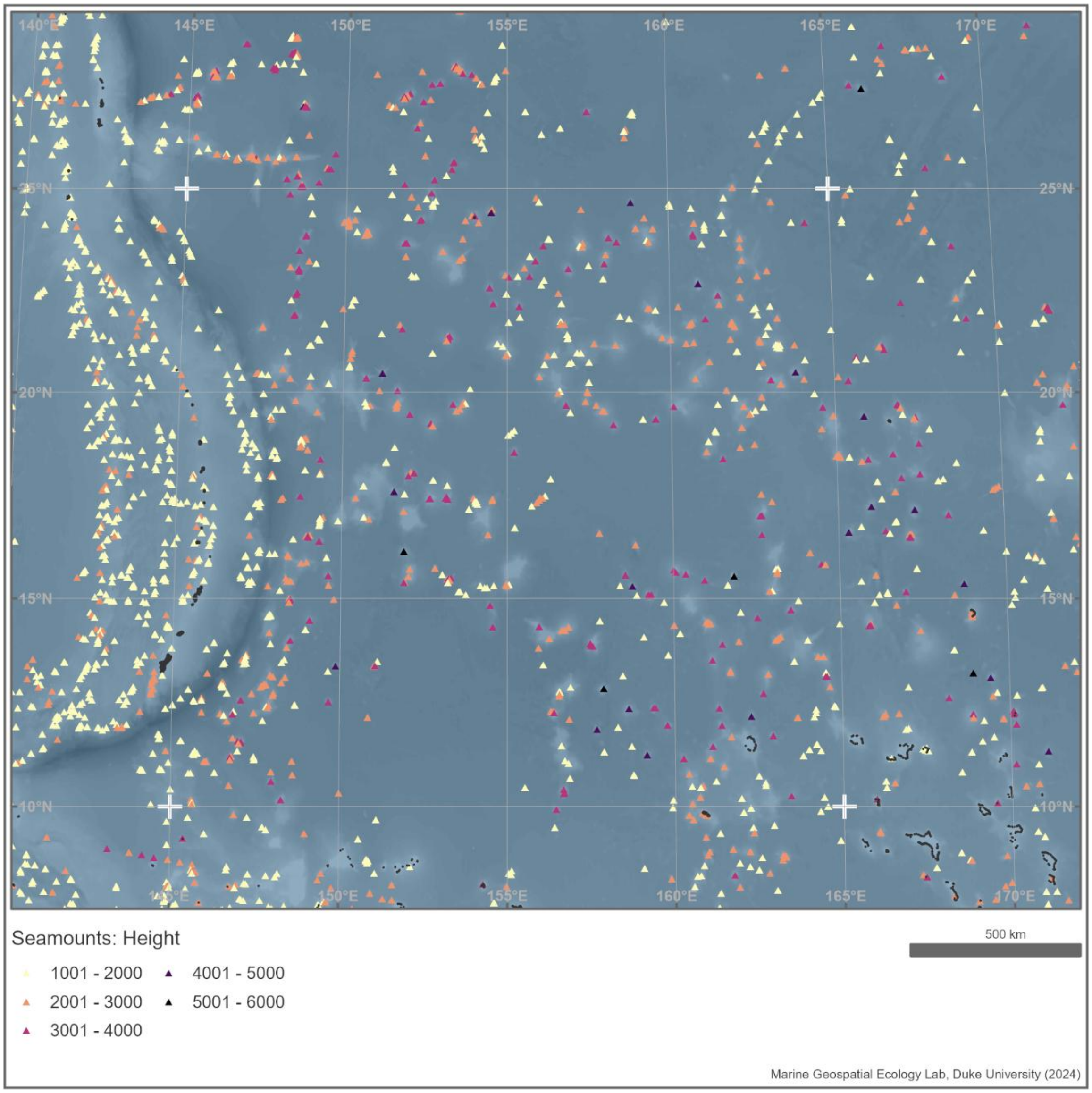


Figure 2.9-2 Seamount height

2.10 Global Seamount Classification

Abstract (Clark et al. 2011):

"Seamounts are prominent features of the world's seafloor, and are the target of deep-sea commercial fisheries, and of interest for minerals exploitation. They can host vulnerable benthic communities, which can be rapidly and severely impacted by human activities. There have been recent calls to establish networks of marine protected areas on the High Seas, including seamounts. However, there is little biological information on the benthic communities on seamounts, and this has limited the ability of scientists to inform managers about seamounts that should be protected as part of a network. In this paper we present a seamount classification based on "biologically meaningful" physical variables for which global-scale data are available. The approach involves the use of a general biogeographic classification for the bathyal depth zone (near-surface to 3500 m), and then uses four key environmental variables (overlying export production, summit depth, oxygen levels, and seamount proximity) to group seamounts with similar characteristics. This procedure is done in a simple hierarchical manner, which results in 194 seamount classes throughout the world's oceans. The method was compared against a multivariate approach, and ground-truthed against octocoral data for the North Atlantic. We believe it gives biologically realistic groupings, in a transparent process that can be used to either directly select, or aid selection of, seamounts to be protected."

Reference:

Clark, Malcolm R., Les Watling, Ashley A. Rowden, John M. Guinotte, and Craig R. Smith. "A global seamount classification to aid the scientific design of marine protected area networks." Ocean & Coastal Management 54, no. 1 (2011): 19-36. doi: 10.1016/j.ocecoaman.2010.10.006

Source: http://seamounts.sdsc.edu/

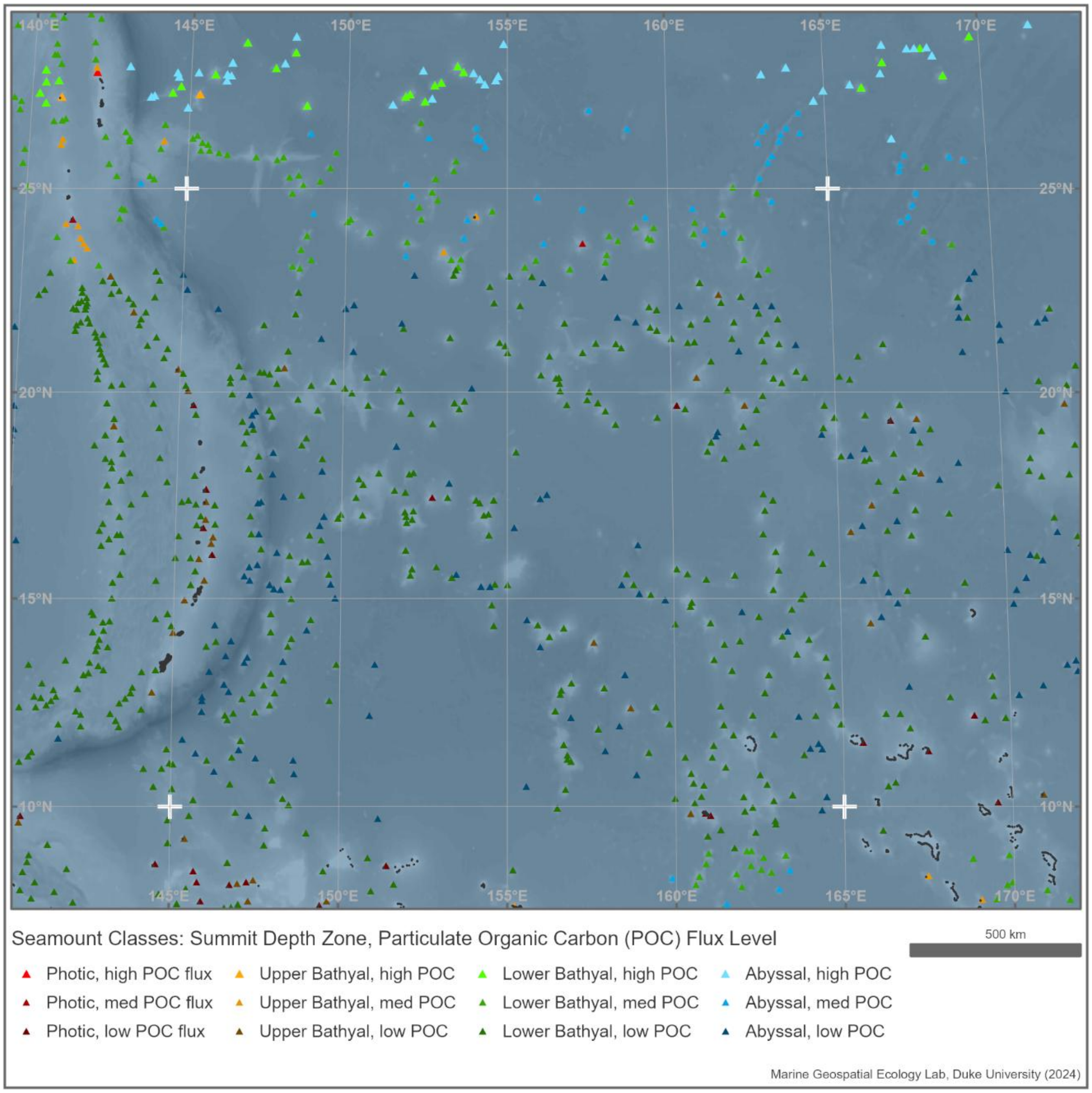


Figure 2.10-1 Global seamount classification, Depth Zone and POC Flux

2.11 Total Sediment Thickness of the World's Oceans & Marginal Seas

"NCEI's global ocean sediment thickness grid of Divins (2003) updated by Whittaker et al. (2013) has been updated again for the NE Atlantic, Arctic, Southern Ocean, and Mediterranean regions. The new global 5-arc-minute total sediment thickness grid, GlobSed, incorporates new data and several regional oceanic sediment thickness maps, which have been compiled and published for the, (1) NE Atlantic (Funck et al., 2017; Hopper et al., 2014), (2) Mediterranean (Molinari & Morelli, 2011), (3) Arctic (Petrov et al., 2016), (4) Weddell Sea (Huang et al., 2014), and (5) the Ross Sea, Amundsen Sea, and Bellingshausen Sea sectors off West Antarctica (Lindeque et al., 2016; Wobbe et al., 2014). This version also includes updates in the White Sea region based on the VSEGEI map of Orlov and Fedorov (2001). GlobSed covers a larger area than NCEI's previous global grids (Divins, 2003; Whittaker et al. 2013), and the new updates results in a 29.7% increase in estimated total oceanic sediment volume."

Source: https://www.ngdc.noaa.gov/mgg/sedthick/

Reference:

Straume, E.O., Gaina, C., Medvedev, S., Hochmuth, K., Gohl, K., Whittaker, J. M., et al. (2019). GlobSed: Updated total sediment thickness in the world's oceans. Geochemistry, Geophysics, Geosystems, 20. DOI: 10.1029/2018GC008115

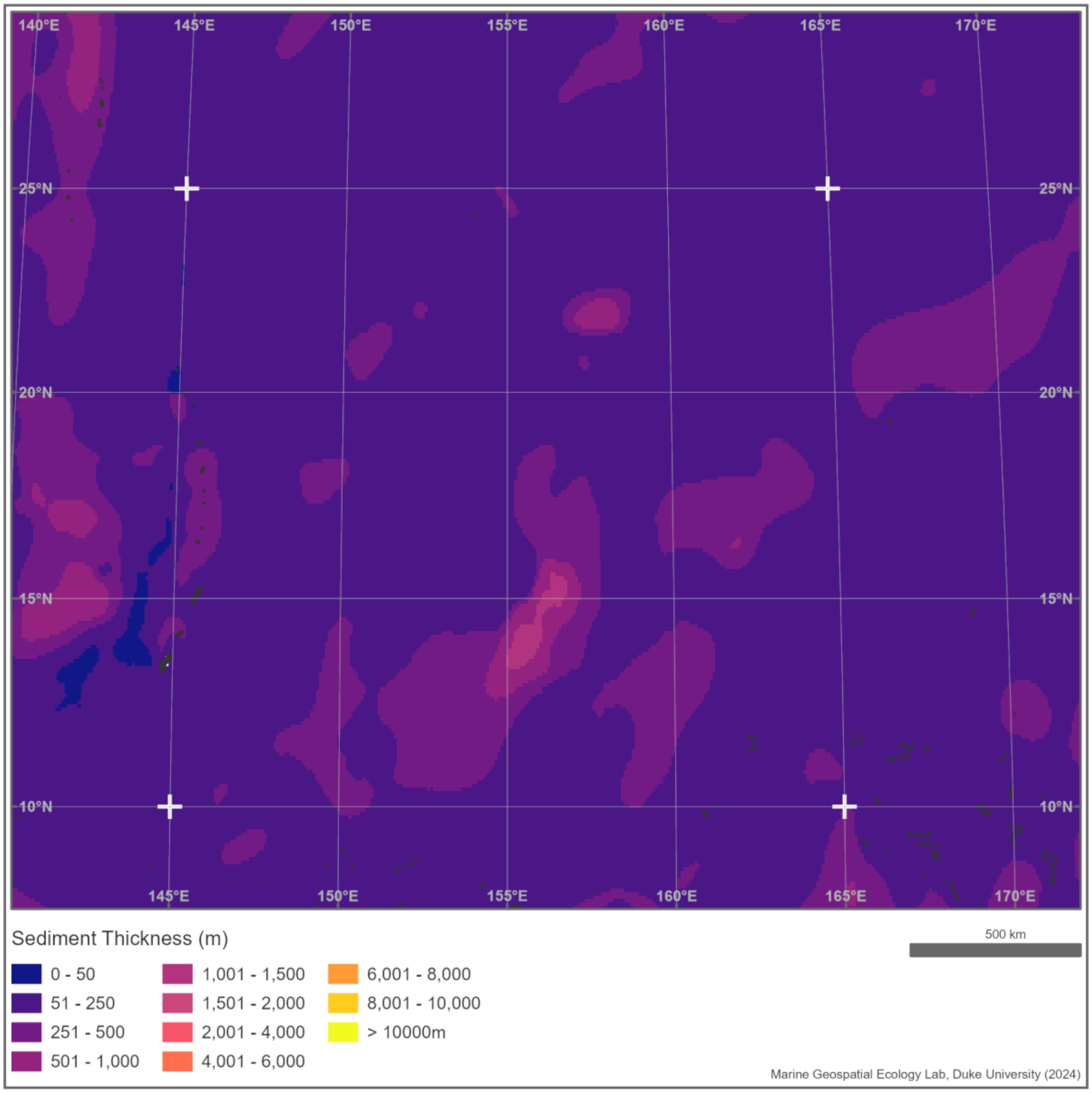


Figure 2.11-1 Sediment thickness

2.12 Seafloor Sediments

Abstract (Dutkiewicz et al. 2015)
"Knowing the patterns of distribution of sediments in the global ocean is critical for understanding biogeochemical cycles and how deep-sea deposits respond to environmental change at the sea surface. We present the first digital map of seafloor lithologies based on descriptions of nearly 14,500 samples from original cruise reports, interpolated using a support vector machine algorithm. We show that sediment distribution is more complex, with significant deviations from earlier hand-drawn maps, and that major lithologies occur in drastically different proportions globally. By coupling our digital map to oceanographic data sets, we find that the global occurrence of biogenic oozes is strongly linked to specific ranges in sea-surface parameters. In particular, by using recent computations of diatom distributions from pigment-calibrated chlorophyll-*a* satellite data, we show that, contrary to a widely held view, diatom oozes are not a reliable proxy for surface productivity. Their global accumulation is instead strongly dependent on low surface temperature (0.9–5.7 °C) and salinity (33.8–34.0 PSS, Practical Salinity Scale 1978) and high concentrations of nutrients. Under these conditions, diatom oozes will accumulate on the seafloor regardless of surface productivity as long as there is limited competition from biogenous and detrital components, and diatom frustules are not significantly dissolved prior to preservation. Quantifying the link between the seafloor and the sea surface through the use of large digital data sets will ultimately lead to more robust reconstructions and predictions of climate change and its impact on the ocean environment."

Reference:
Dutkiewicz, A., R. Müller, S. O'Callaghan, and H. Jónasson. 2015. "Census of Seafloor Sediments in the World's Ocean." *Geology* 43 (9): 795–98. https://doi.org/10.1130/G36883.1.

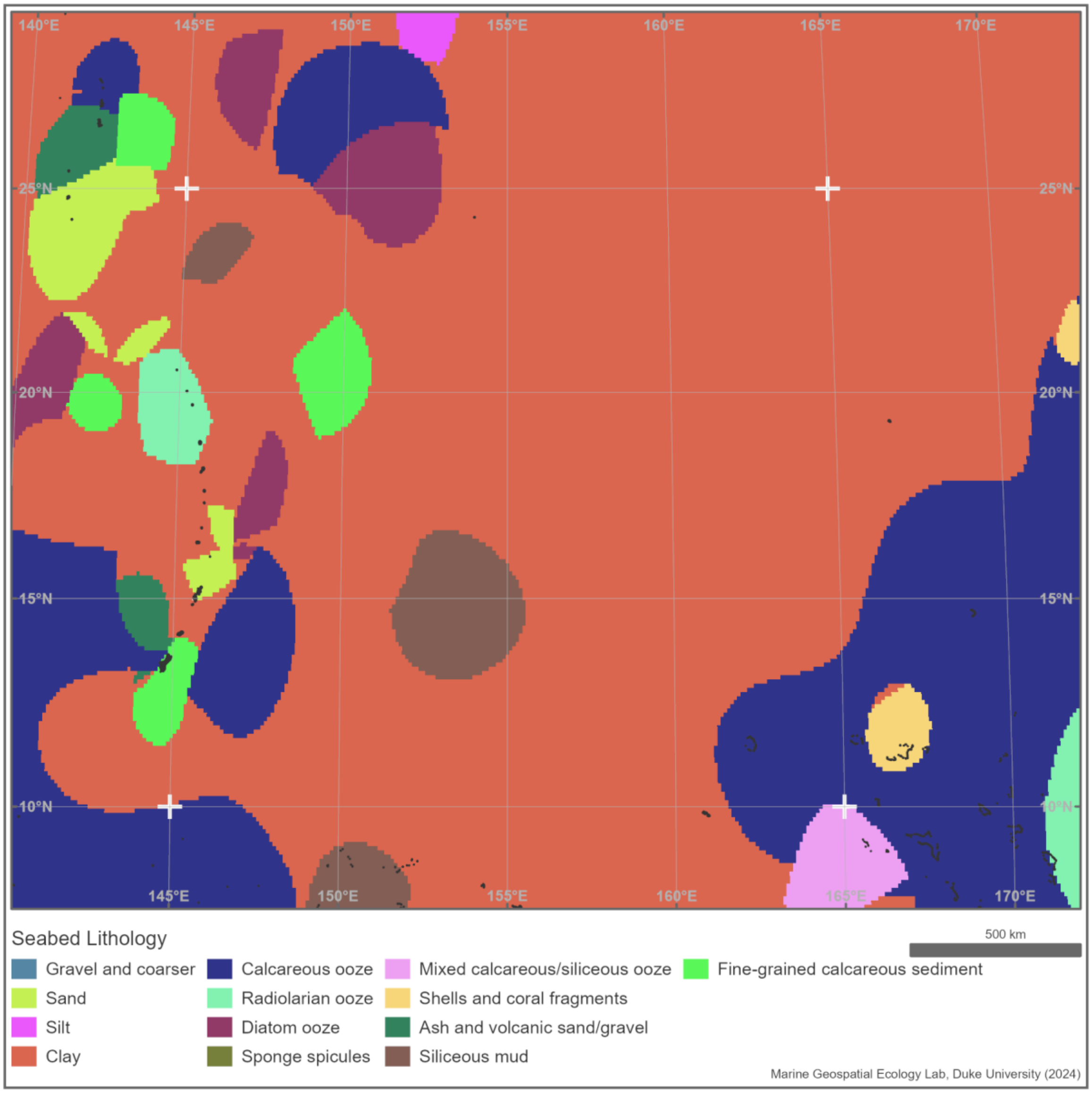


Figure 2.12-1 Seafloor sediments

2.13 World Ocean Atlas – Dissolved Oxygen

"The WOA18 updates previous versions of the World Ocean Atlas to include approximately 3 million new oceanographic casts added to the World Ocean Database and renewed quality control. This final version of WOA18 published in July, 2019 is replacing a prereleased version made available in September, 2018. The changes between the versions include:

- For the first time the Animal mounted pinniped temperature profiles (APB) have been added improving coverage in high latitude areas.
- A different Expendable Bathythermograph (XBT) correction (Cheng et al., 2014) has been employed.
- A double XBT correction has been detected in pre-release version and fixed in final version.
- All temperature and salinity climatological fields were re-calculated to account for these adjustments."

Source: https://www.nodc.noaa.gov/OC5/woa18/
https://www.nodc.noaa.gov/cgi-bin/OC5/woa18/woa18oxnu.pl

Reference:

Locarnini, R. A., A. V. Mishonov, O. K. Baranova, T. P. Boyer, M. M. Zweng, H. E. Garcia, J. R. Reagan, D. Seidov, K. Weathers, C. R. Paver, and I. Smolyar, 2018. *World Ocean Atlas 2018, Volume 1: Temperature.* A. Mishonov Technical Ed.; NOAA Atlas NESDIS 81, 52 pp.

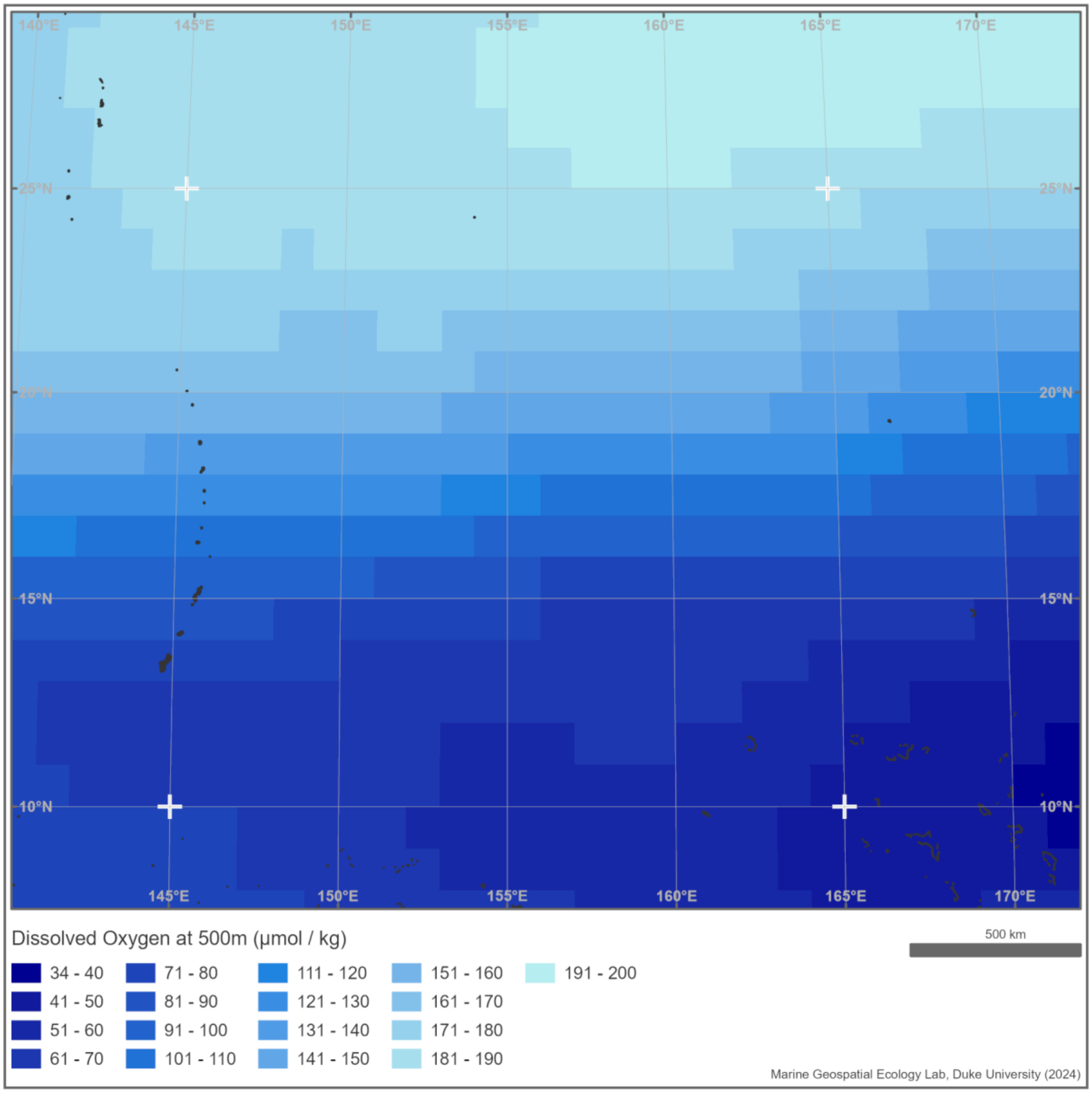


Figure 2.13-1 Dissolved oxygen, 500m

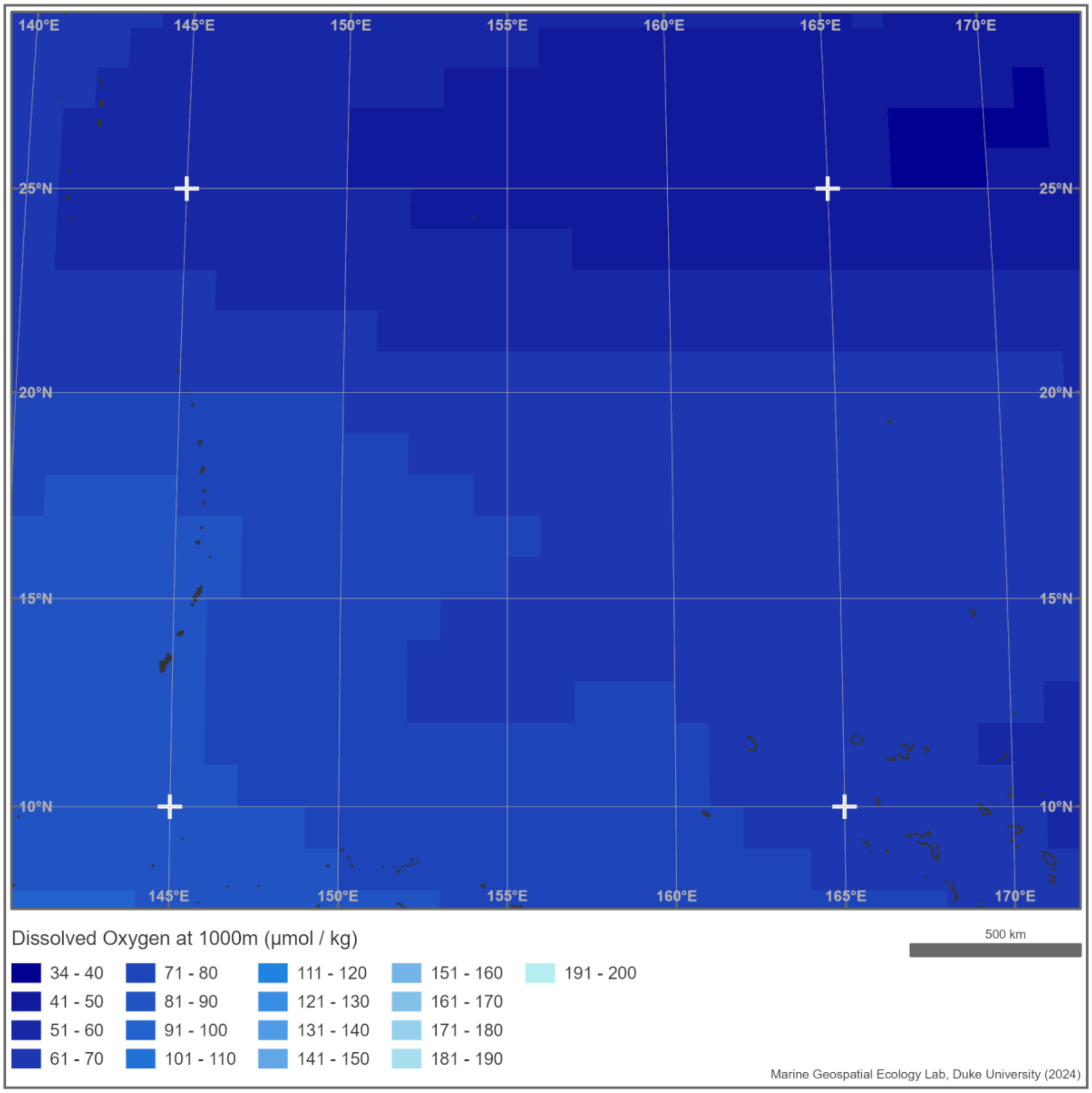


Figure 2.13-2 Dissolved oxygen, 1000m

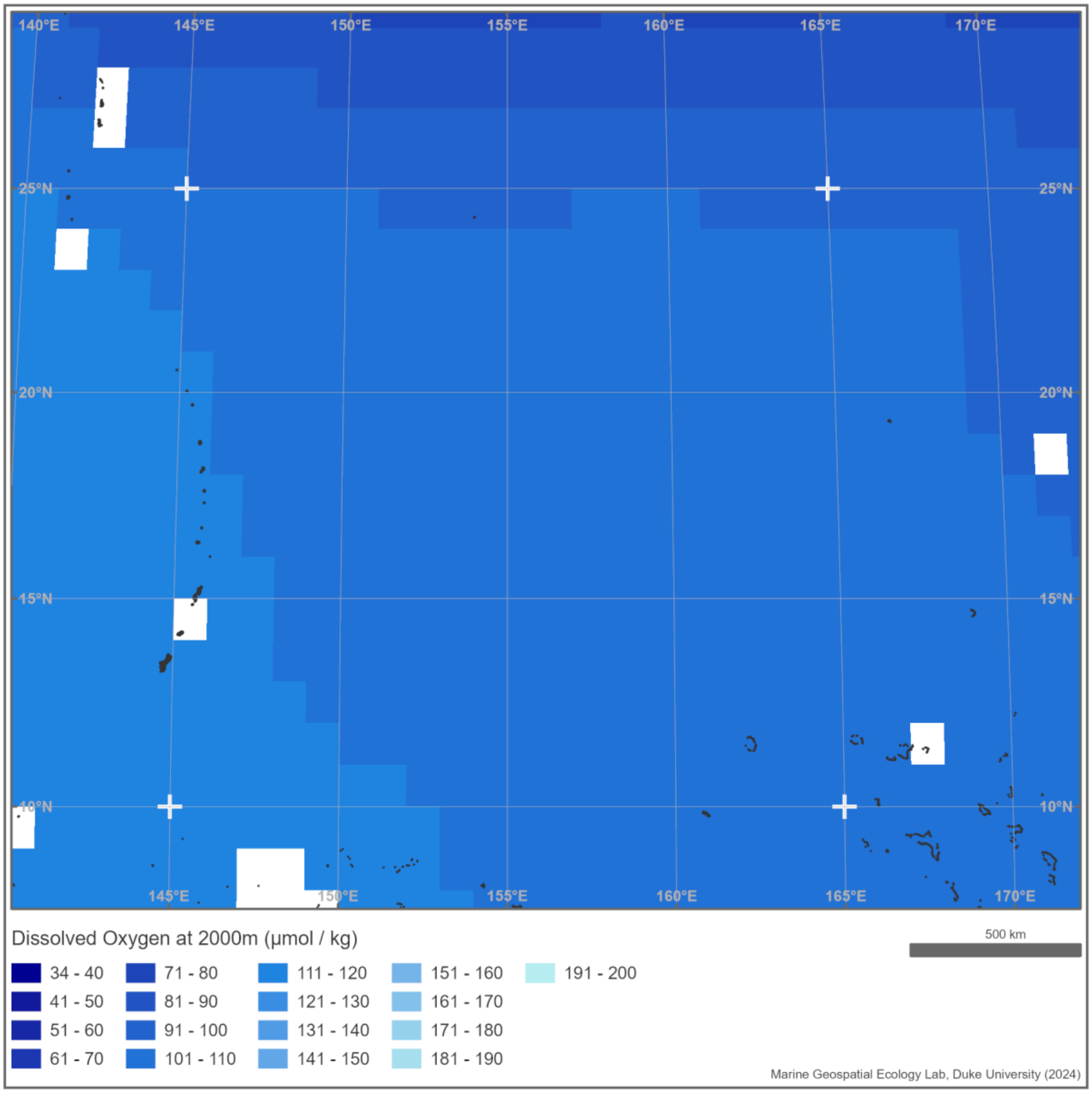


Figure 2.13-3 Dissolved oxygen, 2000m

2.14 Seafloor Dissolved Oxygen

Abstract (Sweetman et al. 2017):
The deep sea encompasses the largest ecosystems on Earth. Although poorly known, deep seafloor ecosystems provide services that are vitally important to the entire ocean and biosphere. Rising atmospheric greenhouse gases are bringing about significant changes in the environmental properties of the ocean realm in terms of water column oxygenation, temperature, pH and food supply, with concomitant impacts on deep-sea ecosystems. Projections suggest that abyssal (3000–6000 m) ocean temperatures could increase by 1°C over the next 84 years, while abyssal seafloor habitats under areas of deep-water formation may experience reductions in water column oxygen concentrations by as much as 0.03 mL L–1 by 2100. Bathyal depths (200–3000 m) worldwide will undergo the most significant reductions in pH in all oceans by the year 2100 (0.29 to 0.37 pH units). O2 concentrations will also decline in the bathyal NE Pacific and Southern Oceans, with losses up to 3.7% or more, especially at intermediate depths. Another important environmental parameter, the flux of particulate organic matter to the seafloor, is likely to decline significantly in most oceans, most notably in the abyssal and bathyal Indian Ocean where it is predicted to decrease by 40–55% by the end of the century. Unfortunately, how these major changes will affect deep-seafloor ecosystems is, in some cases, very poorly understood. In this paper, we provide a detailed overview of the impacts of these changing environmental parameters on deep-seafloor ecosystems that will most likely be seen by 2100 in continental margin, abyssal and polar settings. We also consider how these changes may combine with other anthropogenic stressors (e.g., fishing, mineral mining, oil and gas extraction) to further impact deep-seafloor ecosystems and discuss the possible societal implications.

Reference:
Sweetman, AK et al 2017 Major impacts of climate change on deep-sea benthic ecosystems. Elem Sci Anth, 5: 4, DOI: https://doi.org/10.1525/elementa.203

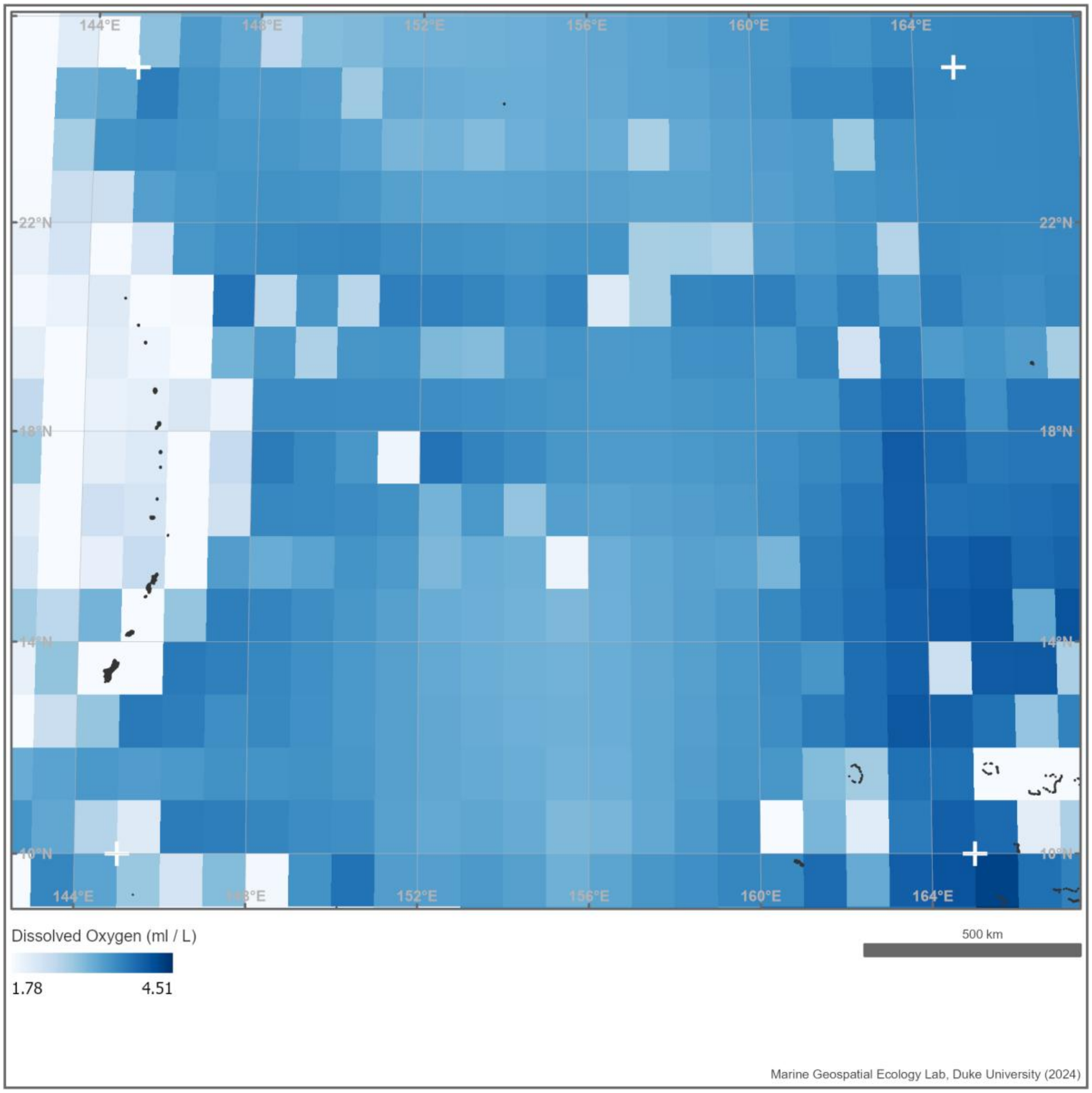


Figure 2.14-1 Seafloor dissolved oxygen

2.15 Hybrid Coordinate Ocean Model (HYCOM) Data

The HYCOM consortium (https://hycom.org/about) is a multi-institutional effort sponsored by the National Ocean Partnership Program (NOPP), as part of the U.S. Global Ocean Data Assimilation Experiment (GODAE), to develop and evaluate a data-assimilative hybrid isopycnal-sigma-pressure (generalized) coordinate ocean model (called HYbrid Coordinate Ocean Model or HYCOM).

"The system uses the Navy Coupled Ocean Data Assimilation (NCODA) system (Cummings, 2005; Cummings and Smedstad, 2013) for data assimilation. NCODA uses the 24-hour model forecast as a first guess in a 3D variational scheme and assimilates available satellite altimeter observations, satellite, and in-situ sea surface temperature as well as in-situ vertical temperature and salinity profiles from XBTs, Argo floats and moored buoys. Surface information is projected downward into the water column using Improved Synthetic Ocean Profiles (Helber et al., 2013)."

Data were summarized for single months in 2023 for surface and bottom temperature and bottom currents and a five-year (2018-2022) monthly climatology for sea surface elevation and can also be summarized into other climatologies as needed.

References:

Cummings, J.A., 2005: Operational multivariate ocean data assimilation. Quart. J. Royal Met. Soc., Part C, 131(613), 3583-3604.

Cummings, J.A. and O.M. Smedstad. 2013: Variational Data Assimilation for the Global Ocean. Data Assimilation for Atmospheric, Oceanic and Hydrologic Applications. Vol. II, chapter 13, 303-343.

Helber, R.W., T.L. Townsend, C.N. Barron, J.M. Dastugue and M.R. Carnes, 2013: Validation Test Report for the Improved Synthetic Ocean Profile (ISOP) System, Part I: Synthetic Profile Methods and Algorithm. NRL Memo. Report, NRL/MR/7320—13-9364.

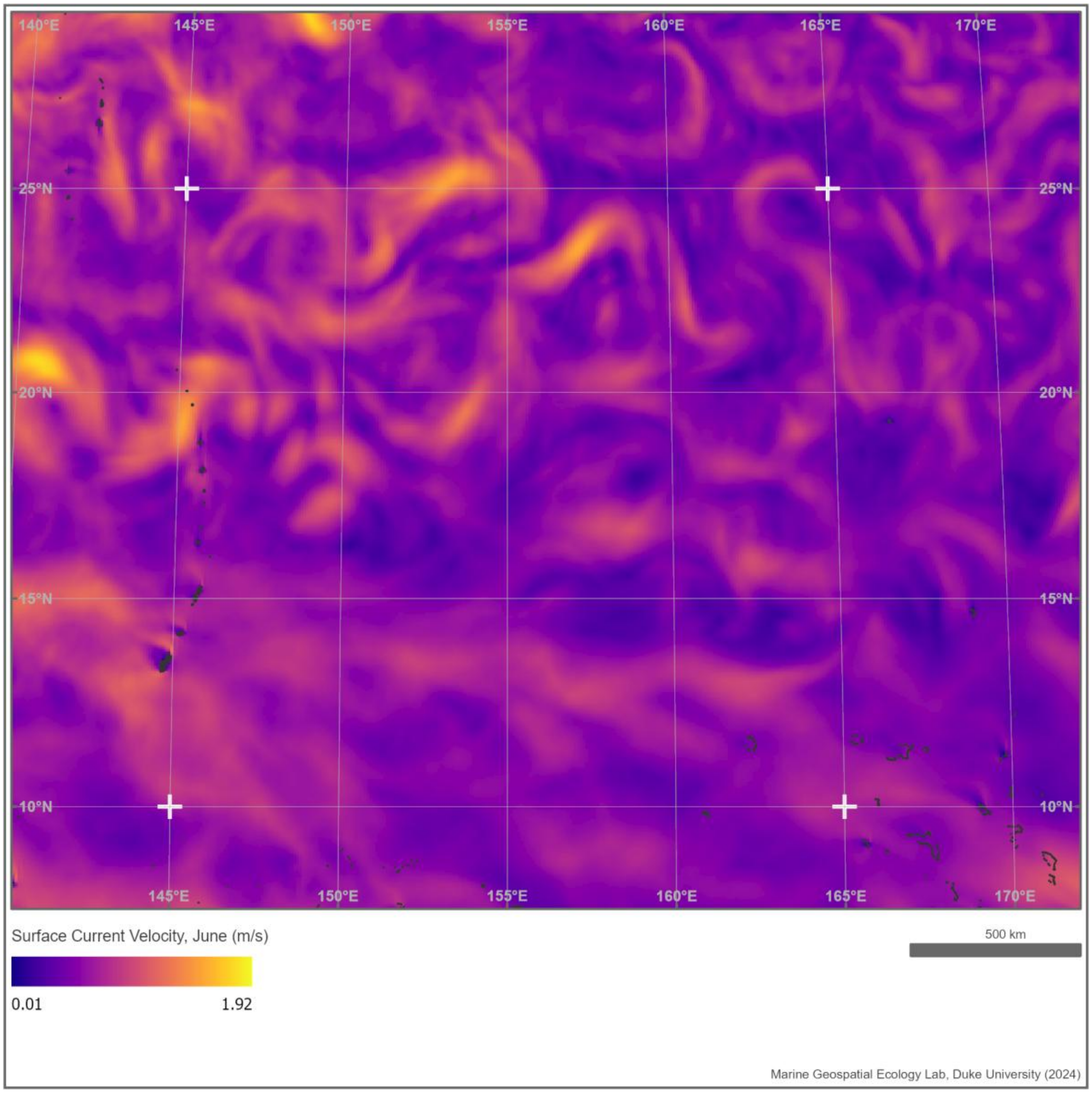


Figure 2.15-1 Current velocity, surface, June 2023

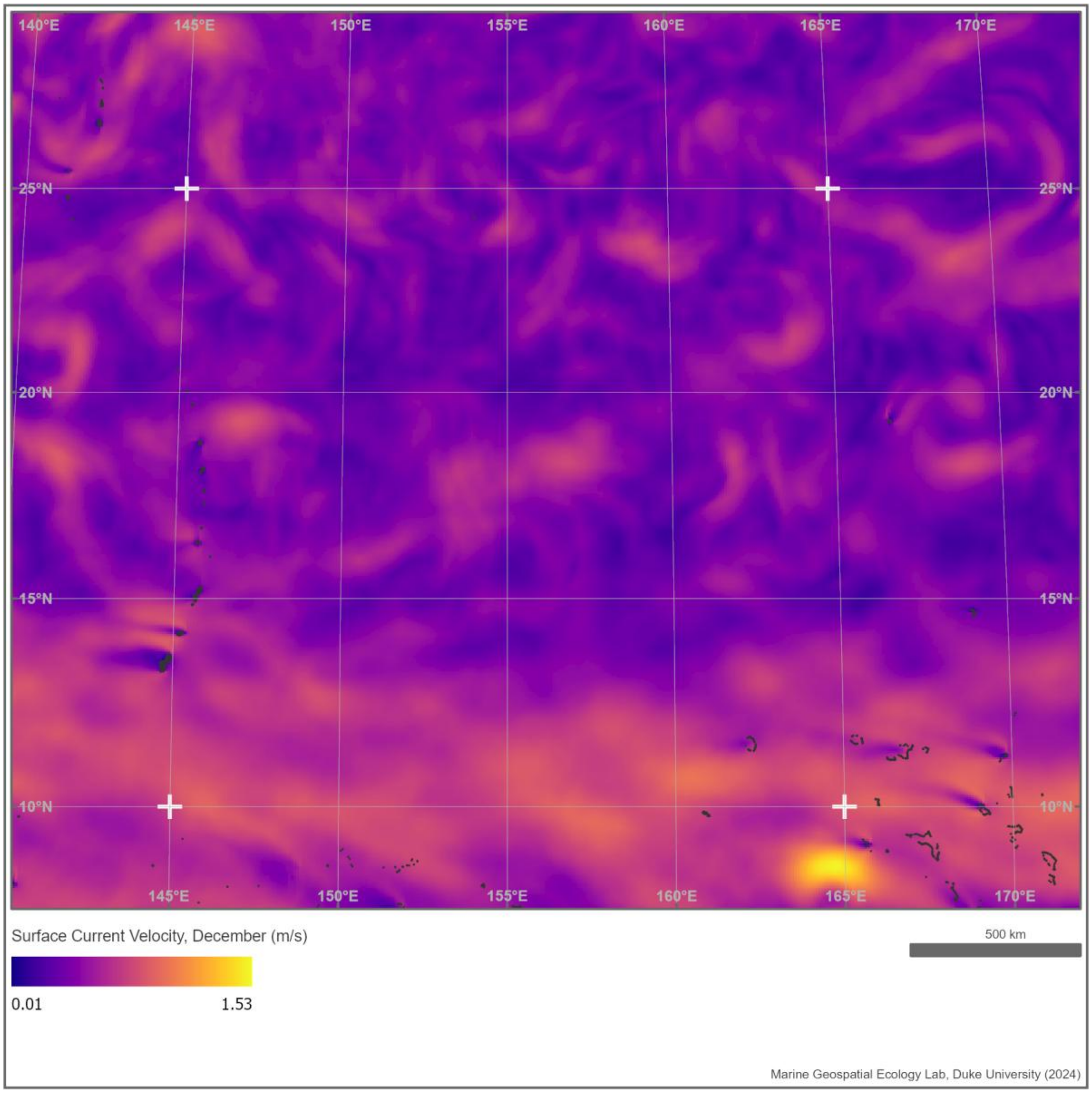


Figure 2.15-2 Current velocity, surface, December 2023

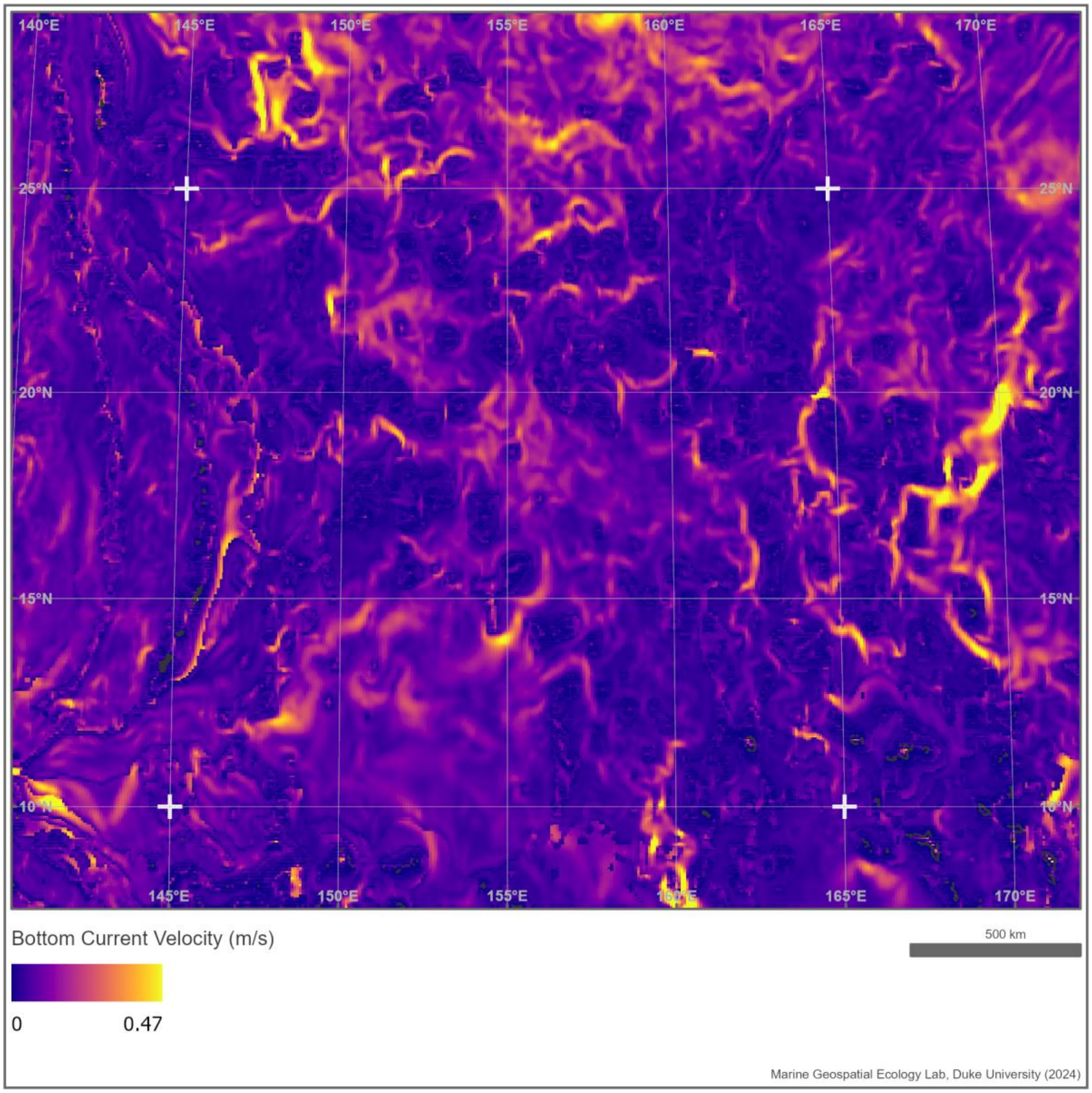


Figure 2.15-3 Current velocity, bottom, June 2023

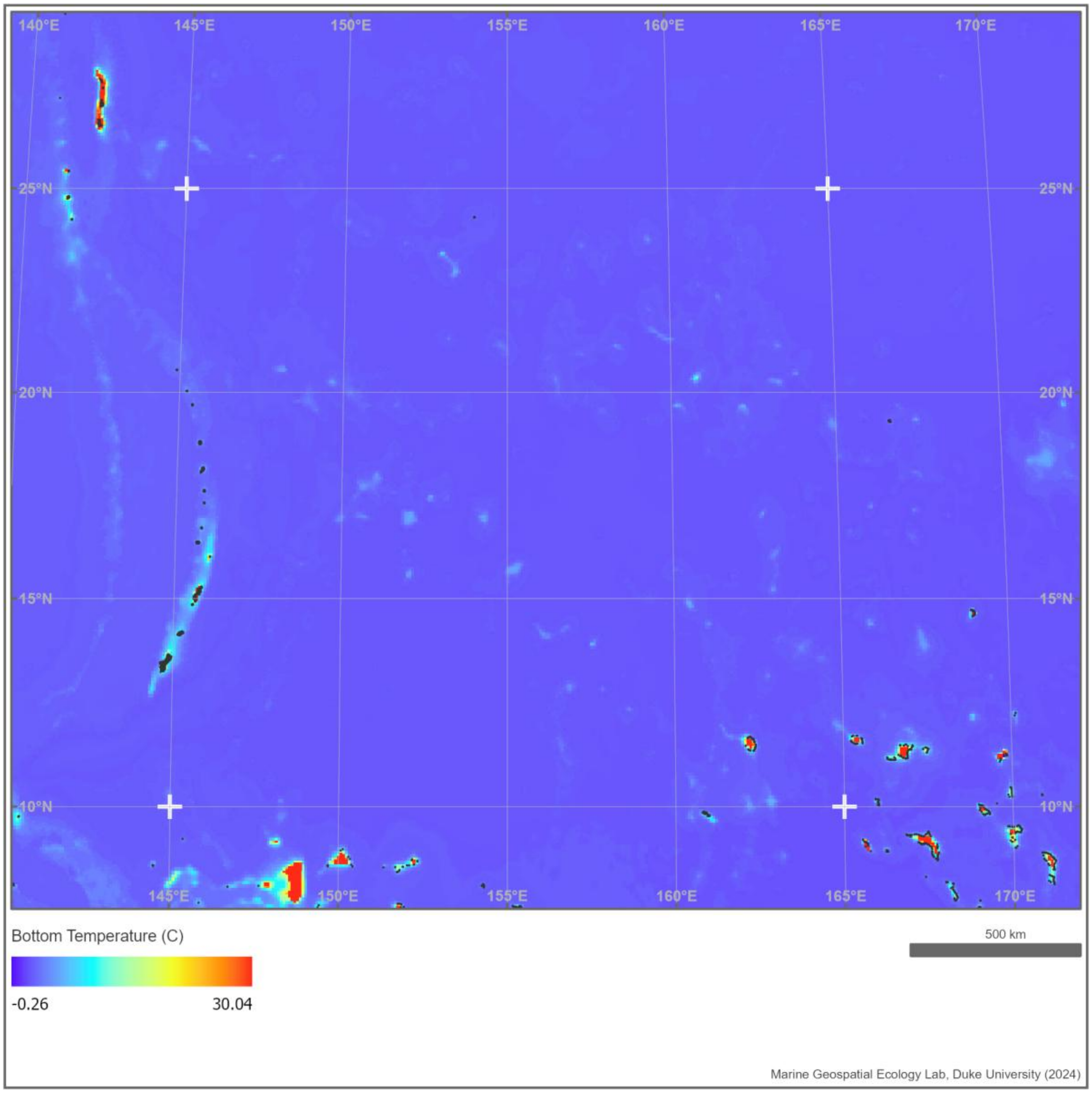


Figure 2.15-4 Bottom temperature, June 2023

2.16 Sea Surface Temperature Front Climatology

The NASA Jet Propulsion Laboratory Physical Oceanography Distributed Active Archive Center (PO.DAAC) publishes sea surface temperature images from the Moderate Resolution Imaging Spectroradiometer (MODIS).

For this effort, SST fronts were detected using the "Find Cayula-Cornillon Fronts in PO.DAAC MODIS L3 SST" tool in the Marine Geospatial Ecology Tools (MGET) for ArcGIS (Roberts et al., 2010). The front threshold was set to 1 degree Celsius, and the tool was run for every daily image available from 2015 – 2019 (inclusive). A custom Python script was then run to calculate the percentage of days with a temperature front over the full set of daily images. Data summaries were created monthly, annually, and over the entire date range.

References:
Roberts, J.J., B.D. Best, D.C. Dunn, E.A. Treml, and P.N. Halpin (2010). Marine Geospatial Ecology Tools: An integrated framework for ecological geoprocessing with ArcGIS, Python, R, MATLAB, and C++. Environmental Modelling & Software 25: 1197-1207.

J.-F. Cayula, P. Cornillon (1992), Edge Detection Algorithm for SST Images, *Journal of Atmospheric and Oceanic Technology* 9, 67–80.

An overall mean is shown below.

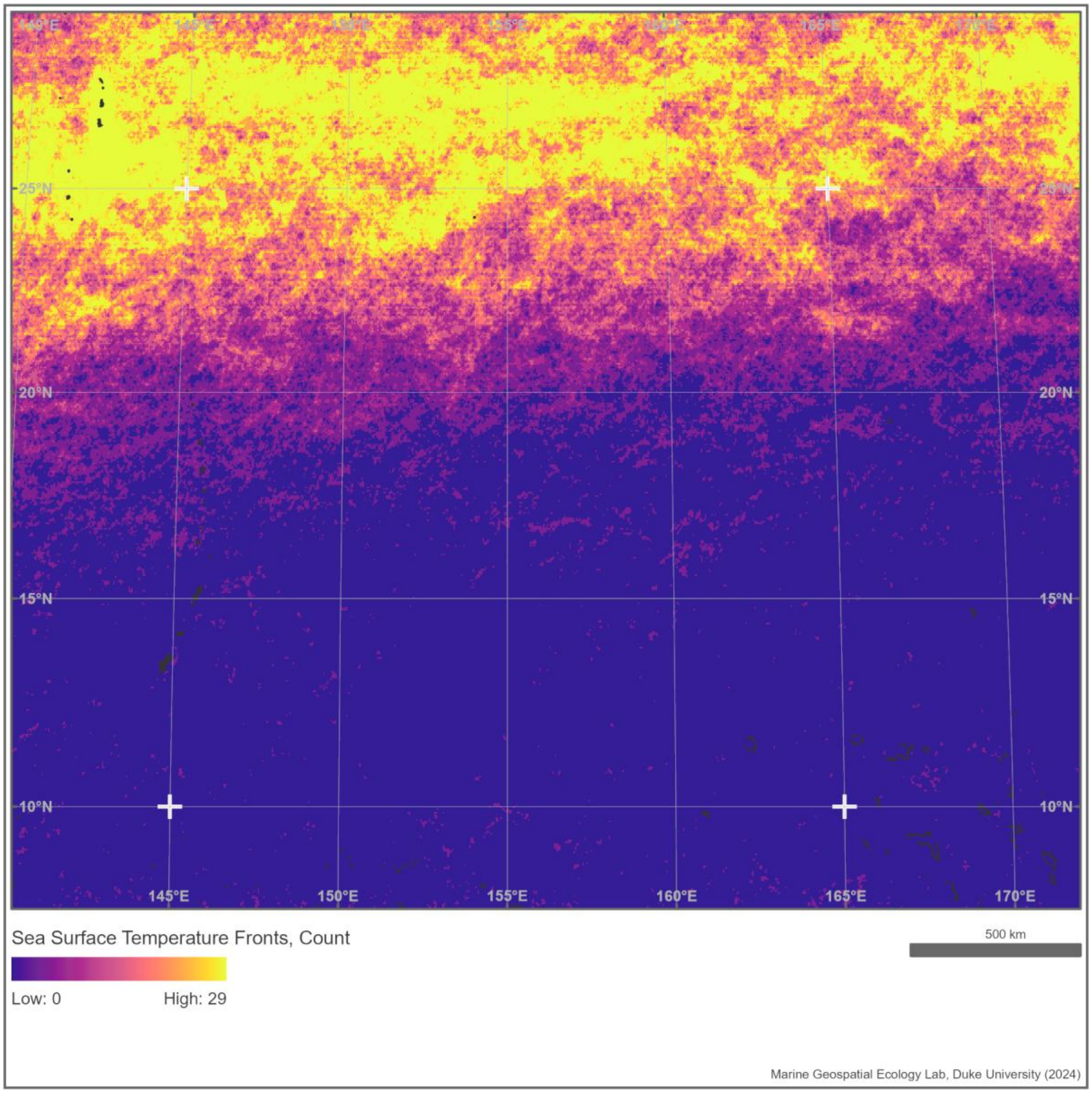


Figure 2.16-1 Sea surface temperature front climatology

2.17 Mesoscale Eddy Climatology

“The altimeter the Mesoscale Eddy Trajectory Atlas products were produced by SSALTO/DUACS and distributed by AVISO+ (http://www.aviso.altimetry.fr/) with support from CNES, in collaboration with Oregon State University with support from NASA. Eddies detected from the multimission altimetry datasets, with location each day for the whole altimetry period (1993-ongoing, in delayed-time), type (cyclonic/anticyclonic), speed, radius and associated metadata.”

Source: Mesoscale Eddy Trajectory Atlas, version 2.0exp, https://www.aviso.altimetry.fr/index.php?id=3280&L=1

Reference:
Mesoscale Eddy Trajectory Atlas Product Handbook, SALP-MU-P-EA-23126, issue 2.0 https://www.aviso.altimetry.fr/fileadmin/documents/data/tools/hdbk_eddytrajectory_2.0exp.pdf

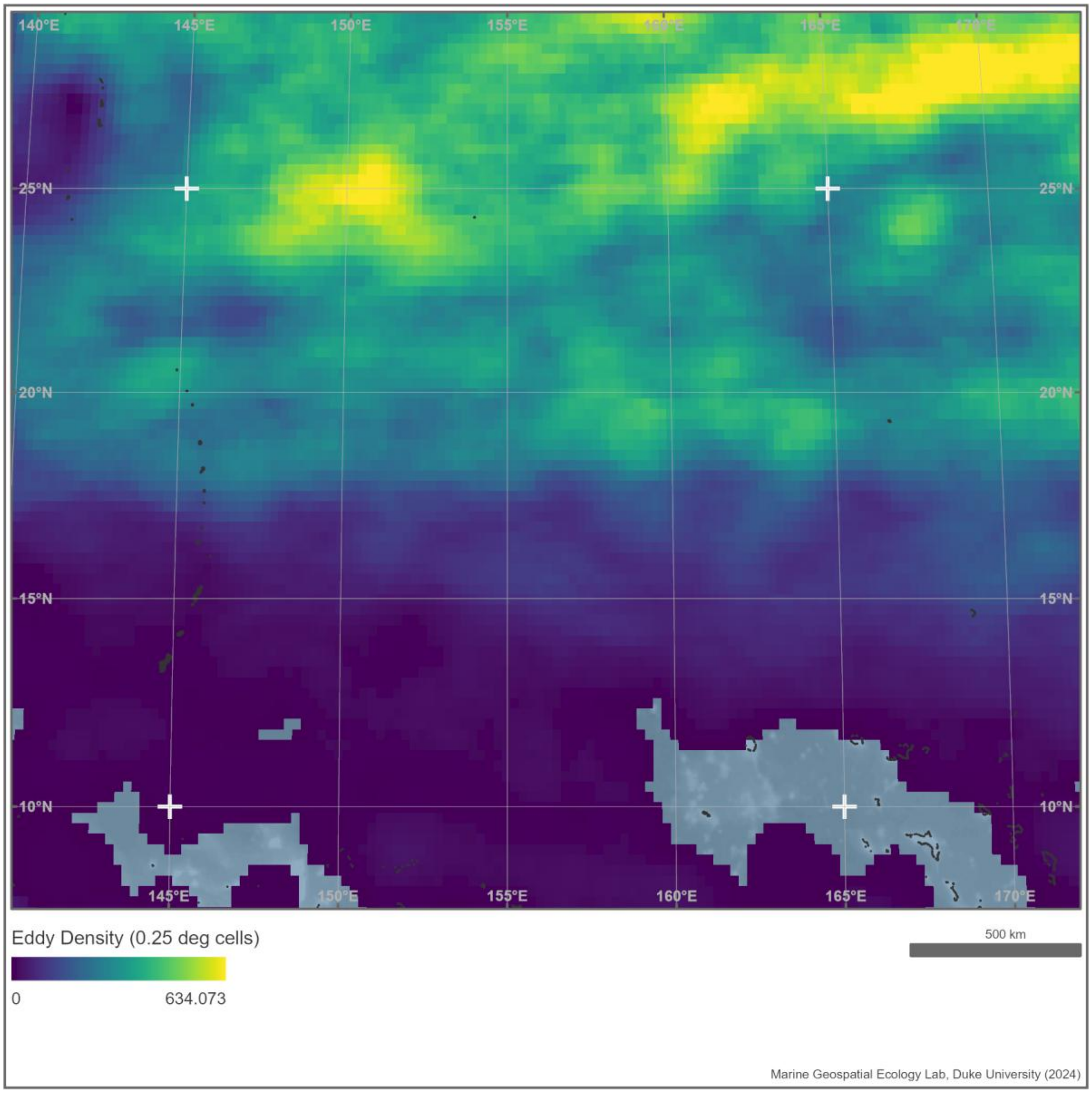


Figure 2.17-1 Mesoscale eddy density

2.18 Drifter Climatology of Near-Surface Currents

Description:
"Satellite-tracked SVP drifting buoys (Sybrandy and Niiler, 1991; Niiler, 2001) provide observations of near-surface circulation at unprecedented resolution. In September 2005, the Global Drifter Array became the first fully realized component of the Global Ocean Observing System when it reached an array size of 1250 drifters. A drifter is composed of a surface float which includes a transmitter to relay data, a thermometer that reads temperature a few centimeters below the air/sea interface, and a submergence sensor used to detect when/if the drogue is lost. The surface float is tethered to a holey sock drogue, centered at 15 m depth. The drifter follows the flow integrated over the drogue depth, although some slip with respect to this motion is associated with direct wind forcing (Niiler and Paduan, 1995). This slip is greatly enhanced in drifters that have lost their drogues (Pazan and Niiler, 2000). Drifter velocities are derived from finite differences of their position fixes. These velocities, and the concurrent SST measurements, are archived at AOML's Drifting Buoy Data Assembly Center, where the data are quality controlled and interpolated to 1/4-day intervals (Hansen and Herman, 1989; Hansen and Poulain, 1996)."

Source: https://www.aoml.noaa.gov/phod/gdp/mean_velocity.php

Reference:
Laurindo, L. C., Mariano, A. J., & Lumpkin, R. (2017). An improved near-surface velocity climatology for the global ocean from drifter observations. Deep Sea Research Part I: Oceanographic Research Papers, 124, 73-92. doi: 10.1016/j.dsr.2017.04.009

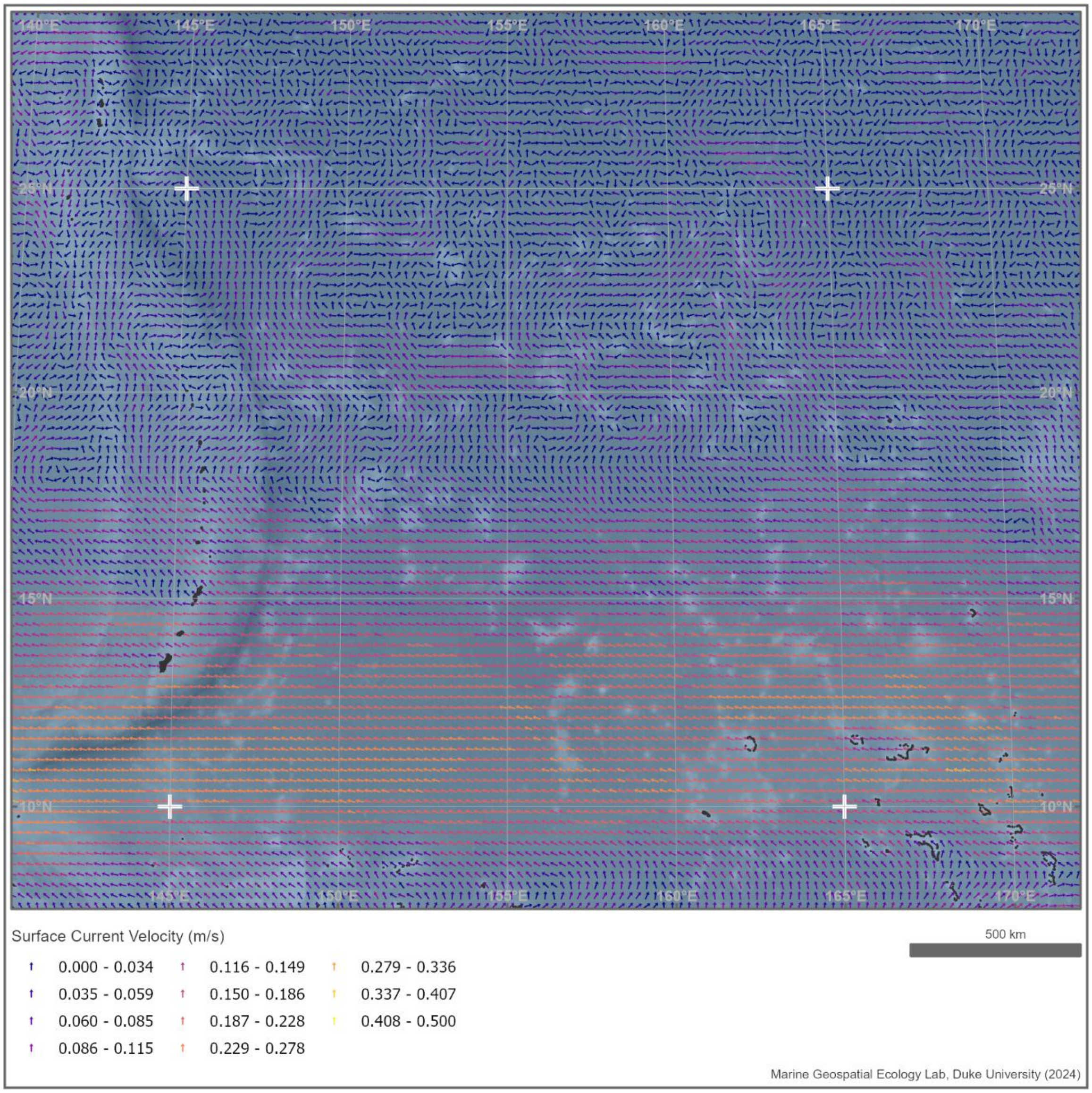


Figure 2.18-1 Drifter-derived climatology of near-surface currents

2.19 Chlorophyll a Concentration Monthly Climatologies

Monthly cumulative Chlorophyll a climatologies were created from Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua data for 2012-2021 (inclusive). These data were created by a script processing the "Ocean Color SMI: Standard Mapped Image MODIS Aqua Data" dataset in Google Earth Engine.

"This level 3 product includes ocean color and satellite ocean biology data produced or collected under EOSDIS. This dataset may be used for studying the biology and hydrology of coastal zones, changes in the diversity and geographical distribution of coastal marine habitats, biogeochemical fluxes and their influence in Earth's oceans and climate over time, and finally the impact of climate and environmental variability and change on ocean ecosystems and the biodiversity they support."

Source:
https://developers.google.com/earth-engine/datasets/catalog/NASA_OCEANDATA_MODIS-Aqua_L3SMI#description

Reference:
NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Ocean Biology Processing Group. Moderate-resolution Imaging Spectroradiometer (MODIS) Aqua Ocean Color Data, NASA OB.DAAC, Greenbelt, MD, USA.

While these datasets were created at a monthly time step, other temporal averages could be created as needed.

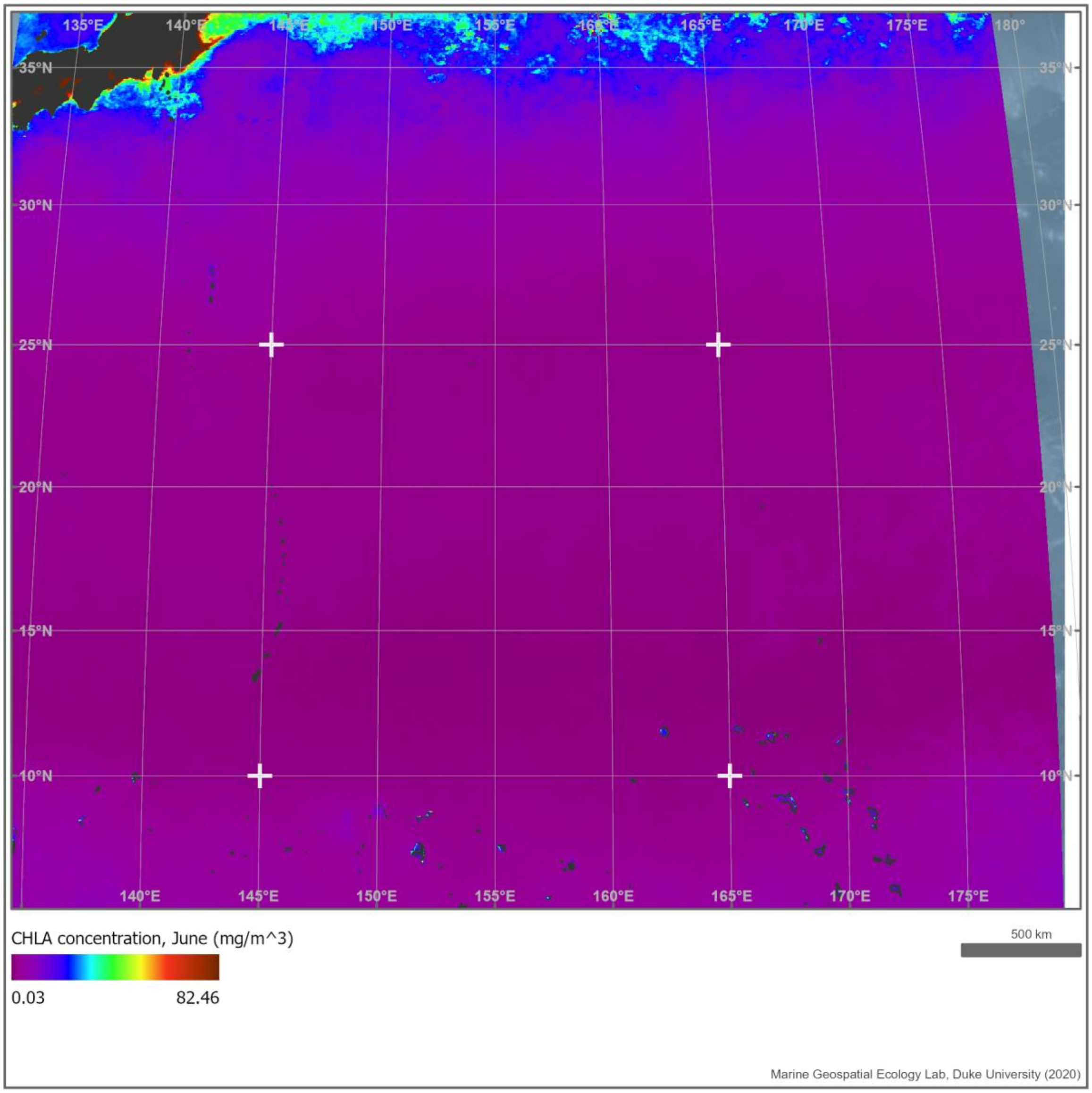


Figure 2.19-1 Chlorophyll a concentration climatology: June

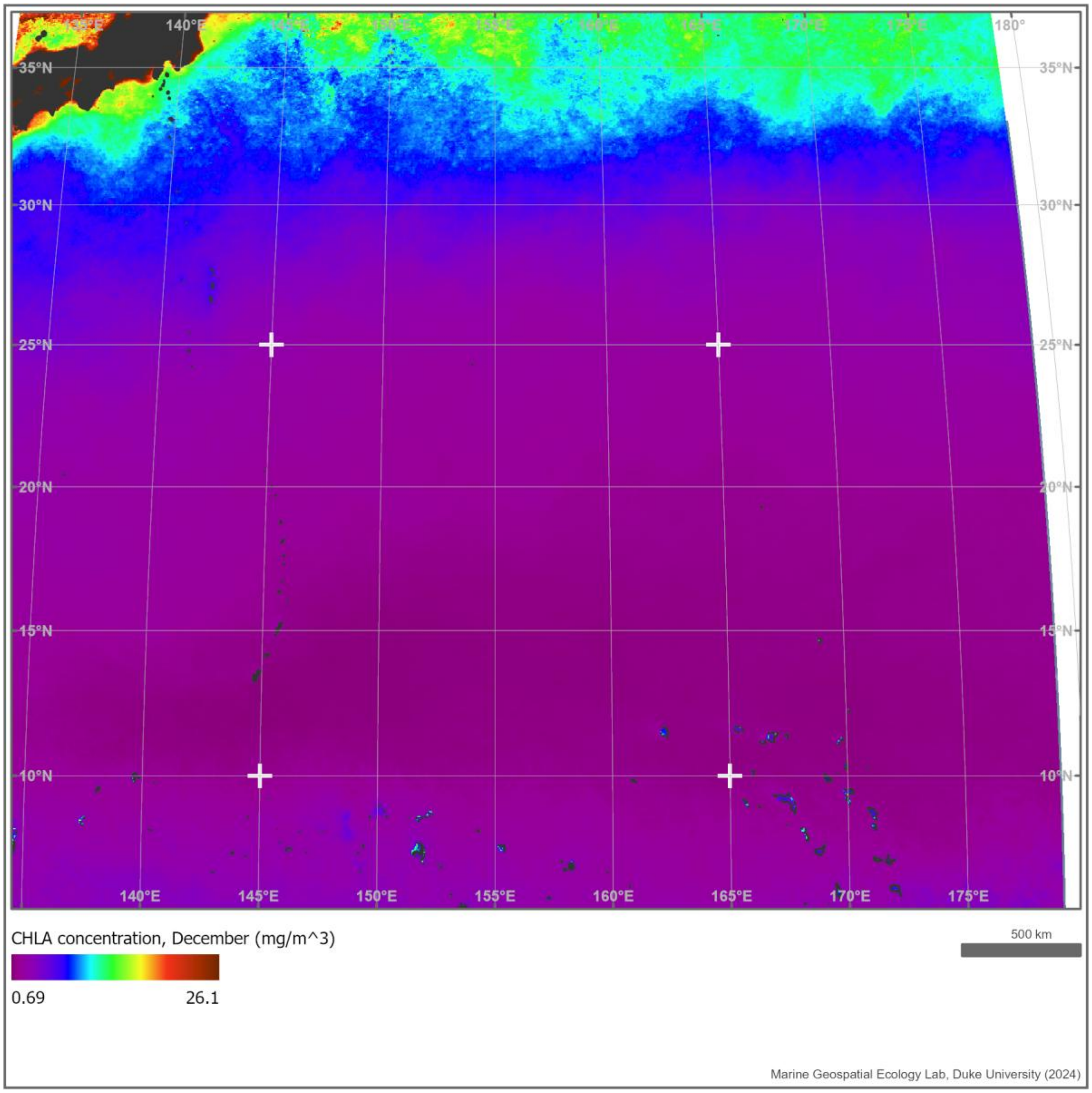


Figure 2.19-2 Chlorophyll a concentration climatology: December

2.20 Vertically Generalized Production Model (VGPM) Primary Productivity

Description:
"Standard Ocean Productivity Products are based on the original description of the Vertically Generalized Production Model (VGPM) (Behrenfeld & Falkowski 1997), MODIS surface chlorophyll concentrations (Chl_{sat}), MODIS 11-micron daytime sea surface temperature data (SST), and MODIS cloud-corrected incident daily photosynthetically active radiation (PAR). Euphotic depths are calculated from Chl_{sat} following Morel and Berthon (1989)."

For this effort, a cumulative climatology was created from Standard VGPM data derived from MODIS data from 2015-2019 (inclusive).

Reference:
Behrenfeld MJ, Falkowski PG (1997) Photosynthetic rates derived from satellite-based chlorophyll concentration. Limonology And Oceanography 42:1–20.

Source:
http://sites.science.oregonstate.edu/ocean.productivity/standard.product.php

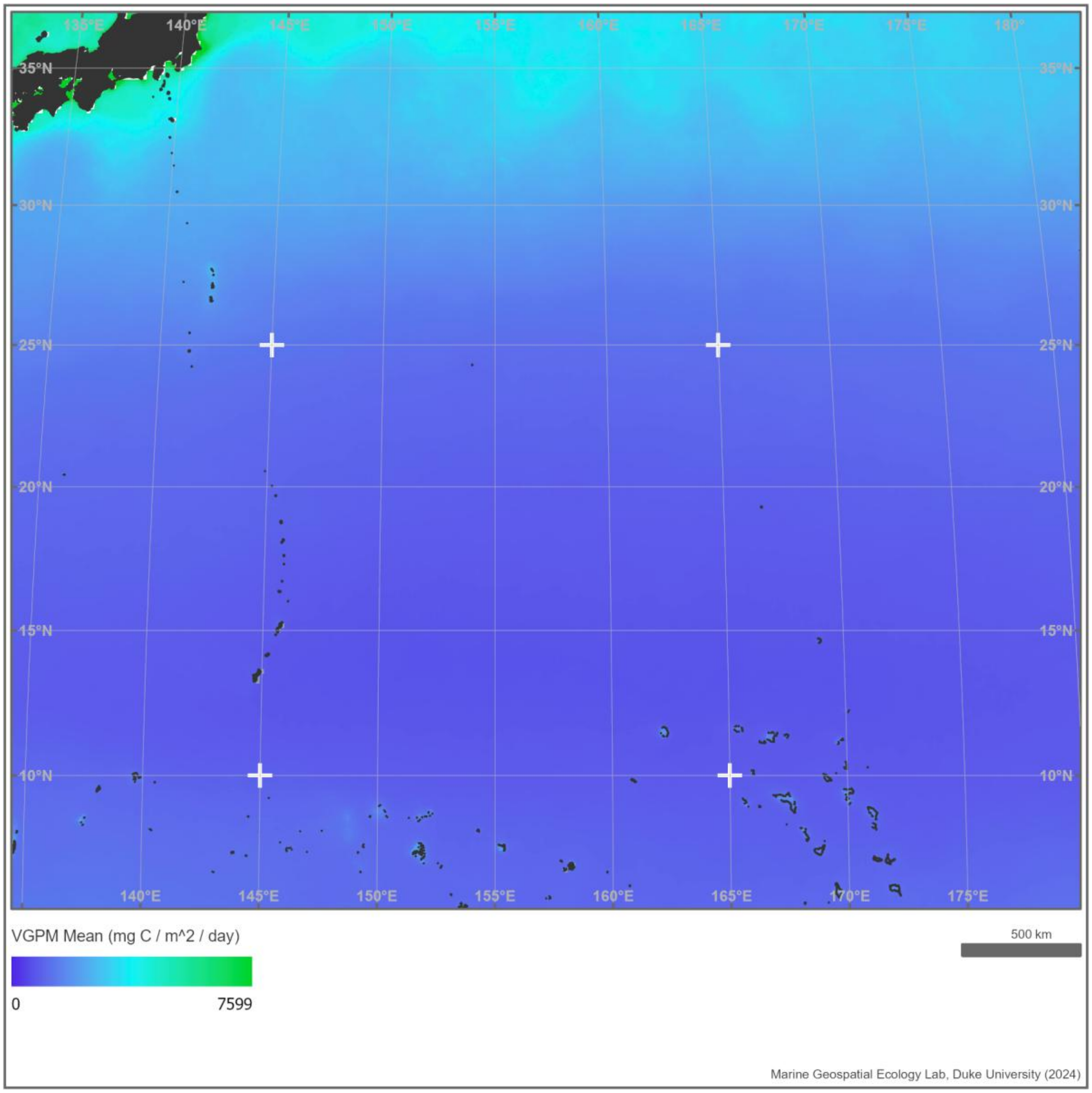


Figure 2.20-1 Vertically generalized production model - primary productivity climatology

2.21 Net Primary Productivity - Operational Mercator Ocean Biogeochemical Global Ocean Analysis and Forecast System

Description:
"The Operational Mercator Ocean biogeochemical global ocean analysis and forecast system at 1/4 degree is providing 10 days of 3D global ocean forecasts updated weekly. The time series is aggregated in time, in order to reach a two full year's time series sliding window. This product includes daily and monthly mean files of biogeochemical parameters (chlorophyll, nitrate, phosphate, silicate, dissolved oxygen, dissolved iron, primary production, phytoplankton, PH, and surface partial pressure of carbon dioxyde) over the global ocean. The global ocean output files are displayed with a 1/4 degree horizontal resolution with regular longitude/latitude equirectangular projection. 50 vertical levels are ranging from 0 to 5700 meters."

Source:
https://data.marine.copernicus.eu/product/GLOBAL_ANALYSISFORECAST_BGC_001_028/description

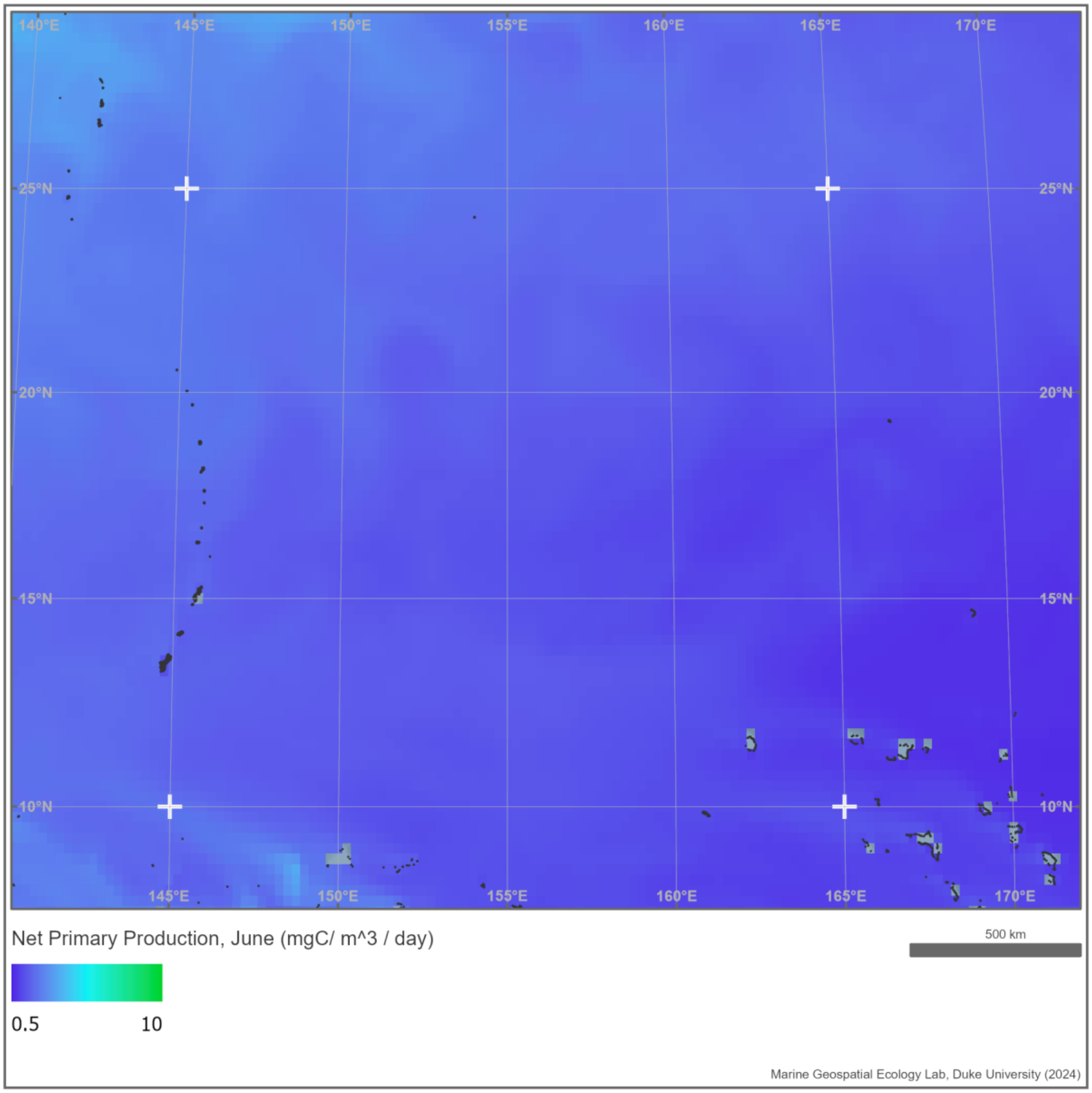


Figure 2.21-1 Net primary production of phytoplankton biomass, June 2022

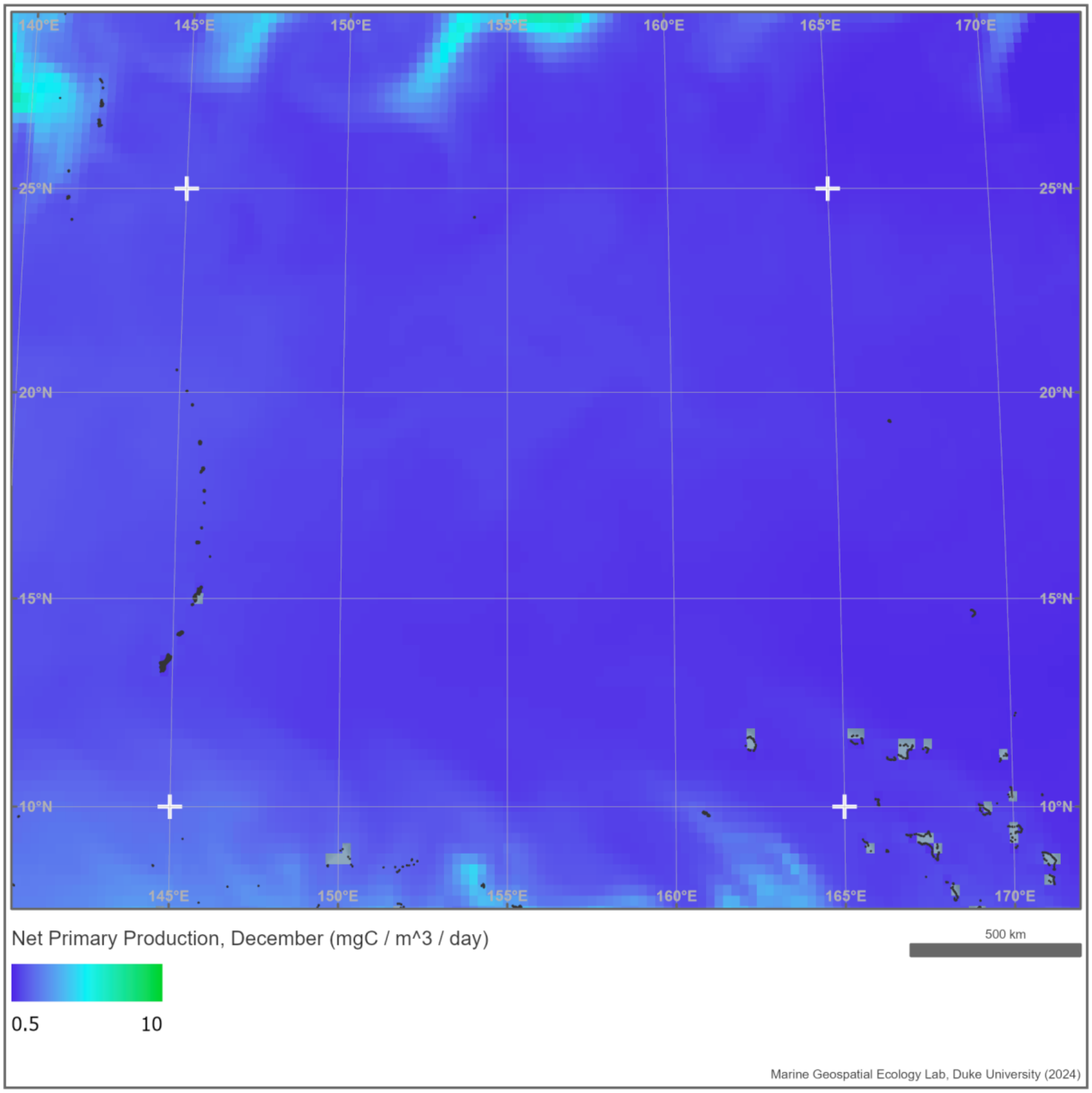


Figure 2.21-2 Net primary production of phytoplankton biomass, December 2022

2.22 Global Ocean Low and Mid Trophic Levels Biomass Hindcast

Description:
"The Low and Mid-Trophic Levels (LMTL) reanalysis for global ocean is produced at CLS on behalf of Global Ocean Marine Forecasting Center. It provides 2D fields of biomass content of zooplankton and six functional groups of micronekton. It uses the LMTL component of SEAPODYM dynamical population model (http://www.seapodym.eu). No data assimilation has been done. This product also contains forcing data: net primary production, euphotic depth, depth of each pelagic layers zooplankton and micronekton inhabit, average temperature and currents over pelagic layers.

Forcings sources:

- Ocean currents and temperature (CMEMS multiyear product)
- Net Primary Production computed from chlorophyll a, Sea Surface Temperature and Photosynthetically Active Radiation observations (chlorophyll from CMEMS multiyear product, SST from NOAA NCEI AVHRR-only Reynolds, PAR from INTERIM) and relaxed by model outputs at high latitudes (CMEMS biogeochemistry multiyear product)"

Source: https://doi.org/10.48670/moi-00

References:
Lehodey P., Murtugudde R., Senina I. (2010). Bridging the gap from ocean models to population dynamics of large marine predators: a model of mid-trophic functional groups. Progress in Oceanography, 84, p. 69-84.

Lehodey, P., Conchon, A., Senina, I., Domokos, R., Calmettes, B., Jouanno, J., Hernandez, O., Kloser, R. (2015) Optimization of a micronekton model with acoustic data. ICES Journal of Marine Science, 72(5), p. 1399-1412.

Conchon A. (2016). Modélisation du zooplancton et du micronecton marins. Thèse de Doctorat, Université de La Rochelle, 136 p.

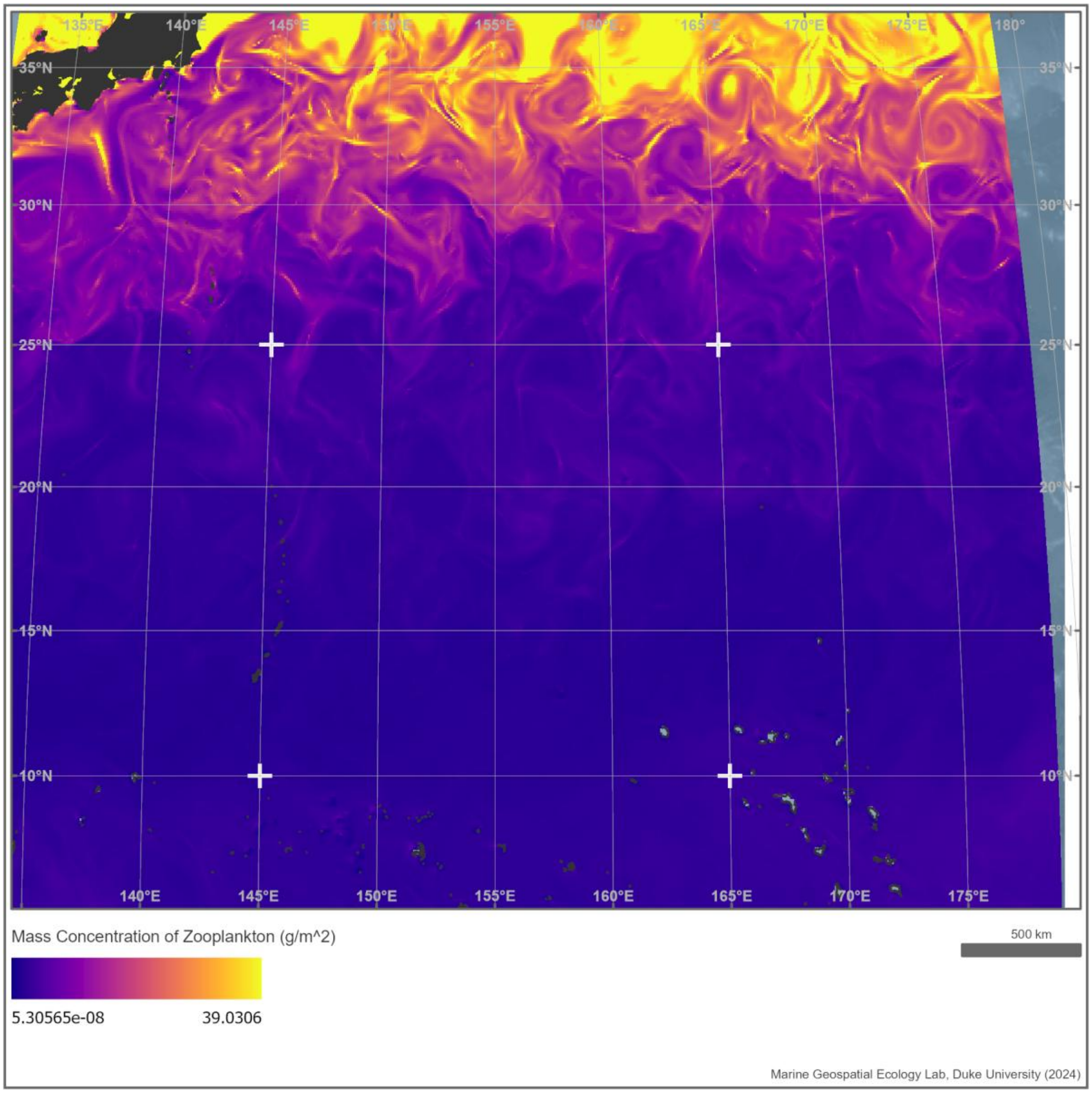


Figure 2.22-1 Zooplankton biomass, June 2022

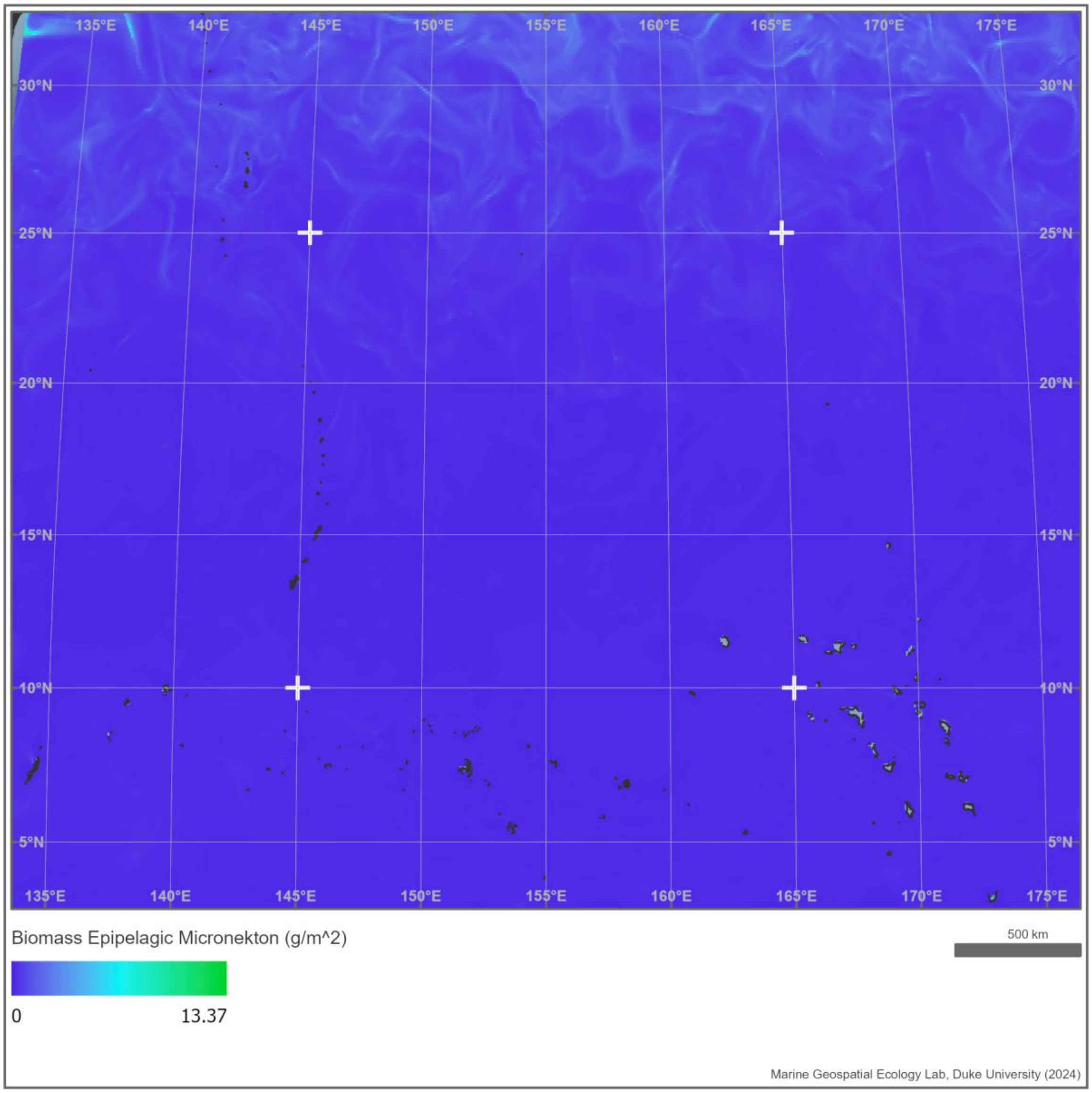


Figure 2.22-2 Epipelagic micronekton biomass, June 2022

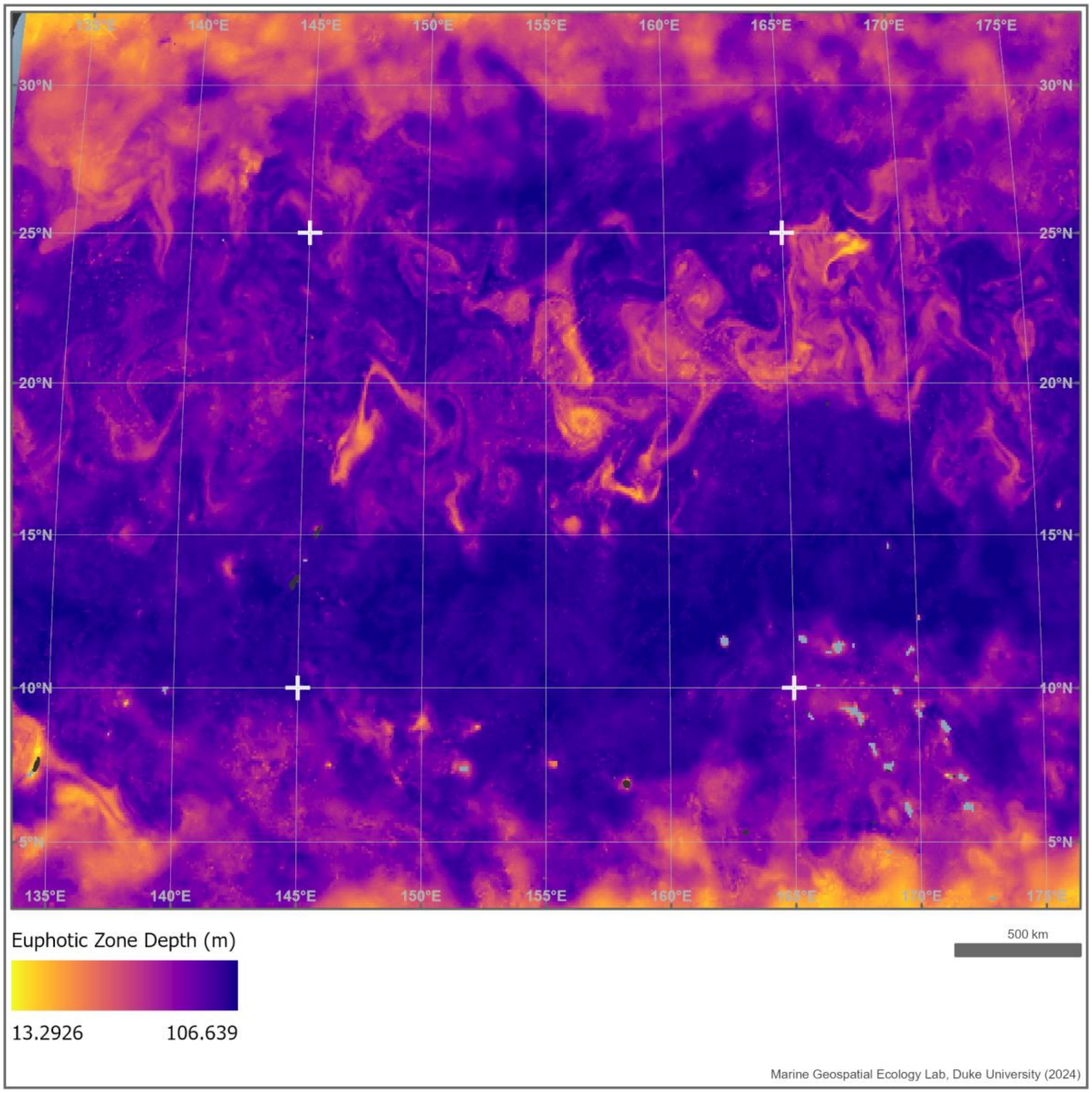


Figure 2.22-3 Euphotic zone depth, June 2022

2.23 Seafloor Particulate Organic Carbon (POC) Flux

Abstract (Sweetman et al. 2017):

The deep sea encompasses the largest ecosystems on Earth. Although poorly known, deep seafloor ecosystems provide services that are vitally important to the entire ocean and biosphere. Rising atmospheric greenhouse gases are bringing about significant changes in the environmental properties of the ocean realm in terms of water column oxygenation, temperature, pH and food supply, with concomitant impacts on deep-sea ecosystems. Projections suggest that abyssal (3000–6000 m) ocean temperatures could increase by 1°C over the next 84 years, while abyssal seafloor habitats under areas of deep-water formation may experience reductions in water column oxygen concentrations by as much as 0.03 mL L–1 by 2100. Bathyal depths (200–3000 m) worldwide will undergo the most significant reductions in pH in all oceans by the year 2100 (0.29 to 0.37 pH units). O2 concentrations will also decline in the bathyal NE Pacific and Southern Oceans, with losses up to 3.7% or more, especially at intermediate depths. Another important environmental parameter, the flux of particulate organic matter to the seafloor, is likely to decline significantly in most oceans, most notably in the abyssal and bathyal Indian Ocean where it is predicted to decrease by 40–55% by the end of the century. Unfortunately, how these major changes will affect deep-seafloor ecosystems is, in some cases, very poorly understood. In this paper, we provide a detailed overview of the impacts of these changing environmental parameters on deep-seafloor ecosystems that will most likely be seen by 2100 in continental margin, abyssal and polar settings. We also consider how these changes may combine with other anthropogenic stressors (e.g., fishing, mineral mining, oil and gas extraction) to further impact deep-seafloor ecosystems and discuss the possible societal implications.

Reference:

Sweetman, AK et al 2017 Major impacts of climate change on deep-sea benthic ecosystems. Elem Sci Anth, 5: 4, DOI: https://doi.org/10.1525/elementa.203

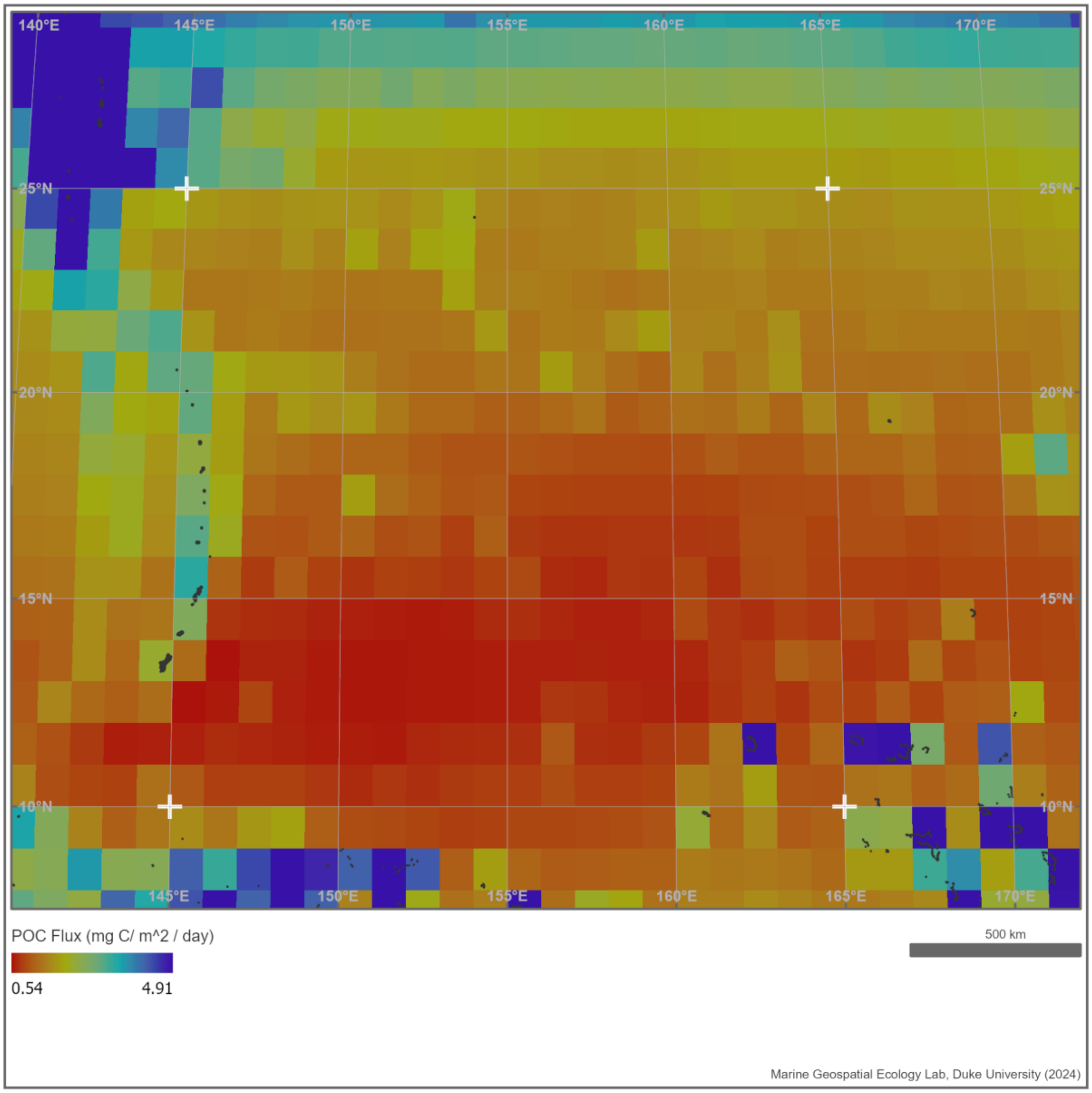


Figure 2.23-1 Particulate organic carbon flux to the seafloor

2.24 International Seabed Authority Deep Data Portal: CTD Data

"The newly developed "ISA Deep Seabed and Ocean Database" (*DeepData*) was launched in July 2019 at the Authority's 25th Session. This database has been designed to serve as a spatial, internet-based data management system. Its main function is to host all deep-seabed activities related data and in particular, data collected by the contractors on their exploration activities as well as any other relevant environmental and resources related data for the Area.

DeepData contains information on mineral resource assessment (geological data) and environmental baseline/assessment data. However, only the environmental data are accessible to the public. This include biological, physical and geochemical parameters of the marine ecosystems from the seafloor to the ocean surface.

The Geographical Information System (GIS) is part of *DeepData* functionalities. As such, it allows visualization of contract areas, reserved areas and designated areas of particular environmental interest (APEIs). GIS information accessible through *DeepData* also include sampling locations containing biological, physical and/or geochemical parameters of the seabed sediments and water column."

Deep Data Portal: https://data.isa.org.jm/isa/map/

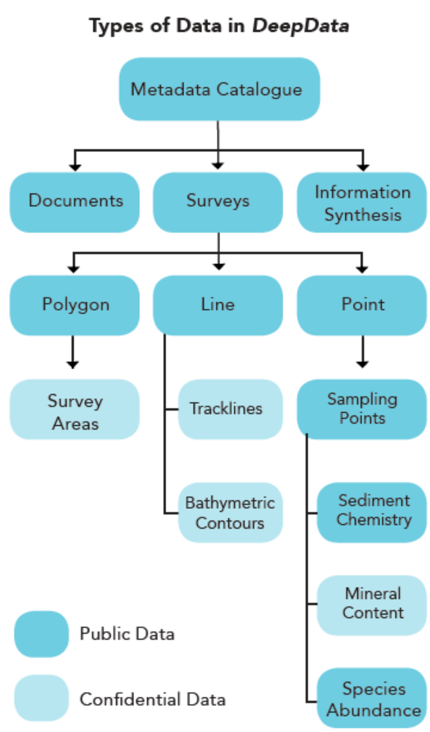


Figure 2.24-1 Chart of data types in Deep Data

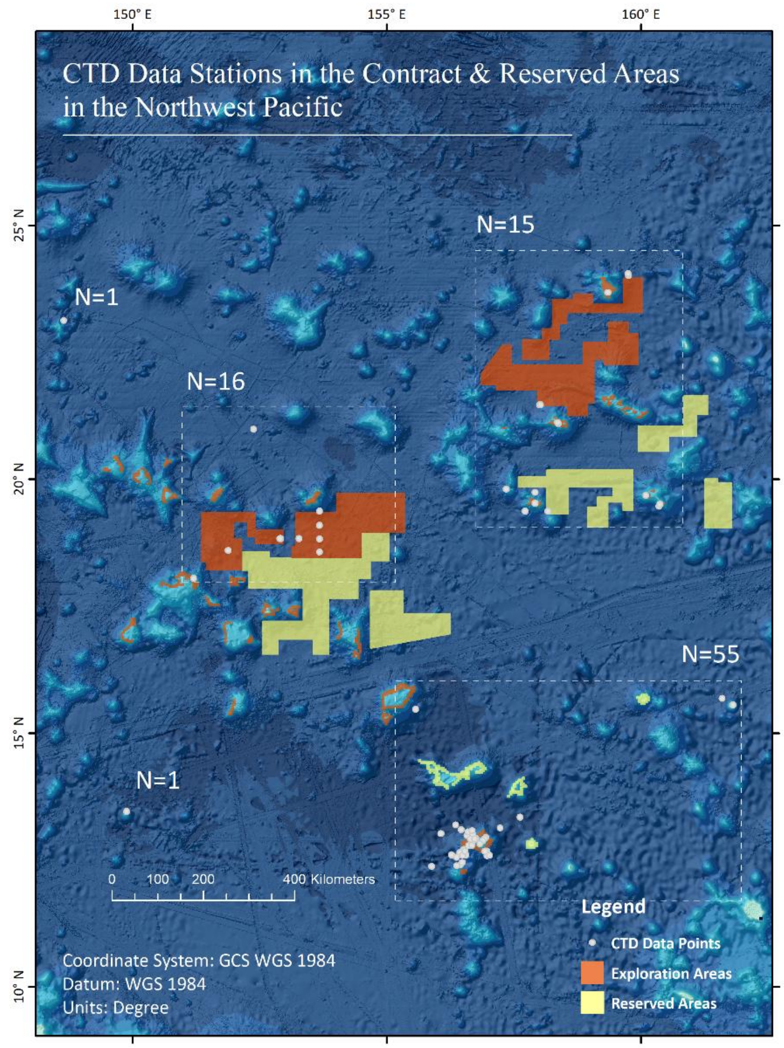


Figure 2.24-2 ISA Deep Data Conductivity, Temperature, Depth (CTD) data stations

2.25 NOAA Climate Change Portal

“A key approach for examining climate, especially how it will change in the future, uses complex computer models of the climate system that includes atmosphere, ocean, sea ice and land components. Some models also include additional aspects of the earth system, including chemistry and biology. The Climate Change Portal is a web interface developed by the NOAA ESRL Physical Sciences Division to access and display the immense volumes of climate and earth system model output that informed the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5). The webtool makes climate change information more accessible to natural resource managers, decision makers and educators.”

Link: https://www.esrl.noaa.gov/psd/ipcc/ocn/

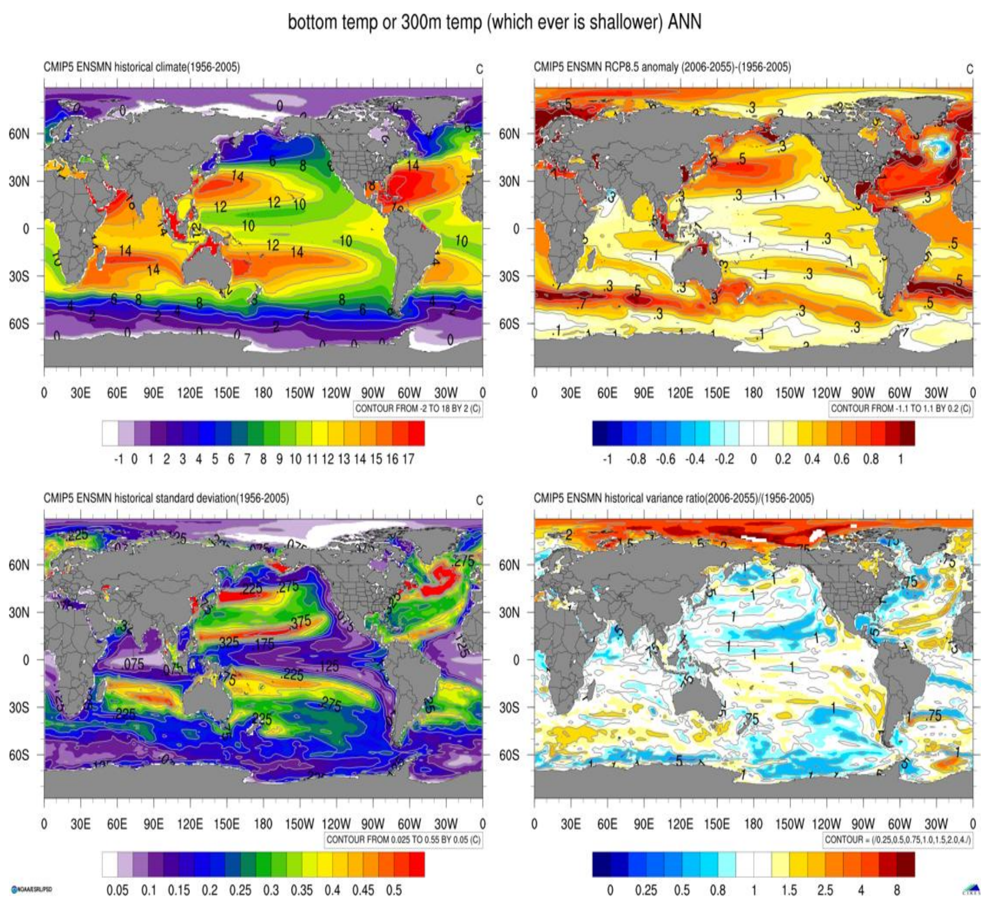


Figure 2.25-1 Climate change variables from CMIP5 data

2.26 Dynamic Seascape Pelagic Habitat Classification

"The CoastWatch Seascape Pelagic Habitat Classification product (CW Seascapes) identifies spatially explicit water masses with particular biogeochemical features using a model and satellite-derived measurements. The seascape product is generated as monthly and 8-day composites at 5 km spatial resolution.

US and global Marine Biodiversity Observation Network (MBON) partnered with US Integrated Ocean Observation System (IOOS), NOAA/OAR/AOML and NOAA/NESDIS/STAR to develop and routinely generate "seascapes" products and to make them available on CoastWatch. Derived from dynamic fields of satellite and modelled data, seascapes are classified and used as a biogeographical framework to describe dynamic, changing ocean habitats for MBON and other applications. CW Seascapes provide information about the quality and extent of different oceanographic habitats or features and can be used to assess and predict the different planktonic and fisheries communities that reside within seascapes. Current CW Seascapes products include monthly and 8-day time steps at 5 km resolution. High resolution (1 km) case studies are planned on a case by case basis as through cooperation with US and global MBON partners."

Data are available at 8-day and monthly timesteps back to January 2003:
https://coastwatch.noaa.gov/cw/satellite-data-products/multi-parameter-models/seascape-pelagic-habitat-classification.html

Reference:
Kavanaugh, Maria T., Matthew J. Oliver, Francisco P. Chavez, Ricardo M. Letelier, Frank E. Muller-Karger, and Scott C. Doney. 2016. "Seascapes as a New Vernacular for Pelagic Ocean Monitoring, Management and Conservation." *ICES Journal of Marine Science* 73 (7): 1839–50. https://doi.org/10.1093/icesjms/fsw086.

Region - Seascape Class ID and Name:
3, TROPICAL SUBTROPICAL TRANSITION
5, SUBTROPICAL GYRE TRANSITION
8, INDOPACIFIC SUBTROPICAL GYRE
9, EQUATORIAL TRANSITION
10, HIGHLY OLIGOTROPHIC SUBTROPICAL GYRE
11, TROPICAL/SUBTROPICAL UPWELLING
13, SUBTROPICAL GYRE MESOSCALE INFLUENCED
15, TROPICAL SEAS
17, SUBTROPICAL TRANSITION LOW NUTRIENT STRESS
20, SUBTROPICAL, FRESH INFLUENCED COASTAL
21, WARM, BLOOMS, HIGH NUTS

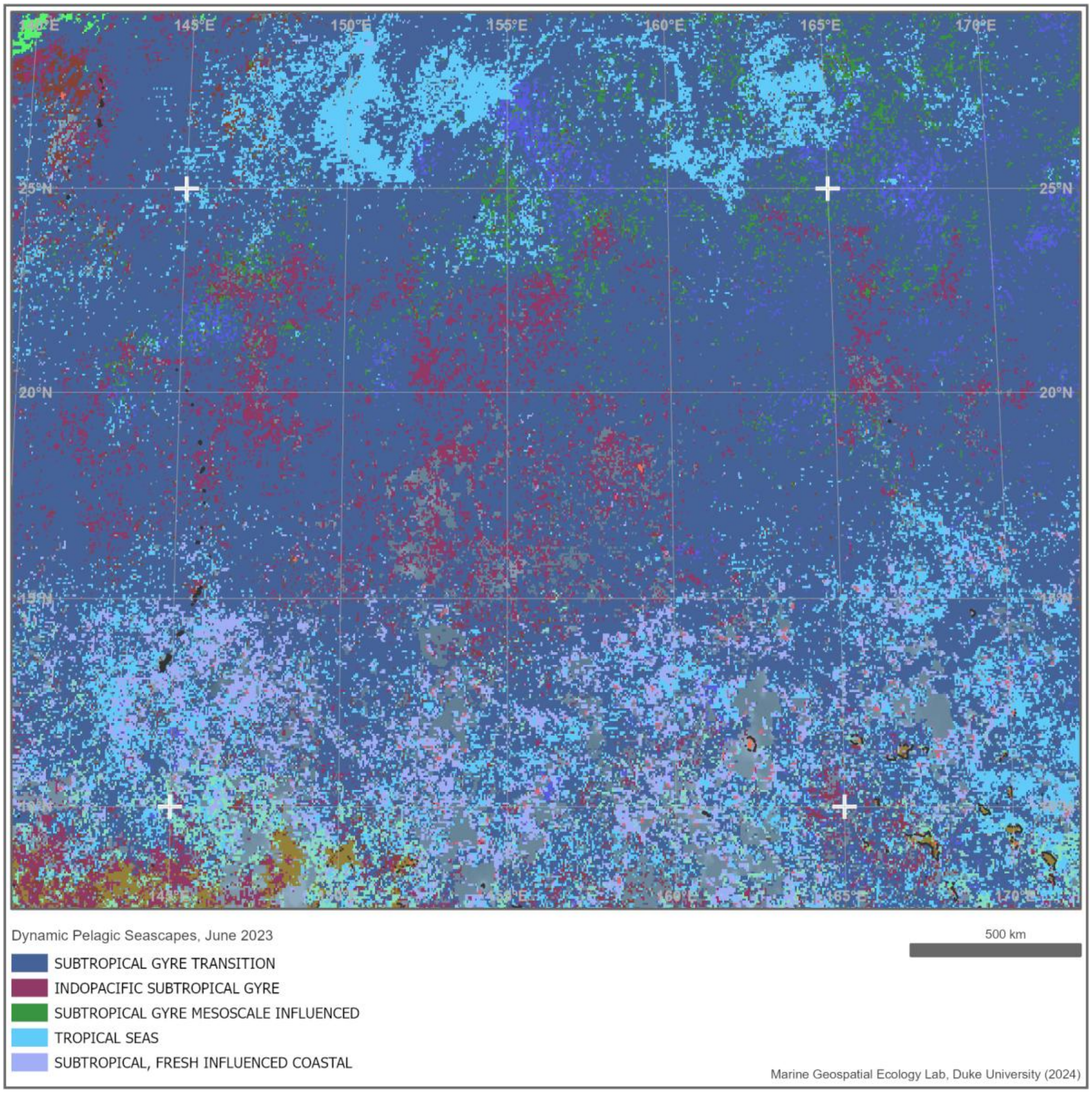


Figure 2.26-1 Dynamic pelagic seascapes – June 2023

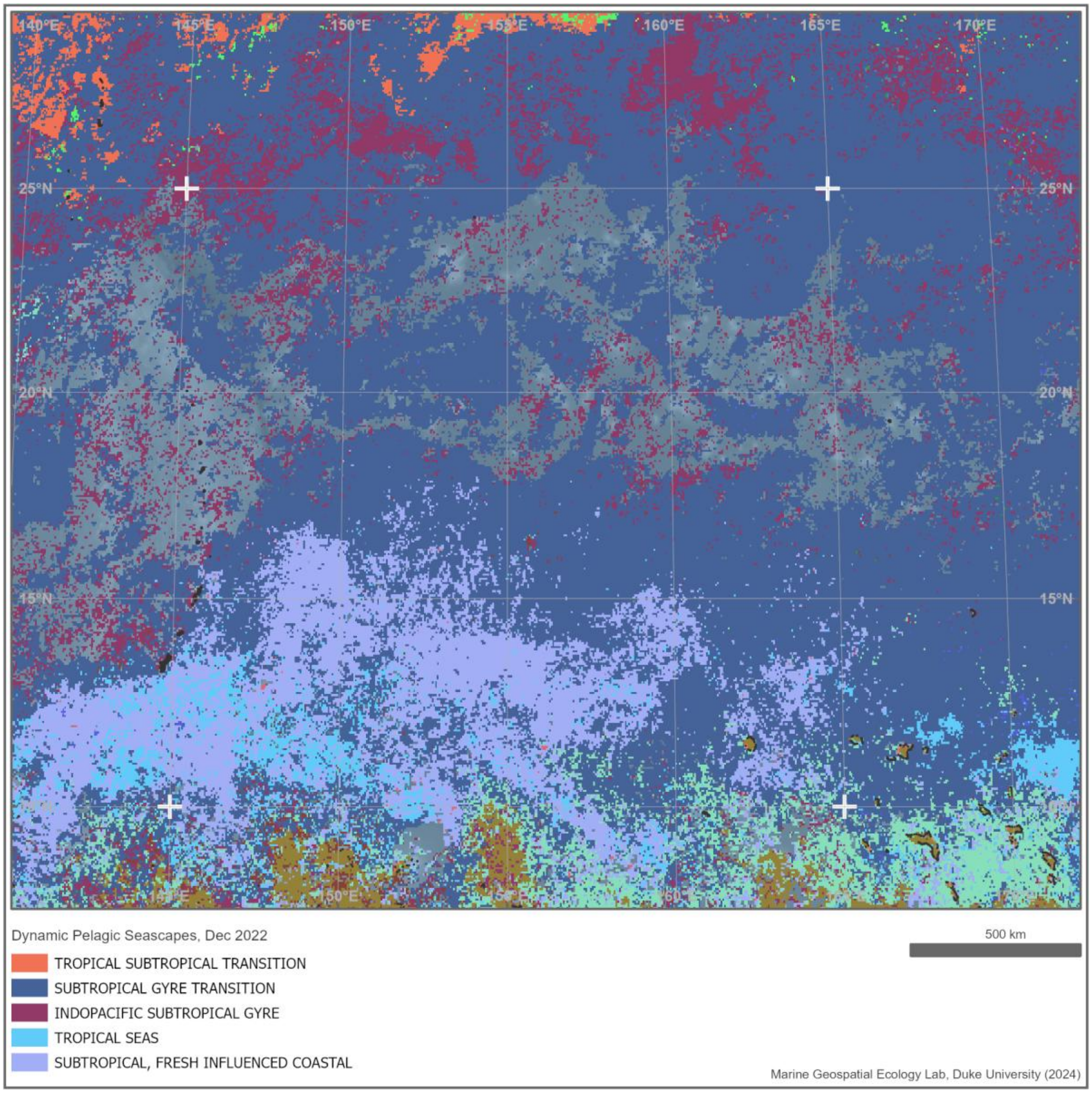


Figure 2.26-2 Dynamic pelagic seascapes – December 2022

2.27 Ecological Marine Units

Abstract:
"In response to an intergovernmental commission for a high resolution and data-derived global marine ecosystems map, distinct marine physical and chemical volumetric regions were characterized in an environmental stratification of the global ocean. The stratification produced 37 ecological marine units (EMUs) at a base resolution of ¼° (approximately 27 kilometers at the equator). The EMUs were objectively derived from non-supervised statistical clustering of over 52 million points from NOAA's World Ocean Atlas 2013 (WOA) database, an authoritative 57-year archive of global water column data. We organized the WOA data into a 3D ocean point mesh which represents a standardized geospatial framework for organizing physical, chemical, and biological data that characterize ocean composition and processes. The points are currently attributed with values for temperature, salinity, dissolved oxygen, nitrate, phosphate, and silicate, the six input values used in the stratification. The data represent the most accurate, current, globally comprehensive, and finest spatial resolution data available for each of the six inputs organized in a standardized geospatial framework for improved understanding of ocean environments. While the methodology and initial findings are reported elsewhere, we provide herein a more detailed description of the open data geospatial resources and associated tool development. We present the EMU Explorer as a web-based query application that allows for the exploration of both the modeled EMUs as volumetric regions, and the comprehensive point data from the WOA."

Reference:
Sayre R, Dangermond J, Wright D, Breyer S, Butler K, Graafeiland K, Costello M, Harris P, Goodin K, Kavanaugh M, Cressie N, Guinotte J, Basher Z, Halpin P, Monaco M, Aniello P, Frye C, Stephens D, Valentine P, Convis C (2017) A New Map of Global Ecological Marine Units – An Environmental Stratification Approach. American Association of Geographers AAG Special Publication:36 p.

Data Access:
Ecological Marine Units V1, Atlantic Ocean
https://esri.maps.arcgis.com/home/item.html?id=8d3465c047324eb290b0acb79be72dd2

3D Mapper:
http://livingatlas.arcgis.com/emu

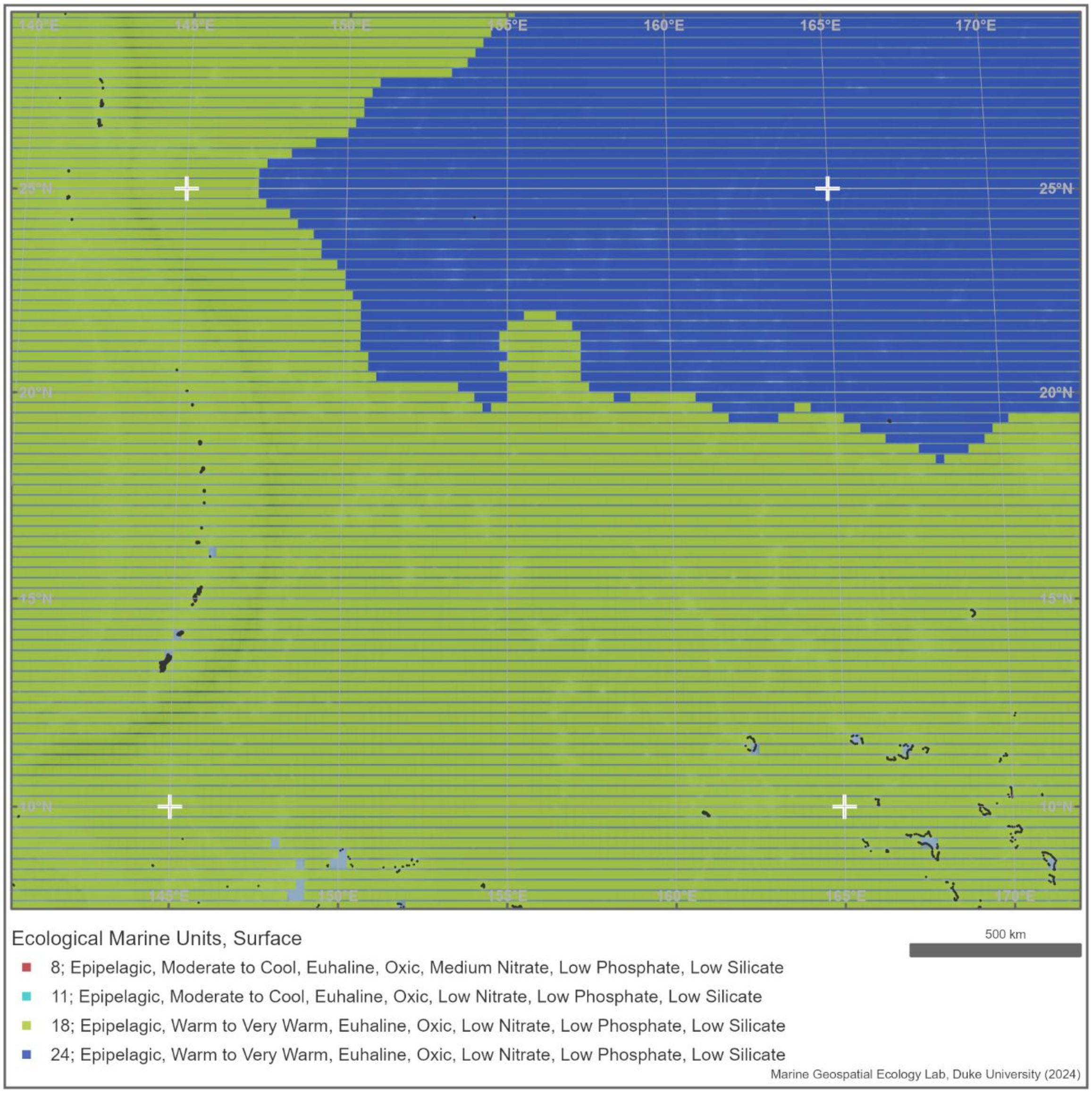


Figure 2.27-1 Ecological marine units - surface

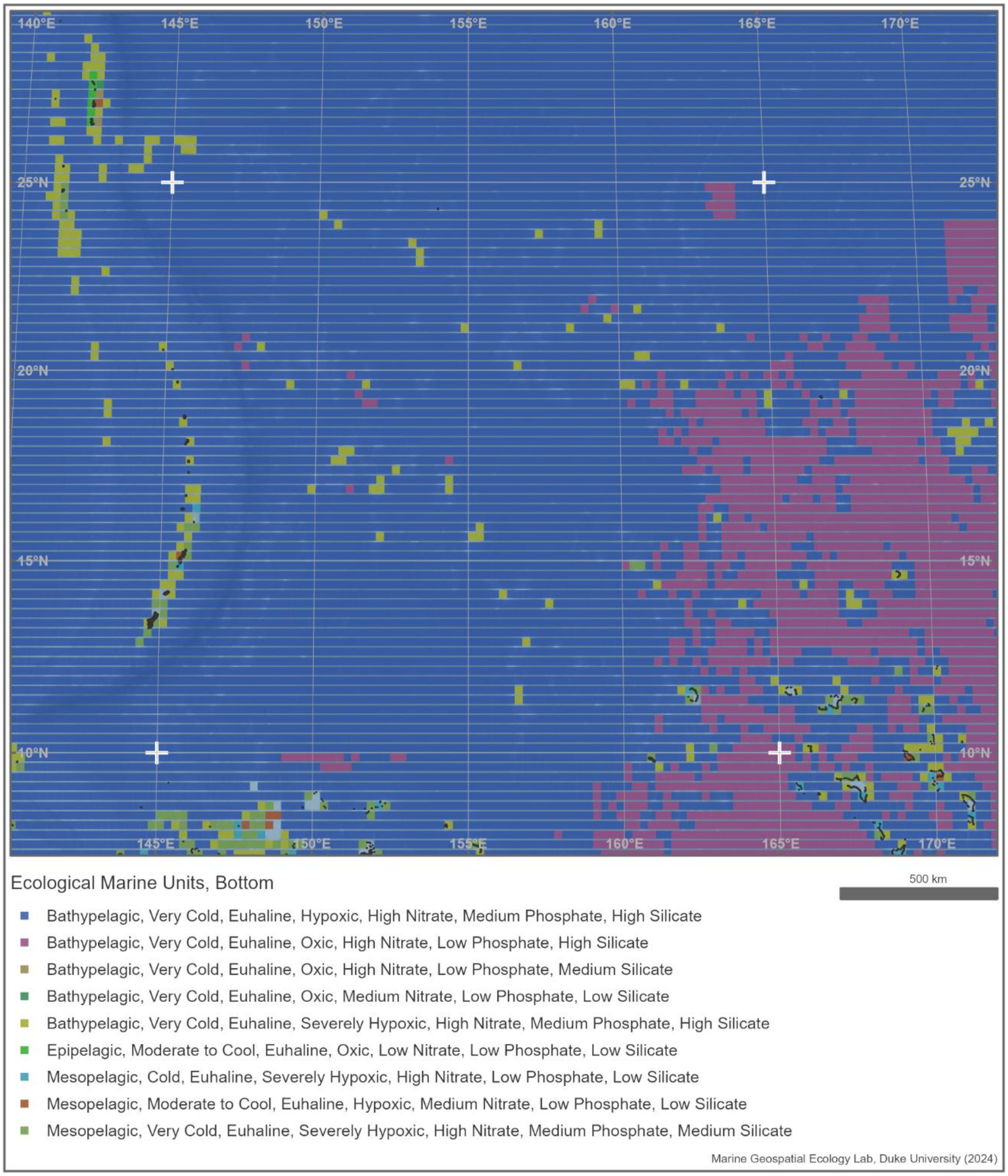


Figure 2.27-2 Ecological marine units - bottom

2.28 Evolution of a deep-water ferromanganese nodule in the South China Sea in response to Pacific deep-water circulation and continental weathering during the Plio-Pleistocene

Abstract (Zhong et al. 2020):
"The South China Sea (SCS) is connected to the West Pacific through a deep channel in the Luzon Strait. Thus the SCS deep water is sensitive to the evolution of Pacific Ocean circulation, which significantly influences the global climate system. Geochemical data (Pb isotope and redox-sensitive elements data) and magnetic data were determined for a Fe–Mn nodule obtained from Jiaolong seamount in the central SCS. These records reflect interactions between changes in ice sheets, deep Pacific circulation, and weathering inputs to the deep SCS during the Pliocene and Quaternary. Our results show that the SCS deep-water environment can be divided into three major Stages (Stages 1–3). Stage 1 (∼4.8–1.4 Ma) was characterized by a well-oxygenated Pacific Deep Water (PDW) and lower dust inputs; then moderate stable deep-water ventilation and greater inputs of Asian dust occurred during Stage 2 (1.4–0.9 Ma). During Stage 3 (<0.9 Ma), a more isolated PDW was accompanied by sluggish Pacific overturning circulation, probably due to the weakened southern-sourced deep-water formation. In general, the progressive intensification of northern hemisphere ice-sheet play an active role in controlling the variation of the deep-water environment in the SCS. Interestingly, the variation in deep-water ventilation lagged behind weathering and erosion around the Middle Pleistocene Transition, which strongly indicates that the ocean and continent environments had different sensitivities to the global paleoclimatic changes at the glacial climate boundary."

Reference:
Zhong, Yi, Zhong Chen, James R. Hein, Francisco Javier González, Zhaoxia Jiang, Xiaoqiang Yang, Jian Zhang et al. "Evolution of a deep-water ferromanganese nodule in the South China Sea in response to Pacific deep-water circulation and continental weathering during the Plio-Pleistocene." Quaternary Science Reviews 229 (2020): 106106. https://doi-org.proxy.lib.duke.edu/10.1016/j.quascirev.2019.106106

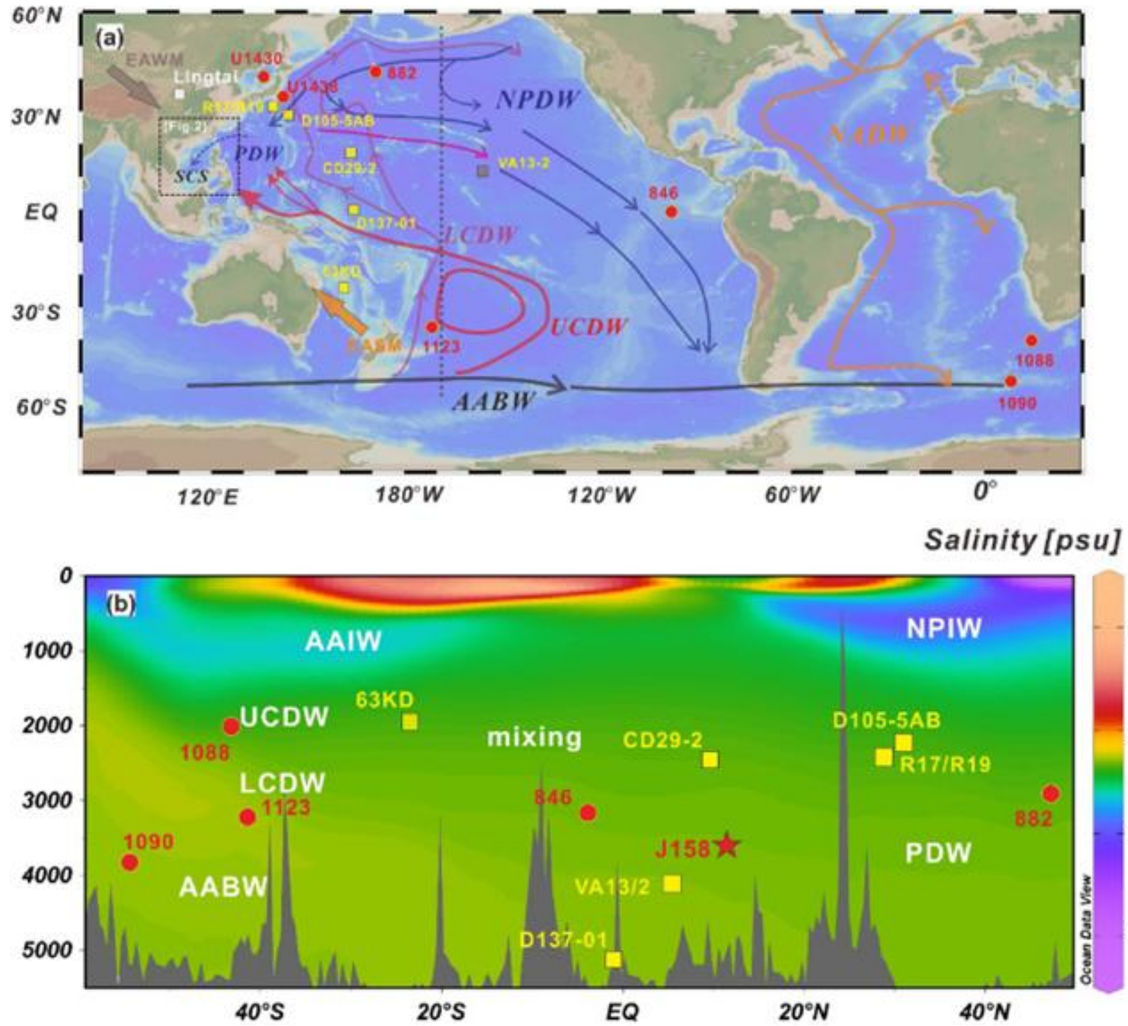


Figure 2.28-1 Originally Figure 1

Original caption: Fig. 1. (a) Regional map showing the location of the study area and the modern distribution of water masses in the Pacific Ocean and Atlantic. The purple, red, and blue lines indicate the pathway of the Lower Circumpolar Deep Water (LCDW), the Upper Circumpolar Deep Water (UCDW), and the North Pacific Deep Water (NPDW), respectively (modified after Kawabe and Fujio (2010)). The pink dashed lines in map denote the flow paths of Pacific Deep Water (PDW) in the SCS. The red star indicates the location of core investigated in this study. The red dots indicate the locations of the Pacific cores (ODP Site 882 (Haug et al., 2005), ODP site 846 (Lawrence et al., 2006), ODP site 1123 (Elderfield et al., 2012) and the Atlantic cores (ODP site 1088, ODP site 1090 (Martínez-Garcia et al., 2010). The white square shows the location of Lingtai loess section (Sun and An, 2005) in the Chinese Loess Plateau (CLP). The yellow squares indicate Fe–Mn deposits in the Pacific (D105-5AB (Chu et al., 2007), R17/R19 (Peate et al., 2009), CD29-2 (Christensen et al., 1997), VA13-2 (Abouchami et al., 1997), D137-01 (Van de Flierdt et al., 2004), and 63KD (Chu et al., 2006)). (b) Modern seawater salinity profile along the Pacific meridional transect based on WOA13 dataset (grey dotted line in (a)). Red dots with yellow numbers are the study sites in (a) and their projection on the meridional transect. AABW = Antarctic Bottom Water, AAIW = Antarctic Intermediate Water, NPIW = North Pacific Intermediate Water, NADW = North Atlantic Deep Water, UCDW = Upper Circumpolar Deep

Water, LCDW = Lower Circumpolar Deep Water, EAWM = East Asian Winter Monsoon, EASM = East Asian Summer Monsoon. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.

2.29 Spatial distribution of planktonic ciliates in the western Pacific Ocean: along the transect from Shenzhen (China) to Pohnpei (Micronesia)

Abstract (Huang et al. 2020):
“Planktonic ciliates have been recognized as major consumers of nano- and picoplankton in pelagic ecosystems, playing pivotal roles in the transfer of matter and energy in the microbial loop. However, due to the difficulties in identification, the species composition of ciliate assemblages, especially for the small, fragile, and naked species that usually dominate the ciliate communities in the oceanic waters, remains largely unknown. In the present study, 22 stations along the transect from Shenzhen (China) to Pohnpei (Micronesia) were sampled for the enumeration of picoplankton and nanoflagellates. In addition, pigment analysis of major phytoplankton groups along with the measurements of environmental variables including temperature, salinity, and nutrients were also carried out. Ciliates were identified at species level using quantitative protargol stain to reveal the species composition and their distribution patterns from off-shore to open ocean. Ciliate abundance was positively correlated with phosphate, silicate, and pico-sized pigmented eukaryotes (PPEs), whereas the biomass was closely related with PPEs, heterotrophic nanoflagellates, and chlorophytes. The combination of silicate and pigmented nanoflagellates was identified as the major factor driving the ciliate community composition. The close relationship between silicate and ciliate abundance and community structure needs further validation based on more data collected from oceanic waters. Our study showed the necessity of using techniques that can reveal the community composition at higher taxonomic resolutions in future studies on ciliates.”

Reference:
Huang, Hungchia, Jinpeng Yang, Shixiang Huang, Bowei Gu, Ying Wang, Lei Wang, Nianzhi Jiao, and Dapeng Xu. "Spatial distribution of planktonic ciliates in the western Pacific Ocean: along the transect from Shenzhen (China) to Pohnpei (Micronesia)." Marine Life Science & Technology 3 2021): 103-115. https://doi.org/10.1007/s42995-020-00075-7

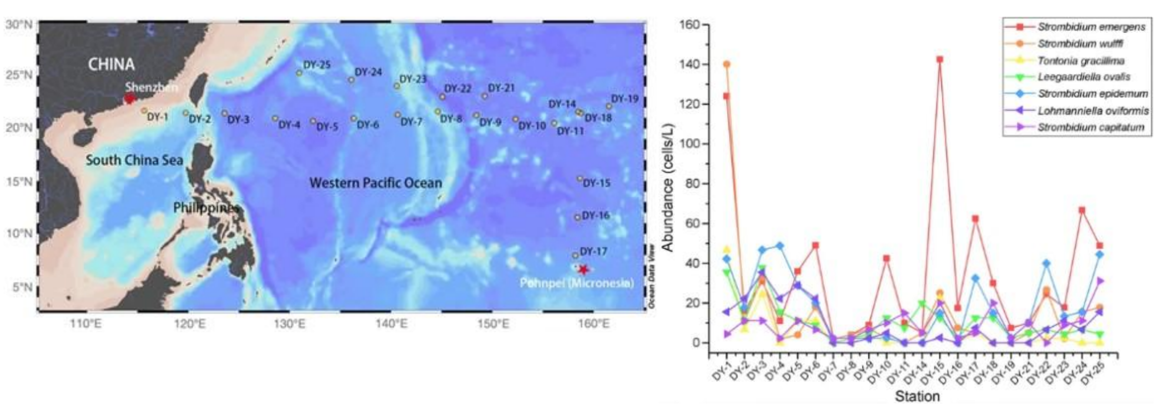


Figure 2.29-1 Original captions: Fig. 1 (LEFT) Sampling stations along the transect from Shenzhen (China) to Pohnpei (Micronesia) in the western Pacifc Ocean; Fig. 6 (RIGHT) Abundances of the seven dominant ciliate species at each sampling station.

2.30 Spatial patterns and co-occurrence networks of microbial communities related to environmental heterogeneity in deep-sea surface sediments around Yap Trench, Western Pacific Ocean

Abstract (Zhang et al. 2021):
“Microbial communities are a large component of abyssal and hadal benthic environments, especially in deep-sea areas like Yap Trench, they provide a continuous source of nutrients and energy in their unique ecosystems. However, due to sampling difficulties, these microbial communities are relatively understudied. In the summer of 2017, sediment samples were collected from 21 stations around Yap Trench in the Western Pacific Ocean (mostly in the West Caroline Basin), at depths ranging from 3156 to 7837 m. Sediment samples from deep water depths and shallow water depths differed in organic matter content, median grain size, silt-clay content, and biodiversity. The structure of the microbial communities in the surface sediments had distinct relationships with environmental factors and their co-occurrence networks exhibited a clear spatial pattern. In addition, for both prokaryotes or eukaryotes, a combination of variables including silt-clay content, organic matter content, median grain size, and depth had the greatest impact on community structure. It was notable that fungi played important roles in the co-occurrence networks of deep water depth sediment samples while bacteria dominated those of shallow water depth samples. The differences in structure and ecological niches in the different networks were due to differences in sediment texture and organic matter content. Since clay had a positive effect on the diversity of bacteria, it had an indirect positive effect on fungi, leading to differences in biodiversity among different groups. More organic matter meant more nutrients were available for the growth and reproduction of microbes, which led to fewer niche overlaps. This study conducted an extensive and systematic sequencing survey of surface sediments around Yap Trench in the Western Pacific Ocean, providing insight into microbial responses to environmental heterogeneity in deep-sea benthic ecosystems.”

Reference:
Zhang, Chenru, Qian Liu, Xianrong Li, Min Wang, Xiaoshou Liu, Jinpeng Yang, Jishang Xu, and Yong Jiang. "Spatial patterns and co-occurrence networks of microbial communities related to environmental heterogeneity in deep-sea surface sediments around Yap Trench, Western Pacific Ocean." Science of the Total Environment 759 (2021): 143799.
https://doi.org/10.1016/j.scitotenv.2020.143799

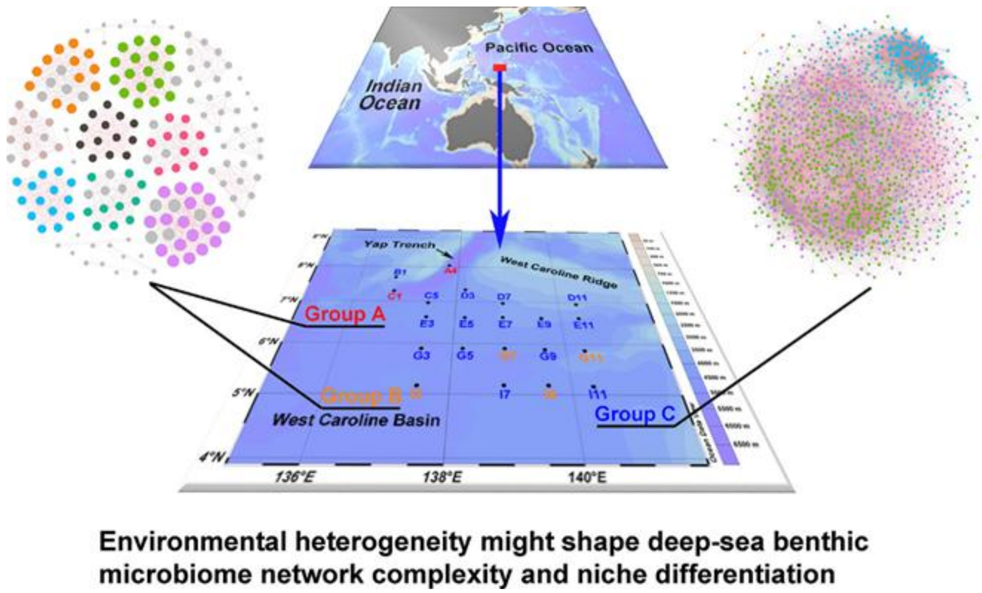


Figure 2.30-1 Original caption: Graphical abstract

2.31 Multi-decadal trends in the tropical Pacific western boundary currents retrieved from historical hydrological observations

Abstract (Hu et al. 2021):
"As large-scale ocean circulation is a key regulator in the redistribution of oceanic energy, evaluating the multi-decadal trends in the western Pacific Ocean circulation under global warming is essential for not only understanding the basic physical processes but also predicting future climate change in the western Pacific. Employing the hydrological observations of World Ocean Atlas 2018 (WOA18) from 1955 to 2017, this study calculated the geostrophic currents, volume transport and multi-decadal trends for the North Equatorial Current (NEC), the North Equatorial Countercurrent (NECC), the Mindanao Current (MC), the Kuroshio Current (KC) in the origin and the New Guinea Coastal Undercurrent (NGCUC) within tropical western Pacific Ocean over multi-decades. Furthermore, this study examined the contributions of temperature and salinity variations. The results showed significant strengthening trends in NEC, MC and NGCUC over the past six decades, which is mainly contributed by temperature variations and consistent with the tendency in the dynamic height pattern. Zonal wind stress averaged over the western Pacific Ocean in the same latitude of each current represents the decadal variation and multi-decadal trends in corresponding ocean currents, indicating that the trade wind forcing plays an important role in the decadal trend in the tropical western Pacific circulation. Uncertainties in the observed hydrological data and trends in the currents over the tropical western Pacific are also discussed. Given that the WOA18 dataset covers most of the historical hydrological sampling data for the tropical western Pacific, this paper provides important observational information on the multi-decadal trend of the large-scale ocean circulation in the western Pacific."

Reference:
Hu, Shijian, Xi Lu, Shihan Li, Fan Wang, Cong Guan, Dunxin Hu, Linchao Xin, and Jie Ma. "Multi-decadal trends in the tropical Pacific western boundary currents retrieved from historical hydrological observations." Science China Earth Sciences 64 (2021): 600-610.
https://doi.org/10.1007/s11430-020-9703-4

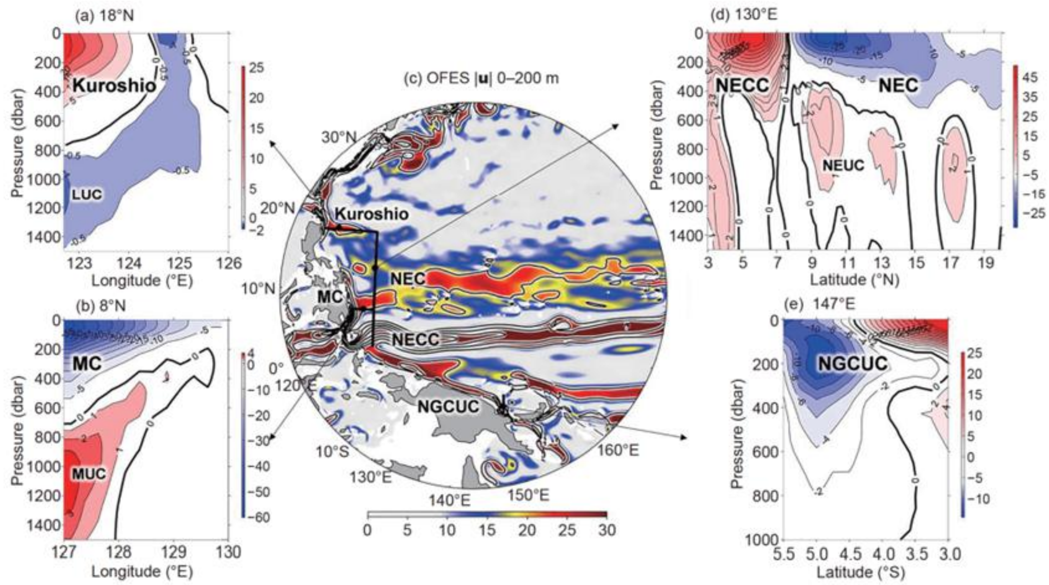


Figure 2.31-1 Originally Figure 2

Original caption: Figure 2 Geostrophic currents retrieved from multi-decadal hydrological observational data based on WOA18 ((a), (b), (d), (e), cm s−1) and the mean horizontal absolute velocity |u| in the upper 200 m simulated by OFES ((c), cm s−1). The black solid line in the intermediate panel (c) represents the location of each section of geostrophic currents. Please note that the interval of velocity contours in the moderately deep undercurrent areas is small.

2.32 Hadal zones of the Northwest Pacific Ocean

Abstract (Jamieson and Stewart 2021):
"Understanding the extent of the hadal ecosystem (habitats exceeding 6000 m water depth) is convoluted due to the complexity of seafloor geomorphology that accounts for 45% of the total ocean depth range. Furthermore, at such great depths, features such as fracture zones and basins, although numerous, are less prominent and therefore have drawn less focus compared to the conspicuous subduction trenches that are typically associated with hadal science. Here we focus on the Northwest Pacific Ocean, where the majority of hadal features are located, to evaluate the true extent of the deepest marine ecosystem. This analysis has highlighted that the Mariana Trench, in terms of continuous hadal habitat, is in fact five isolated areas, with the most northern being what Russian scientists used to call the Volcano Trench. Conversely, we identified that there are no physical partitions either north or south of the Japan Trench to isolate it from the neighbouring Kuril-Kamchatka or Izu-Bonin trenches respectively, thus it forms one continuous hadal habitat. By evaluating the frequency and distribution of smaller features, such as basins and fracture zones, we conclude that in the northwest Pacific, the total area occupied by depths > 6000 m is 2,793,011 km2, which is considerably larger than the 686,114 km2 accounted for by subduction trenches alone. These results demonstrate not only that the hadal ecosystem may be far larger than previously anticipated but that the geomorphology is crucial in understanding the distribution and genetic connectivity of endemic hadal species that inhabit these great depths."

Reference:
Jamieson, Alan J., and Heather A. Stewart. "Hadal zones of the northwest Pacific Ocean." Progress in Oceanography 190 (2021): 102477. https://doi.org/10.1016/j.pocean.2020.102477

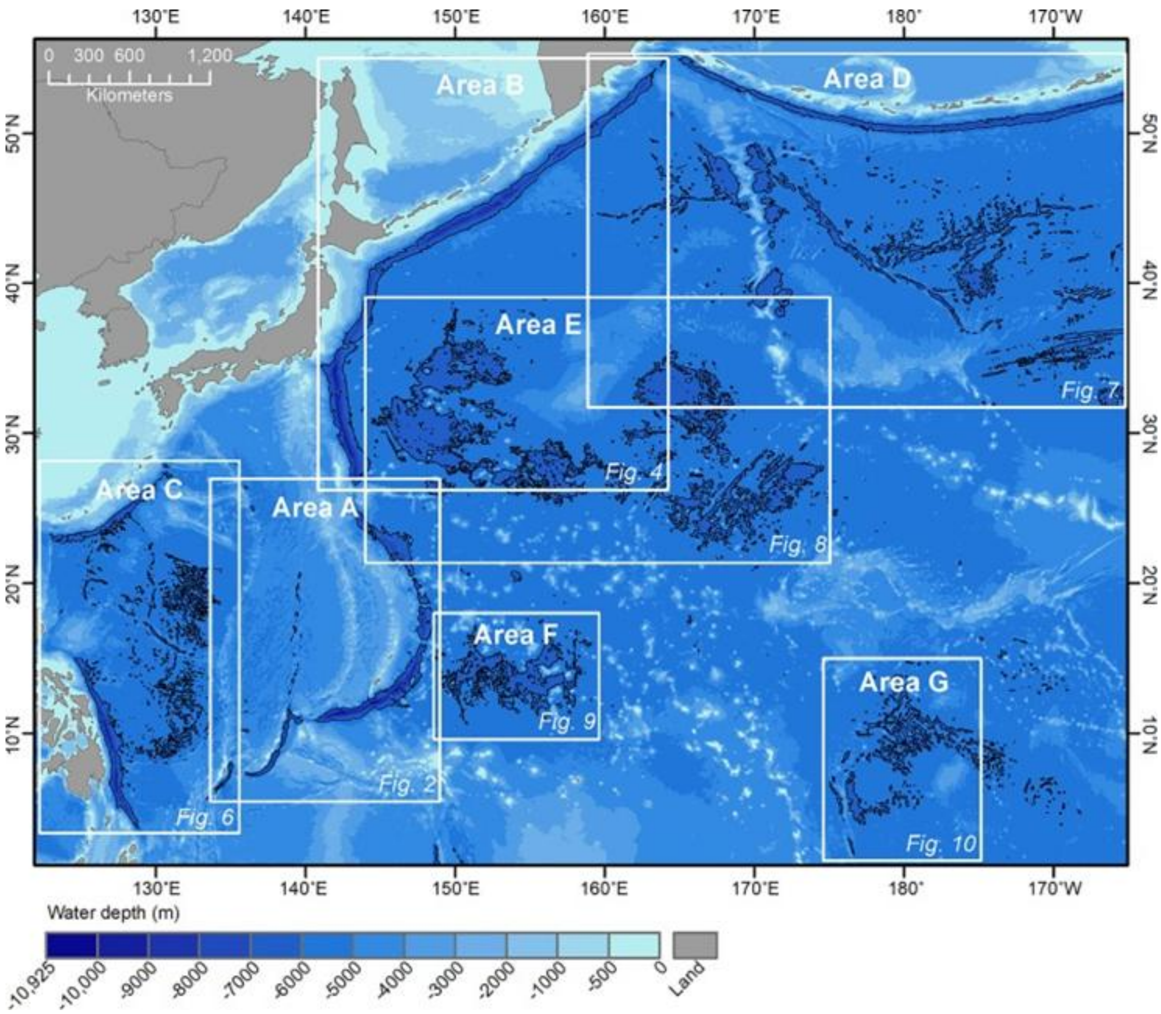


Figure 2.32-1 Originally Figure 1

Original caption: Fig. 1. Bathymetry of the Northwest Pacific Ocean, white boxes relate to specific study areas described herein. Area A, the Palau, Yap, Mariana and Volcano trenches, Area B, the Izu-Bonin, Japan and Kuril-Kamchatka trenches, Area C, the Philippine and Ryukyu trenches, and the Philippine Basin, Area D, the Emperor Fracture Zone, Area E, the Northwest Pacific Basin, Area F, the East Mariana Basin, and Area G, the Central Pacific Basin. The black line represents the 6000 m depth contour. All elevation data sourced from the Global Multi-Resolution Topography Synthesis (Ryan et al., 2009). Copyright British Geological Survey © UKRI 2020.

2.33 Environmental Predictors for Polymetallic Nodules

Abstract (Dutkiewicz et al. 2020):
"Polymetallic nodules found on the abyssal plains of the oceans represent one of the slowest known geological processes, and are a source of critical and rare metals for frontier technologies. A quantitative assessment of their occurrence worldwide has been hampered by a research focus on the northeastern Pacific Ocean and the lack of a global open-access data set of nodules. We have compiled a global data set of >10,000 seabed nodule and control samples, and combine it with digital grids of key environmental parameters to generate a predictive machine-learning model of nodule occurrence. In order of decreasing parameter ranking, we find that nodules are associated with very low sedimentation rates (< 0.5 cm/k.y.), moderately high oxygen values (150 and 210 mmol/m3), lithologies of clay followed by calcareous ooze, low summer surface productivity (<300 mgC/m2/day), low benthic biomass concentration (<1 log mgC/m2), water depths >4500 m, and low total organic carbon content (0.3–0.5 wt%). Competing hypotheses for nodule sustention and thus continued growth on the seafloor are the removal of sediment by bottom-water currents and biological activity. Using a high-resolution eddy-resolving ocean circulation model, we find that the bottom-current speeds over nodule fields are too low (<5 cm/s) to remove sediment, implicating the activity of epibenthic megafauna as the most likely mechanism. Our global nodule probability map combined with the assessment of a range of environmental drivers provides an improved basis for decision and policy making in the controversial area of deep-sea exploration."

Reference:
Dutkiewicz, Adriana, Alexander Judge, and R. Dietmar Müller. "Environmental predictors of deep-sea polymetallic nodule occurrence in the global ocean." Geology 48, no. 3 (2020): 293-297. https://doi.org/10.1130/G46836.1

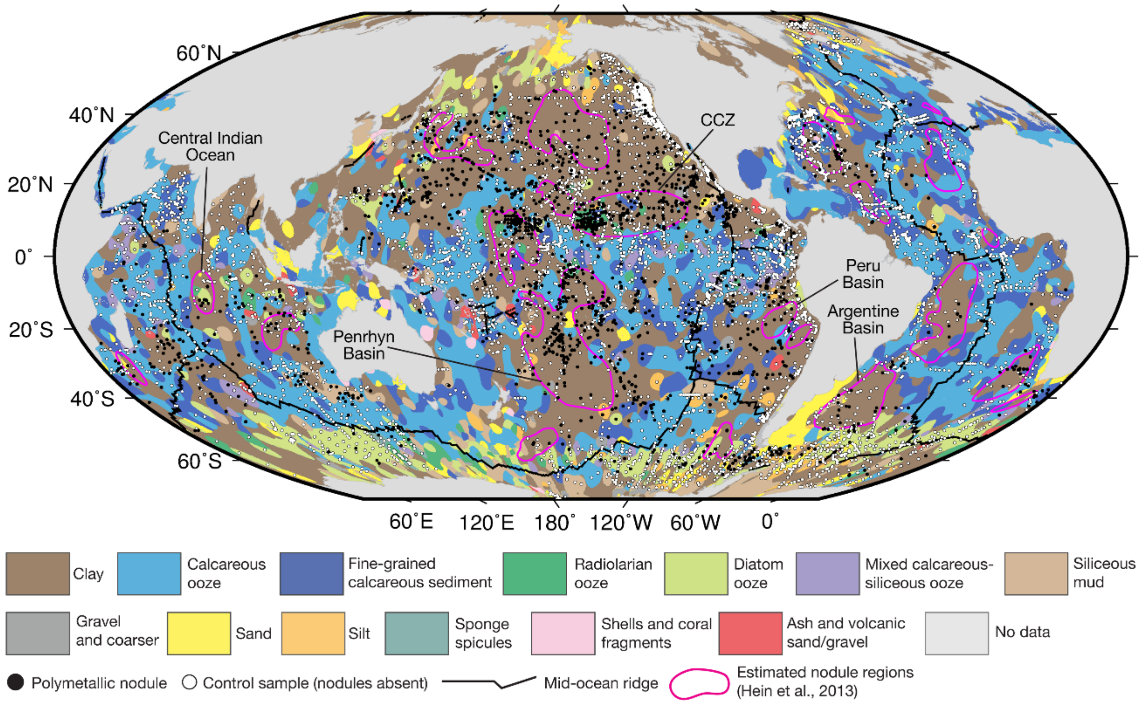


Figure 2.33-1 Originally Figure 1 - Global distribution of polymetallic nodules

Original Caption: Figure 1. Polymetallic nodule occurrences in the global ocean. Nodules (black dots) and control samples lacking nodules (white dots) are shown in relation to seafloor lithology (Dutkiewicz et al., 2015). Mollweide projection. CCZ—Clarion-Clipperton Zone.

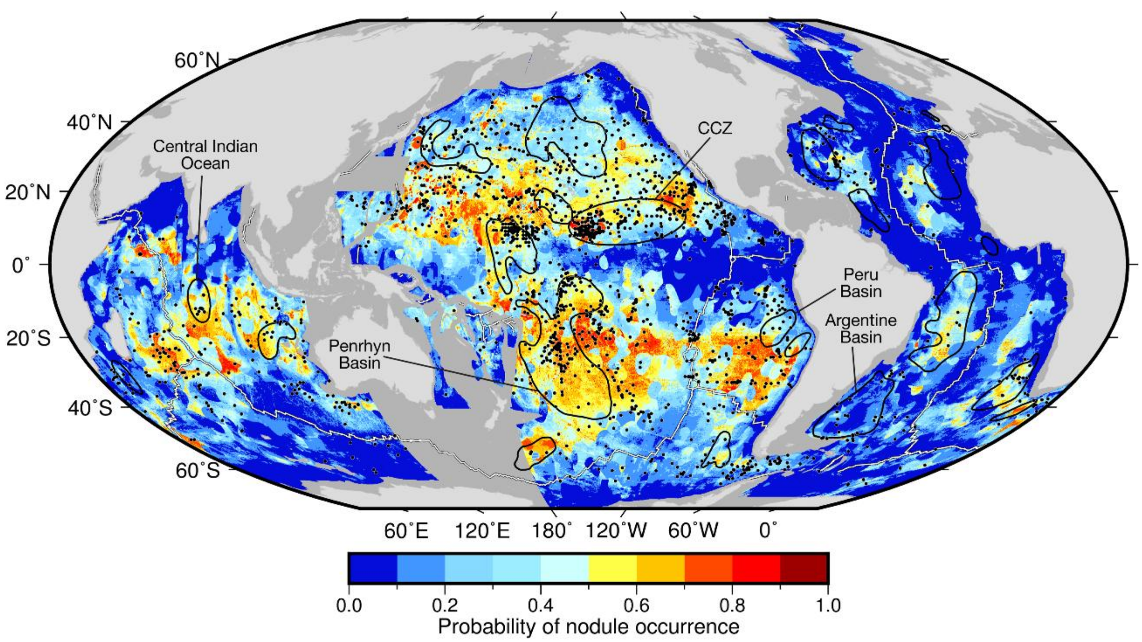


Figure 2.33-2 Originally Figure 3 - Predicted distribution of polymetallic nodules

Original Caption: Figure 3. Prediction of probability of polymetallic nodule occurrence. Dark gray denotes regions with missing data in at least one of the environmental data sets (Figs. DR1–DR7 [see footnote 1]). Nodules are shown as black dots. Black outline indicates known nodule fields and poorly explored areas that are deemed to be permissive for economic development (Hein et al., 2013). Uncertainty of nodule occurrence probability is represented by lower and upper bounds of 90% credible interval for probability estimate, based on joint uncertainty in all model parameters (Figs. DR8 and DR9 [see footnote 1]). Our predictions exclude nodule density. CCZ—Clarion-Clipperton Zone. Mollweide projection.

2.34 A possible link between seamount sector collapse and manganese nodule occurrence in the abyssal plains, NW Pacific Ocean

Abstract (Li et al. 2021):

"Manganese nodules are a potential source of critical metals such as Cu, Ni, and Co and are widely distributed on the abyssal plains of the global oceans. A polymetallic nodule metallogenic belt with a heterogeneous and spatially clustered nodule distribution was recently discovered in NW Pacific inter-seamount basin (NPIB) areas. However, the geological processes that regulate the nodule occurrence in that region are unresolved. Here, we report on the characteristics of a high-density field of manganese nodules in the abyssal plain north of Suda Seamount. Ship-borne multibeam bathymetric data reveal a typical seamount sector-collapse topography characterized by radial lineaments of debris channels and ridges formed by rapid debris-avalanche flow. Backscatter data linked with underwater observation indicate that manganese nodules are more concentrated (50%–80% areal coverage) along the main body of the debris apron compared to adjacent neighboring areas (<30%). The extremely high concentrations (~80% areal coverage) characterized by overlapping nodules are apparently associated with downslope movement, possibly triggered by block movement along the fault slip plane or by gravity processes. Our results indicate that seamount sector collapse may have provided sufficient nucleus material for nodule growth and contributed to high nodule concentrations locally. The destruction of submarine volcanic edifices is universal, and the debris aprons and plains around such seamounts are potential prospecting areas for manganese nodule resources throughout the NPIB."

Reference:

Li, Zhenggang, Huaming Li, James R. Hein, Yanhui Dong, Mingwei Wang, Xiangwen Ren, Zhaocai Wu, Xiaohu Li, and Fengyou Chu. "A possible link between seamount sector collapse and manganese nodule occurrence in the abyssal plains, NW Pacific Ocean." Ore Geology Reviews 138 (2021). https://doi.org/10.1016/j.oregeorev.2021.104378

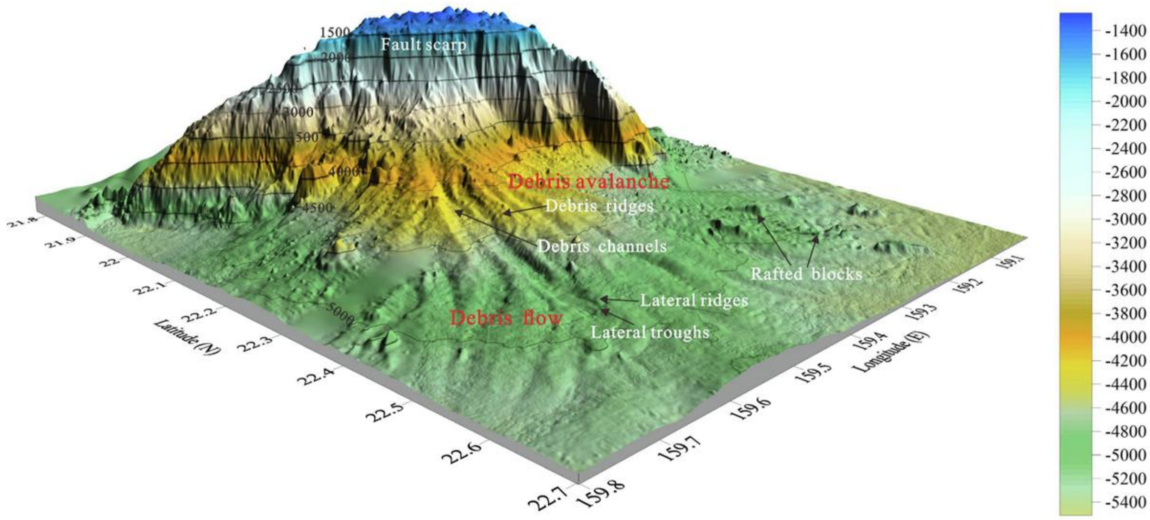


Figure 2.34-1 Originally Figure 3

Original Caption: Figure 3. Three-dimensional representation of geomorphological features of the northern flank of Suda Seamount.

2.35 Distribution and composition of marine hydrogenetic and hydrothermal manganese deposits in the northwest Pacific

Abstract (Usui and Someya 1997):
"The distribution and composition of Mn deposits in the northwest Pacific (15-50° N and 120--160 ° E) are characterized using a Mn deposits database compiled from our original data, published and unpublished papers, published databases, and other international sources. The results demonstrate a close association with geological settings. Hydrogenetic nodules and crusts formed in areas of erosion or nondeposition on Cretaceous seamounts and plateaus of the Pacific plate, and to a lesser extent on seamounts of remnant arcs of Palaeogene to Neogene ages. The Cretaceous seamount deposits are most enriched in Co, and the plateaus less so, while both show moderate Ni enrichment. Nodules and crusts are rare in enclosed backarc basins, which have not been affected by deep water circulation. A slight early-diagenetic influence is observed in some Pacific basin nodules. By contrast, modern hydrothermal Mn deposits are broadly distributed on active submarine volcanoes and backarc rifts. These hydrothermal Mn deposits consist typically of pure Mn oxide containing negligible levels of metals except for Mg, Ba, K and Li. Similar fossil hydrothermal Mn deposits are observed in places on old basement or within deep cores as geological records of past hydrothermal activity."

Reference:
Usui, Akira and Masao Someya. "Distribution and composition of marine hydrogenetic and hydrothermal manganese deposits in the northwest Pacific." Geological Society Special Publications 119 (1997): 177-198. https://doi.org/10.1144/GSL.SP.1997.119.01.12

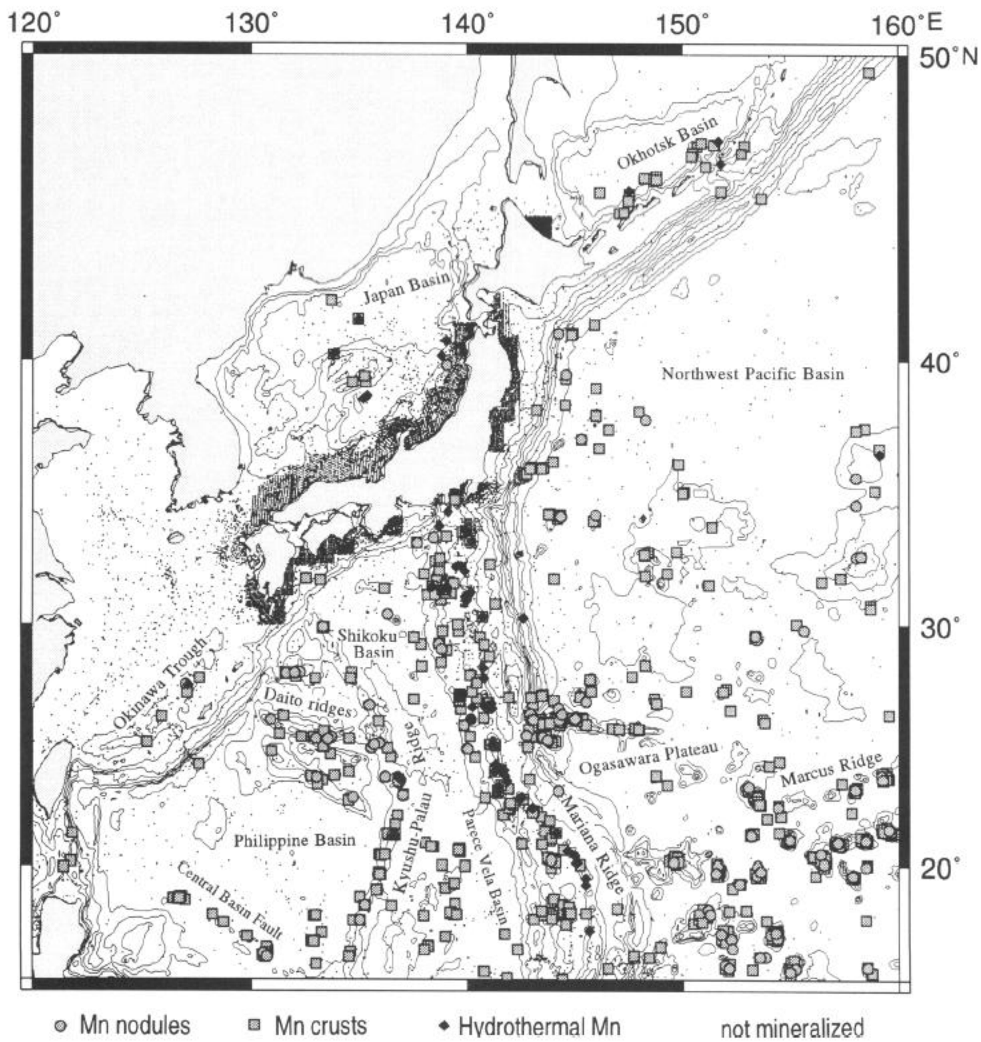


Figure 2.35-1 Originally Figure 4

Original Caption: Figure 4. Occurrence of manganese deposits in relation to topography (contour: 1000m interval). The plot shows occurrence of manganese deposits whose thickness exceed 1 mm.

3 Biological Data

3.1 Ocean Biodiversity Information System (OBIS) Data Summaries

"The Ocean Biodiversity Information System (OBIS) seeks to absorb, integrate, and assess isolated datasets into a larger, more comprehensive picture of life in our oceans. The system hopes to stimulate research about our oceans to generate new hypotheses concerning evolutionary processes, species distributions, and roles of organisms in marine systems on a global scale. The abstracts that OBIS generates are maps that contribute to the 'big picture' of our oceans: a comprehensive, collaborative, worldwide view of our oceans.

OBIS provides a portal or gateway to many datasets containing information on where and when marine species have been recorded. The datasets are integrated so researchers can search them all seamlessly by species name, higher taxonomic level, geographic area, depth, and time; and then map and find environmental data related to the locations."

The data provided here are summaries of available OBIS data. Observation counts, Species Richness, Hurlbert's Index (ES[50]), and Shannon Diversity data summaries for hexagons are provided for all species. Observation locations are provided for VME taxa. Data gaps do exist in OBIS and thus these summaries are not exhaustive.

Source:
https://obis.org/about/

Reference:
Intergovernmental Oceanographic Commission (IOC) of UNESCO. The Ocean Biodiversity Information System. Web. http://www.iobis.org.

Gridded data preparation code repository - https://github.com/iobis/ebsa

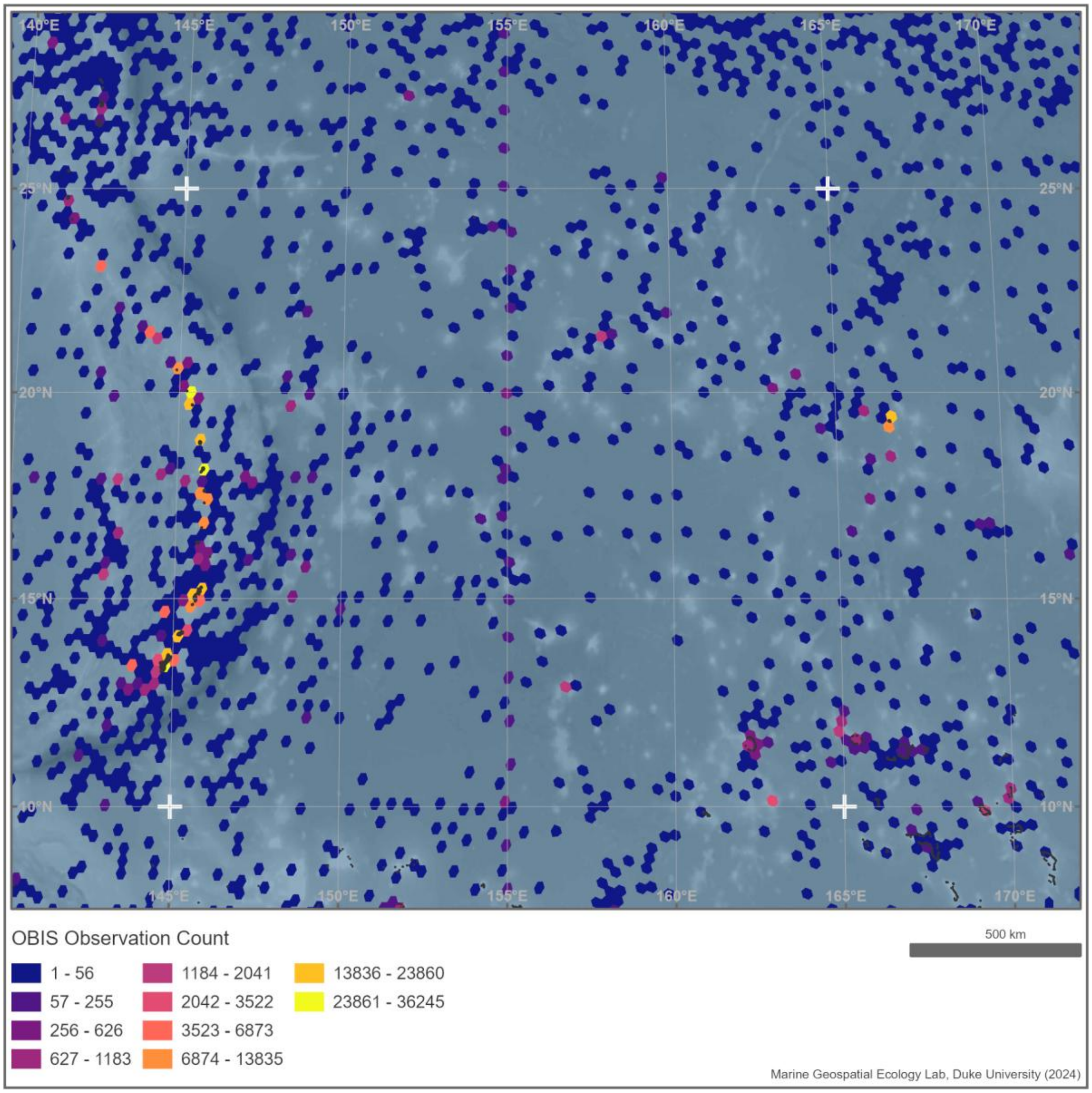


Figure 3.1-1 Observation count – all taxa

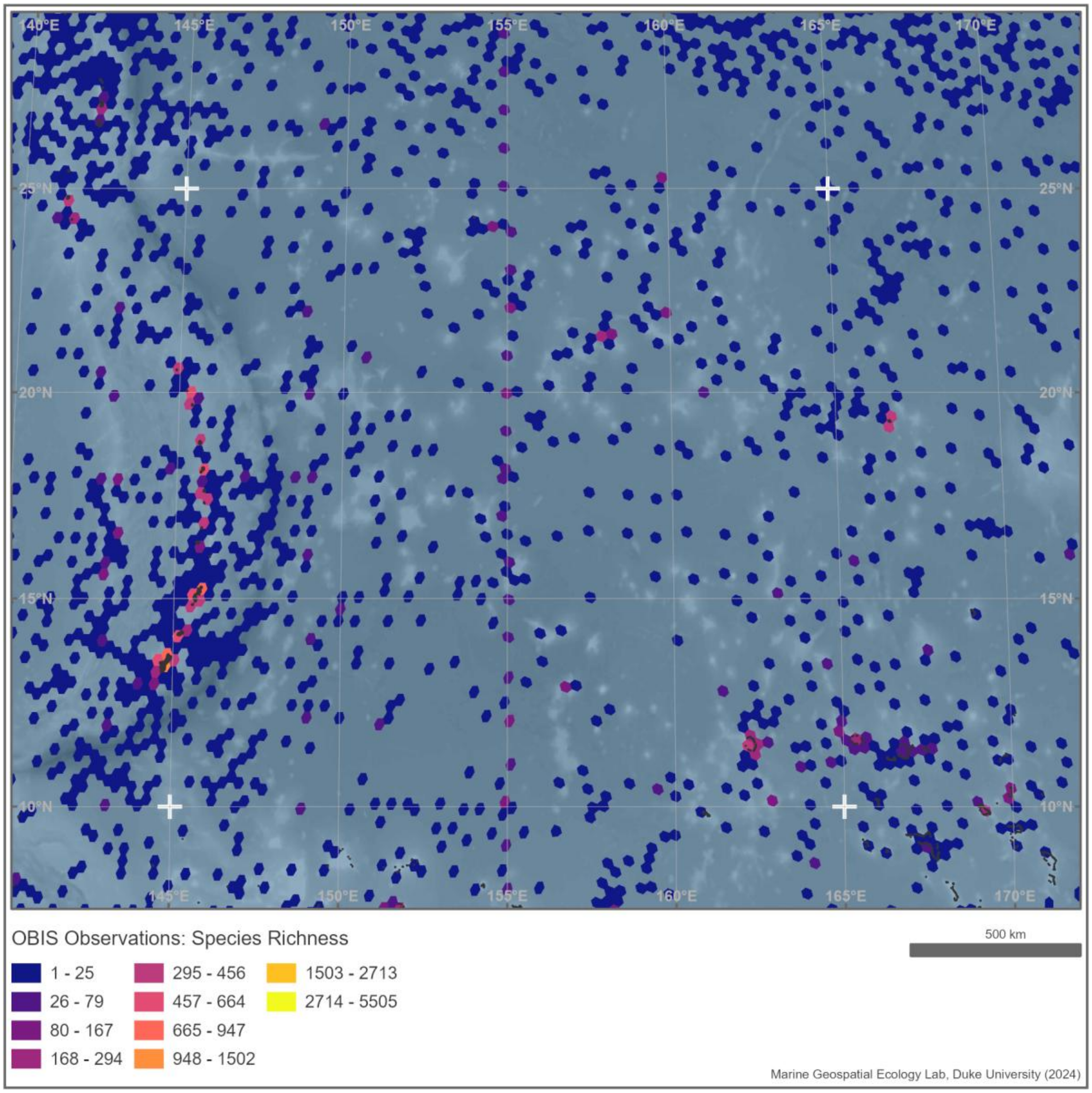


Figure 3.1-2 Species richness for all taxa

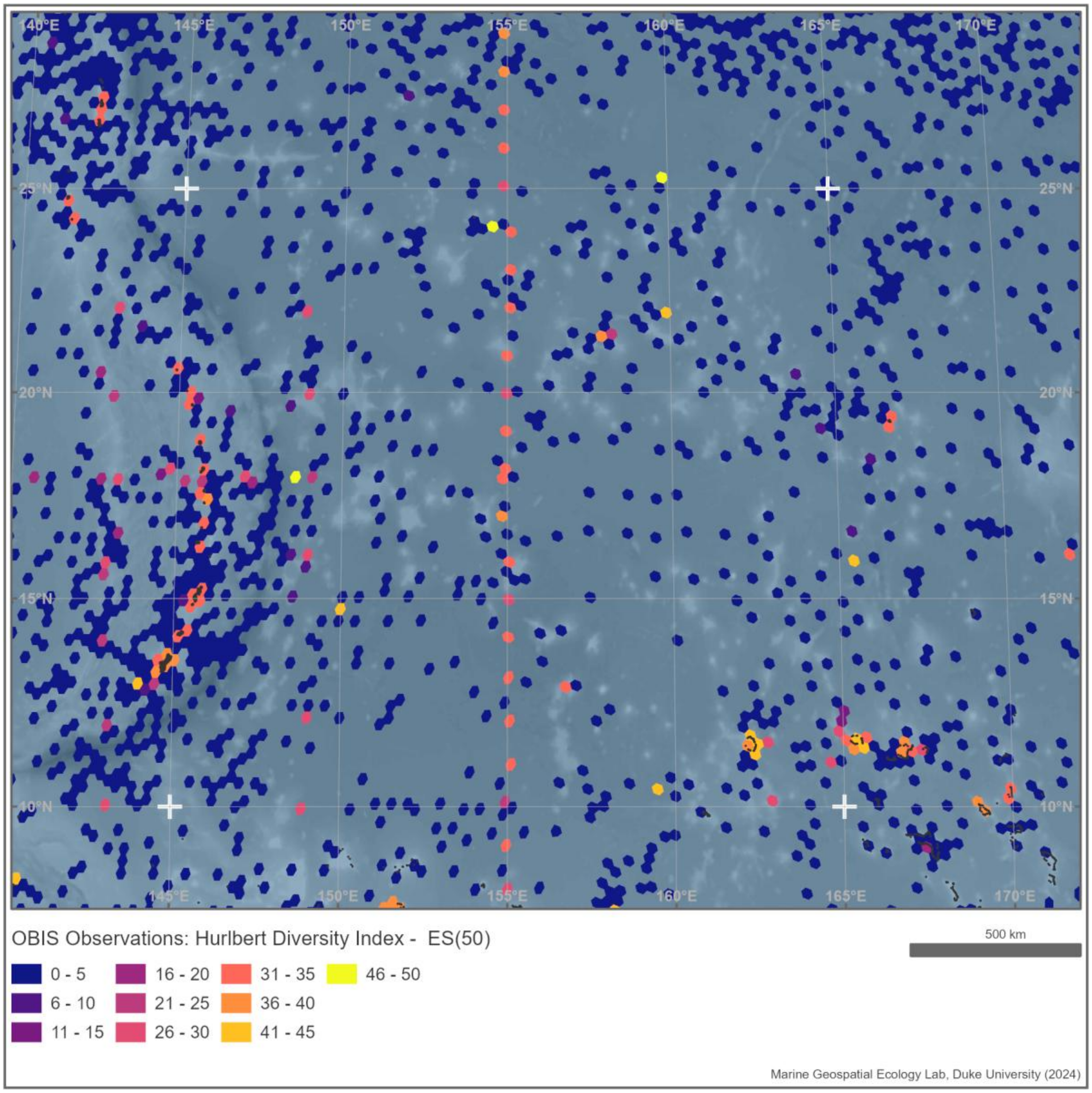


Figure 3.1-3 Hurlbert diversity index for all taxa, es(50)

3.2 OBIS Vulnerable Marine Ecosystems (VMEs) Indicator Taxa

The Food and Agriculture Organization (FAO) of the United Nations International Guidelines for the Management of Deep-sea Fisheries in the High Seas (FAO, 2009) provide general tools and considerations for the identification of vulnerable marine ecosystems (VMEs). They include a set of criteria that should be used, individually or in combination, for the identification process. Specifically: Uniqueness or rareness, Functional significance of the habitat, Fragility, Life-history of species make recovery difficult, and Structural complexity.

VME Indicator taxa from the North Pacific Fisheries Commission (NPFC) are:

Scientific name	Taxonomical level
Scleractinia	Order
Antipatharia	Order
Alcyonacea	Order

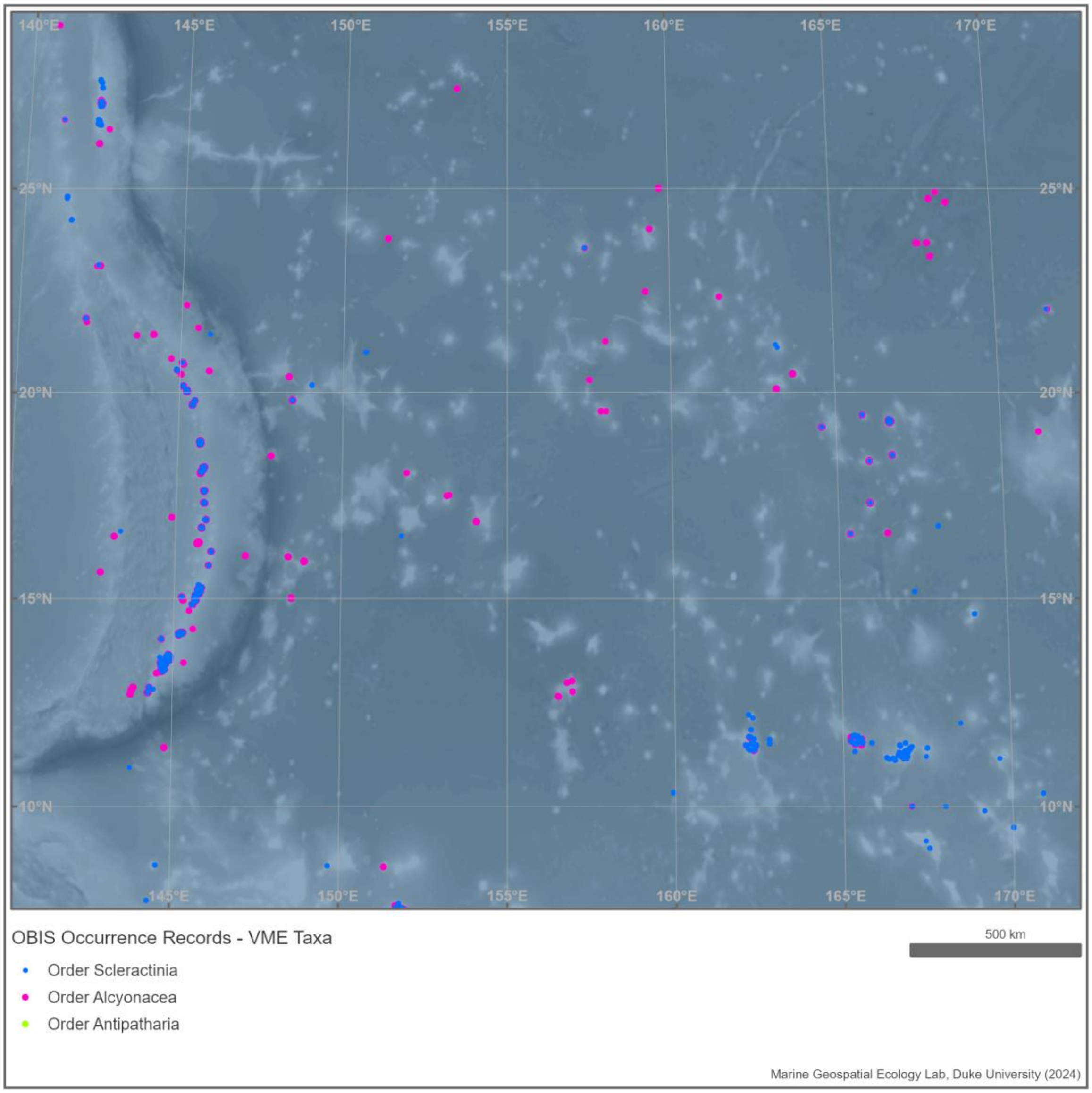


Figure 3.2-1 OBIS records for VME taxa

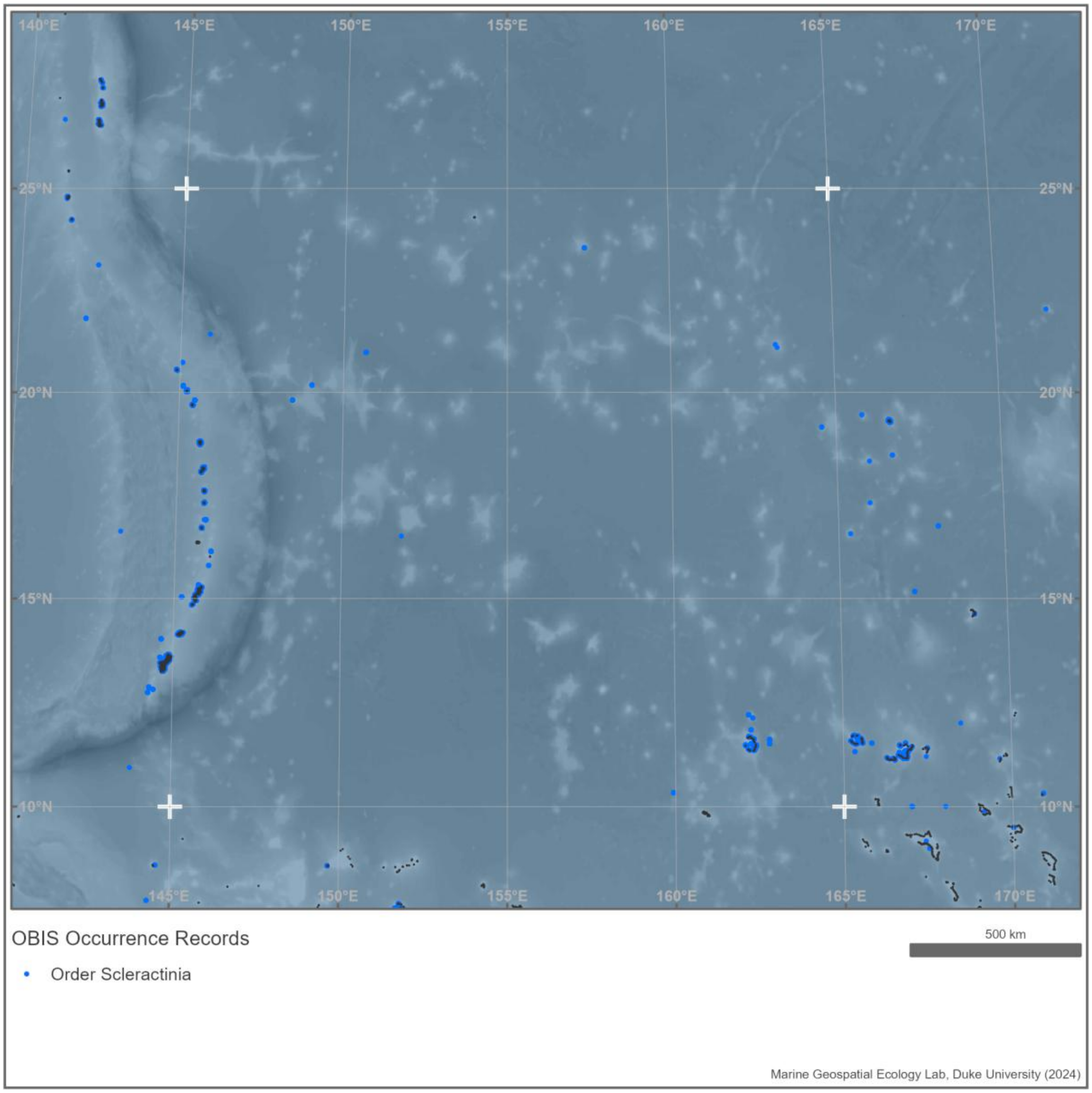


Figure 3.2-2 OBIS records of *Scleractinia*

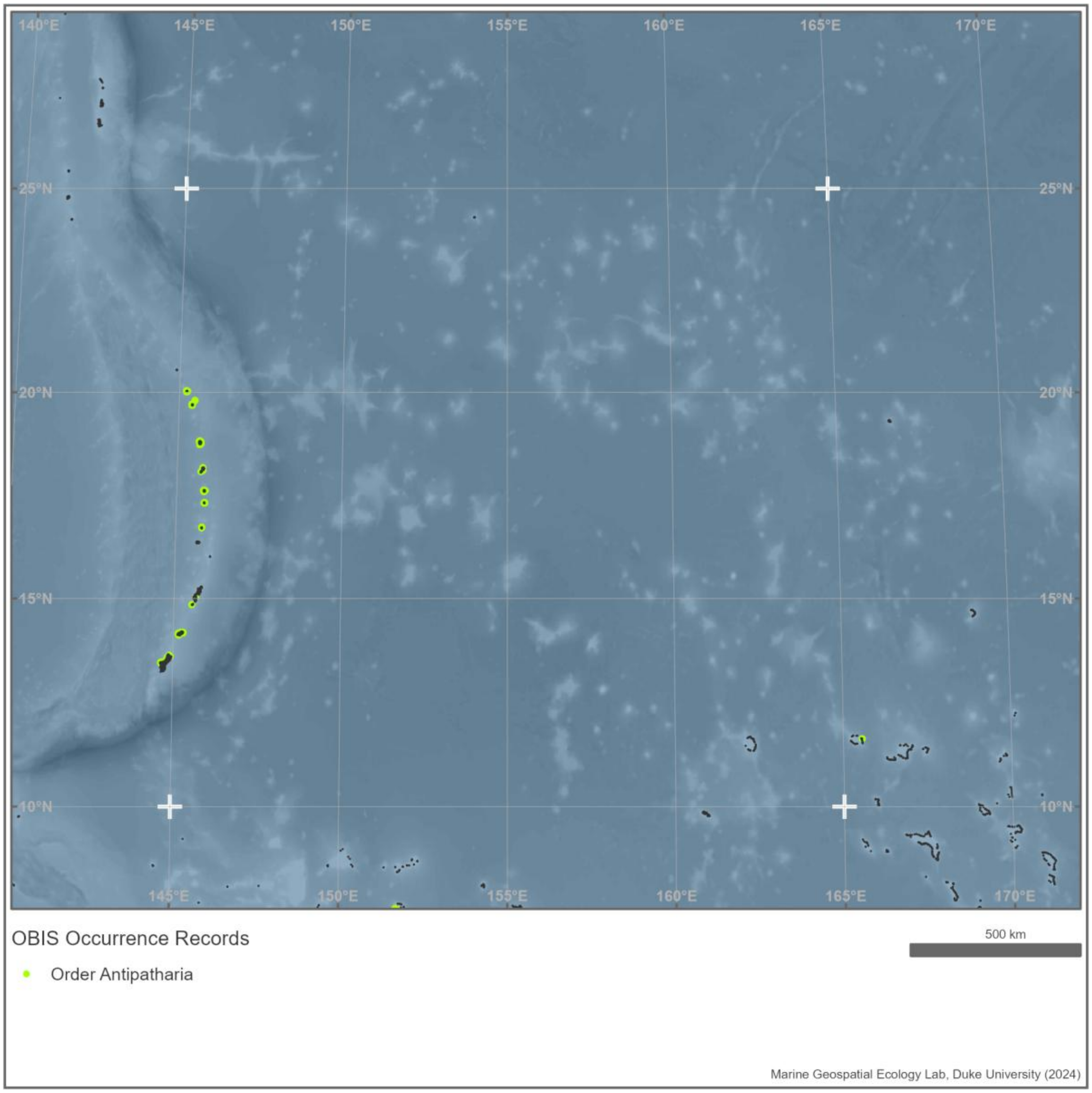


Figure 3.2-3 OBIS records of *Antipatharia*

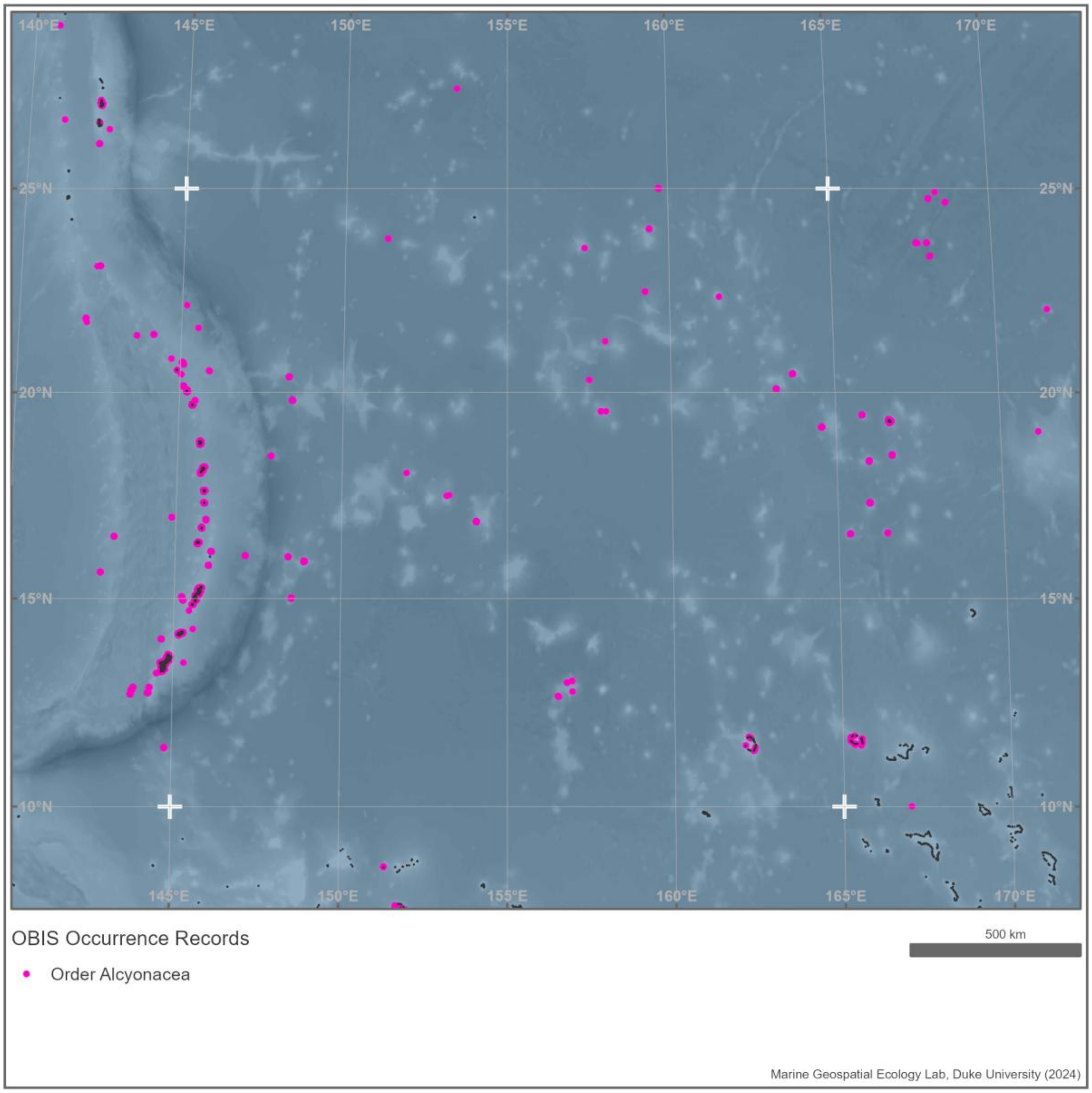


Figure 3.2-4 OBIS records of *Alcyonacea*

3.3 International Seabed Authority Deep Data Portal: Biological Data

"The newly developed "ISA Deep Seabed and Ocean Database" (*DeepData*) was launched in July 2019 at the Authority's 25th Session. This database has been designed to serve as a spatial, internet-based data management system. Its main function is to host all deep-seabed activities related data and in particular, data collected by the contractors on their exploration activities as well as any other relevant environmental and resources related data for the Area.

DeepData contains information on mineral resource assessment (geological data) and environmental baseline/assessment data. However, only the environmental data are accessible to the public. This include biological, physical and geochemical parameters of the marine ecosystems from the seafloor to the ocean surface.

The Geographical Information System (GIS) is part of *DeepData* functionalities. As such, it allows visualization of contract areas, reserved areas and designated areas of particular environmental interest (APEIs). GIS information accessible through *DeepData* also include sampling locations containing biological, physical and/or geochemical parameters of the seabed sediments and water column."

Deep Data Portal: https://data.isa.org.jm/isa/map/

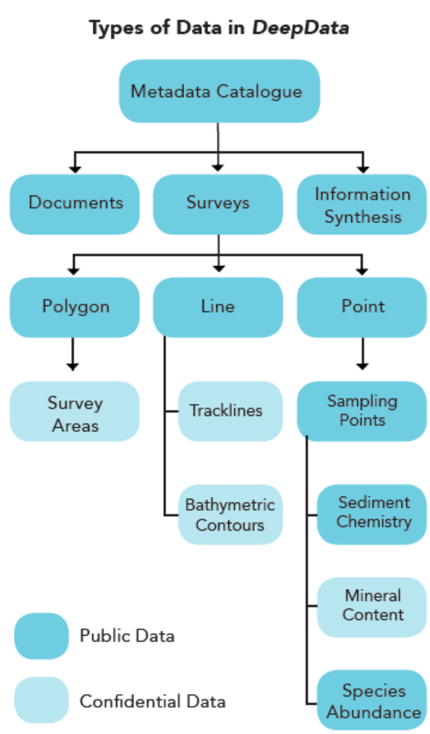


Figure 3.3-1 Chart of data types in Deep Data

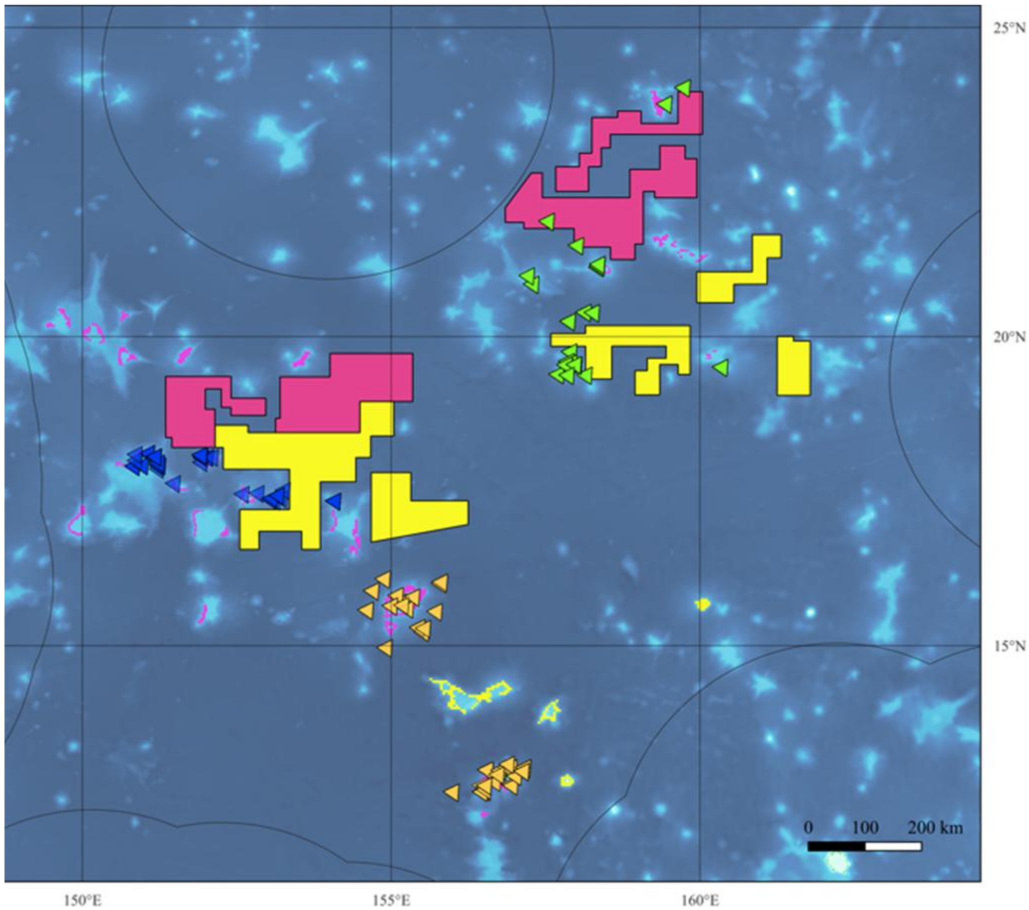


Figure 3.3-2 Distribution of DeepData biological records in northwest Pacific Ocean

3.4 Species Richness from Aquamaps Models

"AquaMaps is a tool for generating model-based, large-scale predictions of natural occurrences of species. For marine species, the model uses estimates of environmental preferences with respect to depth, water temperature, salinity, primary productivity, and association with sea ice or coastal areas. These estimates of species preferences, called environmental envelopes, are derived from large sets of occurrence data available from online collection databases such as GBIF (www.gbif.org) and OBIS (www.obis.org), and from independent knowledge from the literature about the distribution of a given species and its habitat usage that are available in FishBase (and in SeaLifeBase and AlgaeBase for non-fish). The environmental envelopes are matched against local environmental conditions to determine the suitability of a given area in the ocean for a particular species. Predictions of relative probabilities of species occurrence are shown as color coded species range maps in a global grid of half-degree latitude and longitude cell dimensions. The maps are displayed on the web through the use of C-squares Mapper developed at CSIRO Marine and Atmospheric Research in Australia (Rees 2002, 2003)."

Source:
https://www.aquamaps.org/search.php

Reference:
Kaschner, K., K. Kesner-Reyes, C. Garilao, J. Rius-Barile, T. Rees, and R. Froese. 2016. AquaMaps: Predicted range maps for aquatic species. World wide web electronic publication, www.aquamaps.org, Version 08/2016d.

Species Richness was created for selected taxonomic groups using the AquaMaps website:

- Computer Generated Richness Map for Animalia. www.aquamaps.org, version Aug. 2016. Web. Accessed 16 Jul. 2019. Map generated 2017-09-22.
- Computer Generated Richness Map for Mammalia. www.aquamaps.org, version Aug. 2016. Web. Accessed 16 Jul. 2019. Map generated 2017-09-22.
- Computer Generated Richness Map for Elasmobranchii. www.aquamaps.org, version Aug. 2016. Web. Accessed 16 Jul. 2019. Map generated 2016-09-15.

Species Richness maps are available for 27 taxonomic groups (class or order level) via the AquaMaps website. For a full list see
https://www.aquamaps.org/MultiSpeciesMapsList.php?what=orig

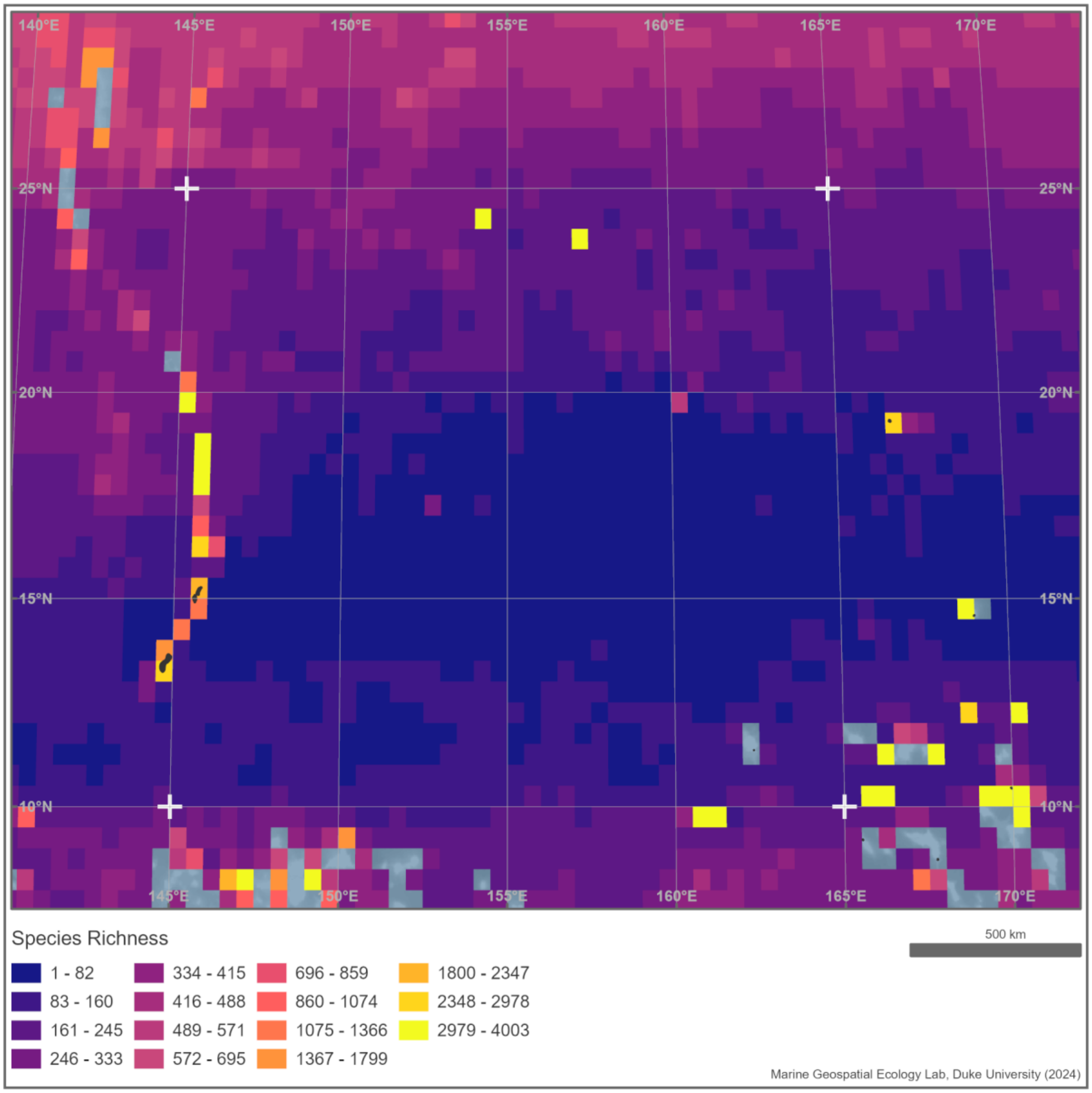


Figure 3.4-1 AquaMaps species richness for all modeled species

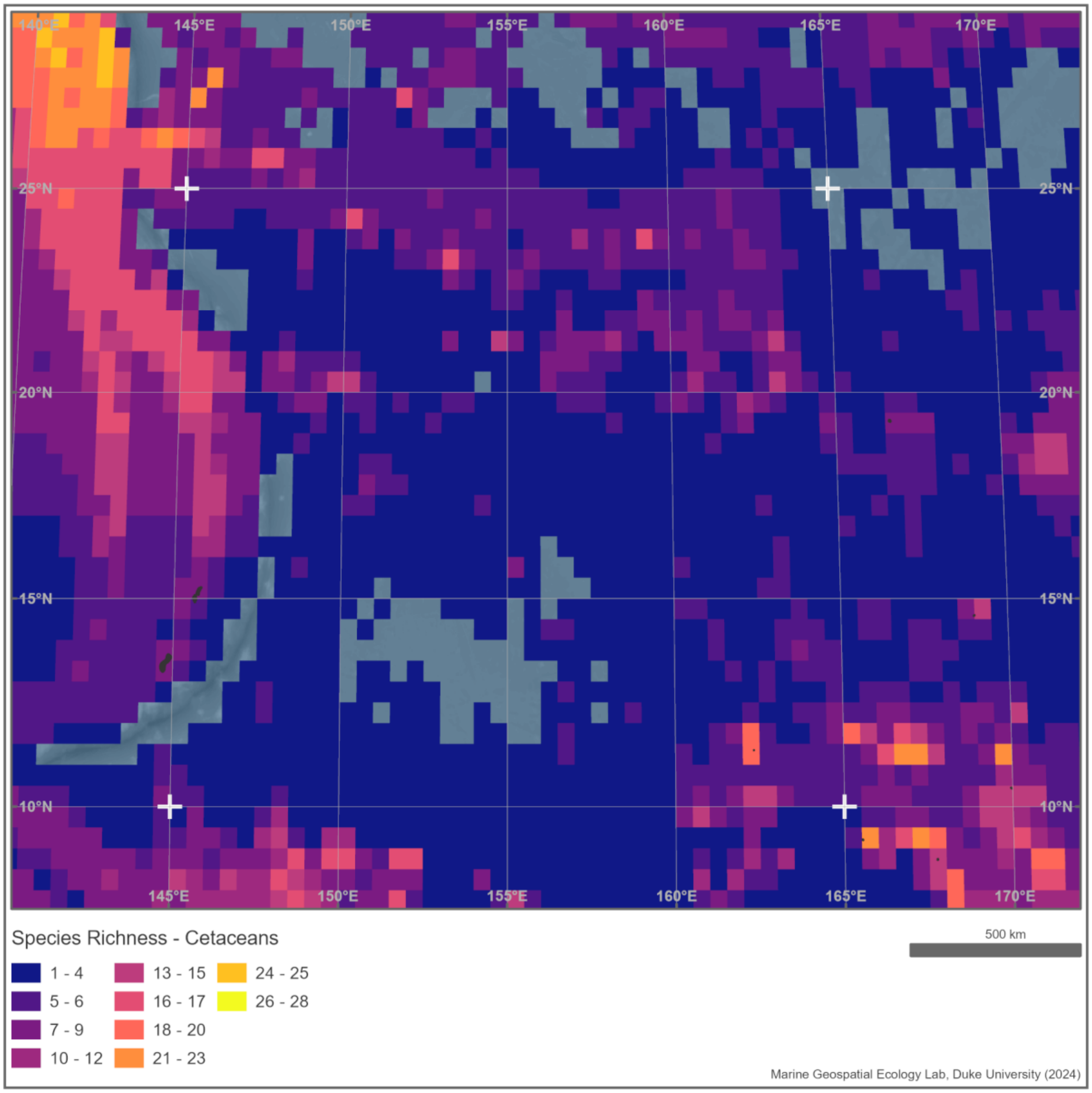


Figure 3.4-2 AquaMaps species richness for Cetaceans

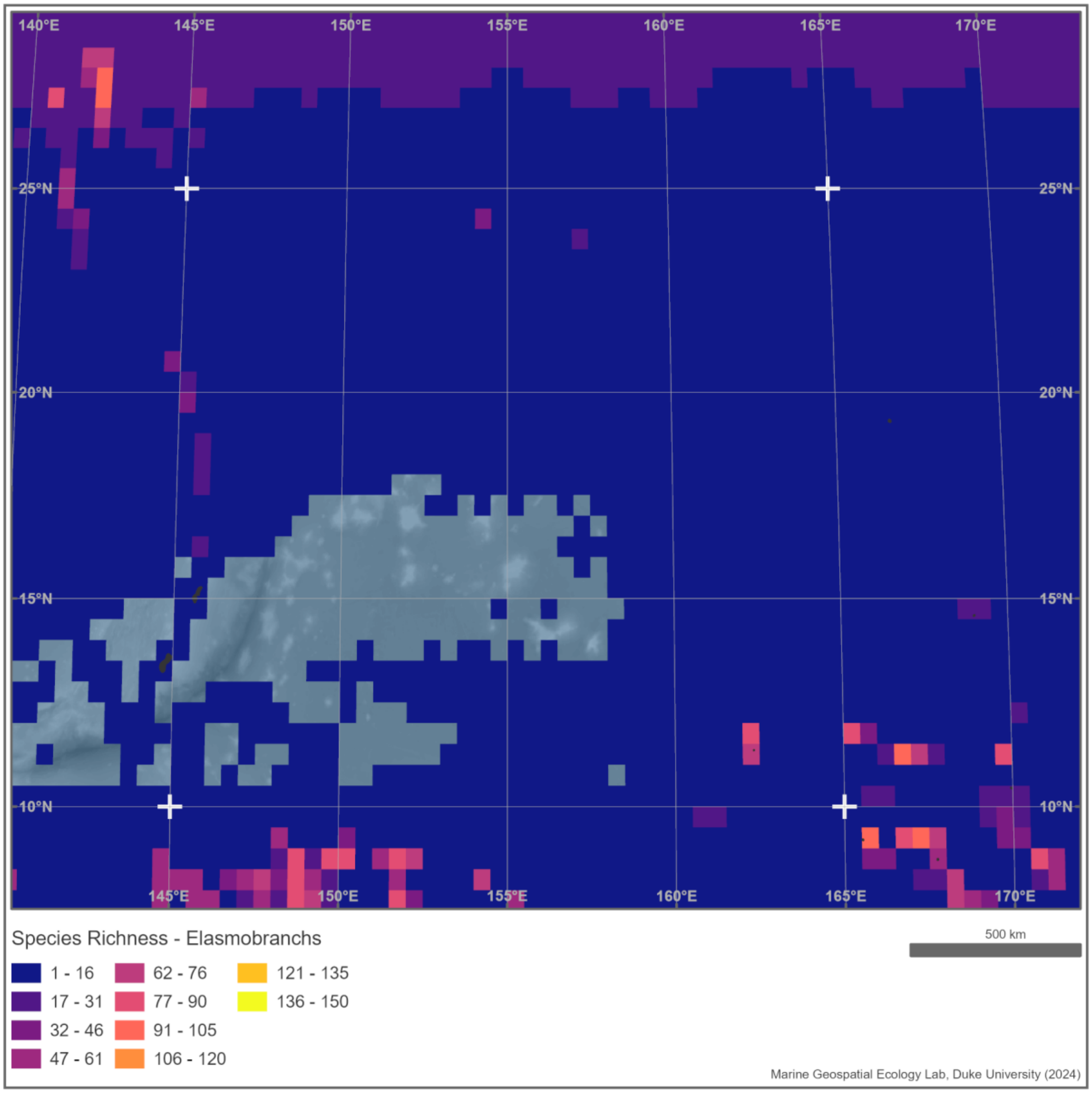


Figure 3.4-3 AquaMaps species richness for Elasmobranchs

3.5 Cetacean data aggregated by OBIS-SEAMAP

OBIS-SEAMAP (http://seamap.env.duke.edu/), Ocean Biodiversity Information System Spatial Ecological Analysis of Megavertebrate Populations, is a spatially referenced online database, aggregating marine mammal, seabird and sea turtle observation data from across the globe. Data from several turtle tracking efforts were extracted from OBIS-SEAMAP data center for the study area and displayed on a per species basis.

Reference:

Halpin P, Read A, Fujioka E, Best B, Donnelly B, Hazen L, Kot C, Urian K, LaBrecque E, Dimatteo A, Cleary J, Good C, Crowder L, Hyrenbach K (2009) OBIS-SEAMAP The World Data Center for Marine Mammal, Sea Bird, and Sea Turtle Distributions. OCEANOGRAPHY 22:104–115.

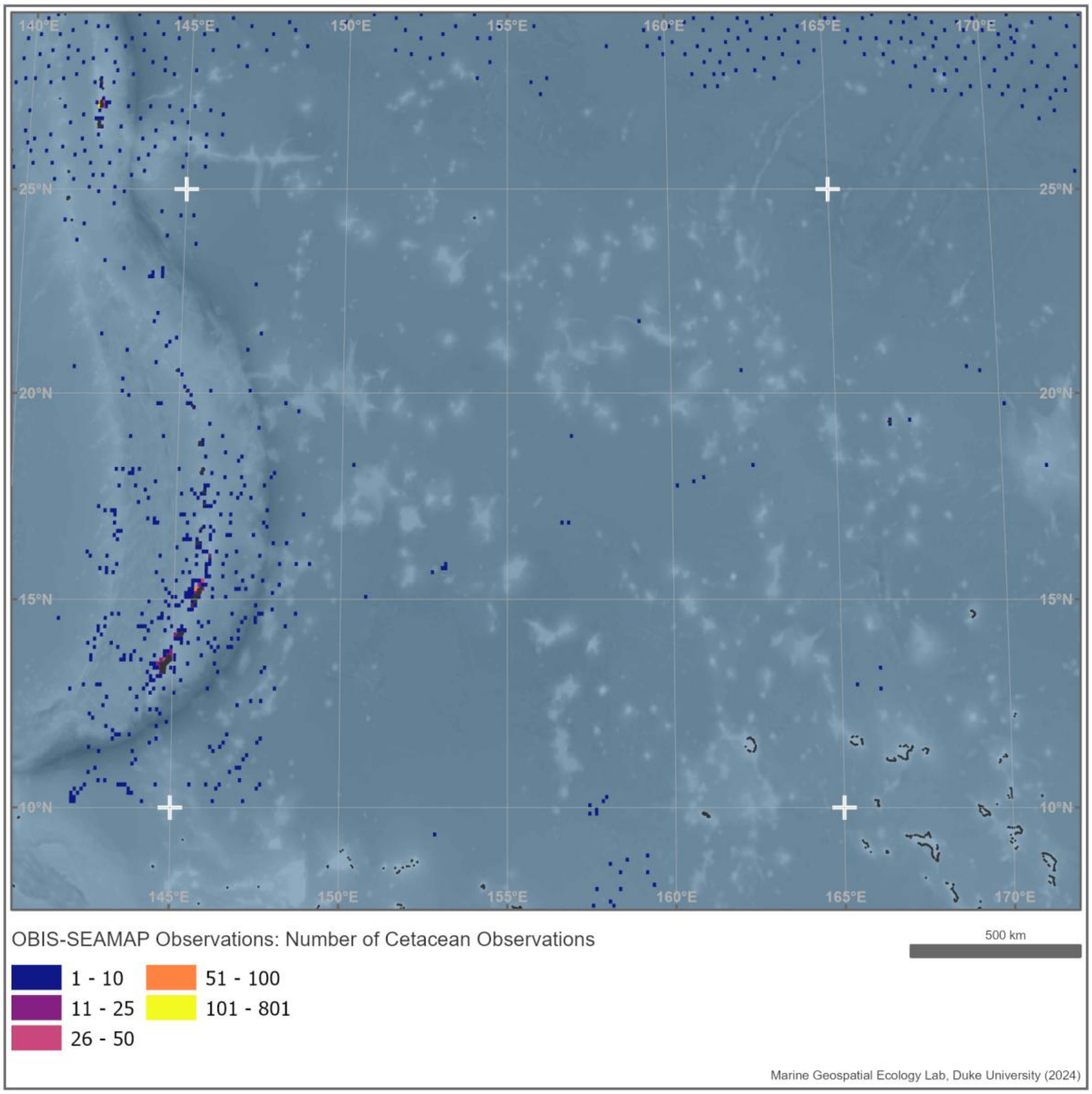


Figure 3.5-1 Cetacean observations from OBIS-SEAMAP

3.6 Turtle data aggregated by OBIS-SEAMAP

OBIS-SEAMAP (http://seamap.env.duke.edu/), Ocean Biodiversity Information System Spatial Ecological Analysis of Megavertebrate Populations, is a spatially referenced online database, aggregating marine mammal, seabird and sea turtle observation data from across the globe. Data from several turtle tracking efforts were extracted from OBIS-SEAMAP data center for the study area and displayed on a per species basis.

Reference:
Halpin P, Read A, Fujioka E, Best B, Donnelly B, Hazen L, Kot C, Urian K, LaBrecque E, Dimatteo A, Cleary J, Good C, Crowder L, Hyrenbach K (2009) OBIS-SEAMAP The World Data Center for Marine Mammal, Sea Bird, and Sea Turtle Distributions. OCEANOGRAPHY 22:104–115.

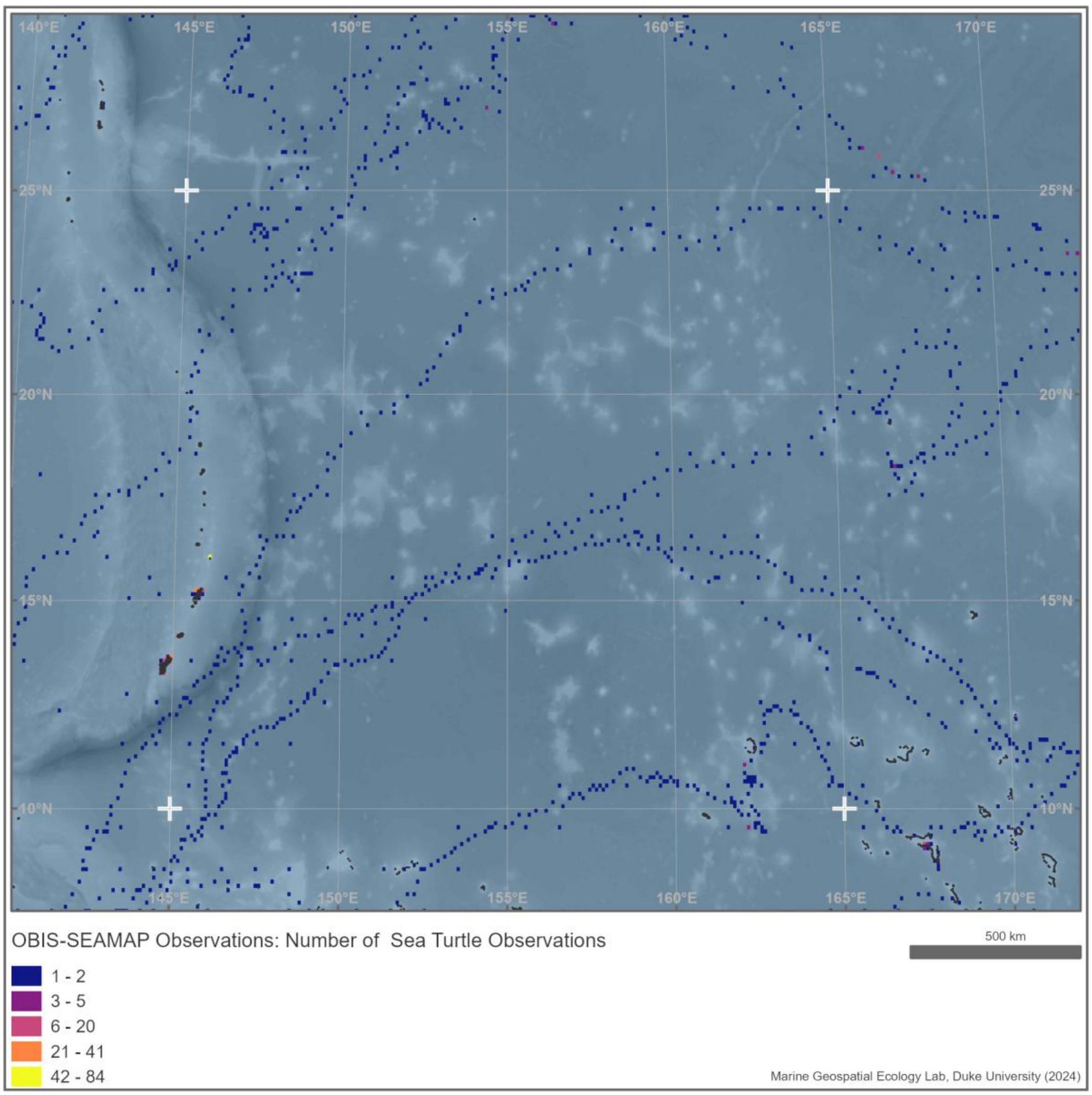


Figure 3.6-1 Sea turtle observations from OBIS-SEAMAP

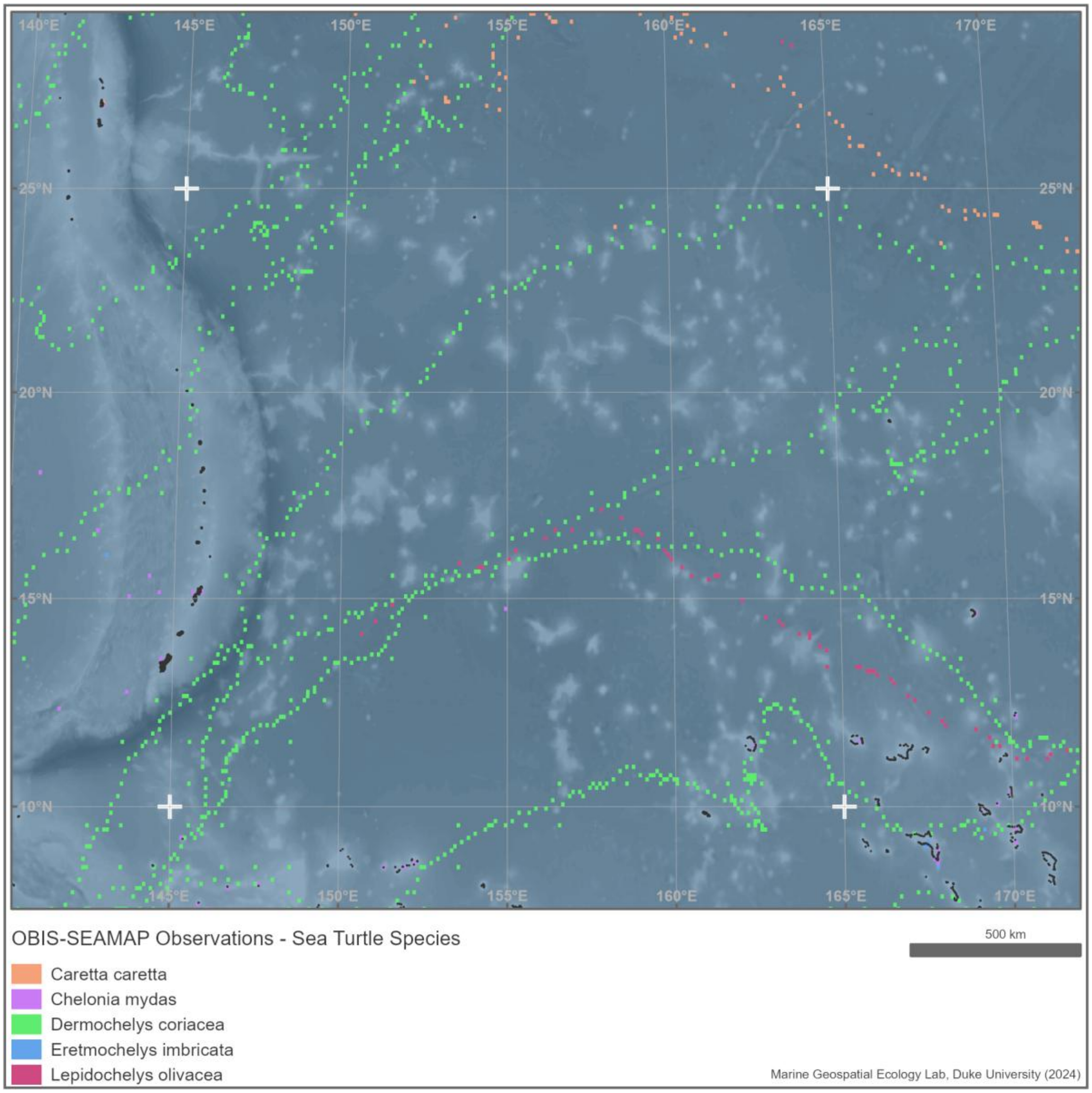


Figure 3.6-2 Sea turtle species data from OBIS-SEAMAP

3.7 Important Bird Areas (IBAs)

BirdLife Important Bird Areas (IBAs) have been identified using several data sources: 1) terrestrial seabird breeding sites are shown with point locality and species that qualifies at the IBA (http://www.birdlife.org/datazone/site/search), 2) marine areas around breeding colonies have been identified based on literature review where possible to guide the distance required by each species; where literature is sparse or lacking, extensions have been applied on a precautionary basis (http://seabird.wikispaces.com/), and 3) sites identified by satellite tracking data via kernel density analysis, first passage time analysis and bootstrapping approaches (www.seabirdtracking.org). Together these IBAs form a network of sites of importance to coastal, pelagic, resident and or migratory species.

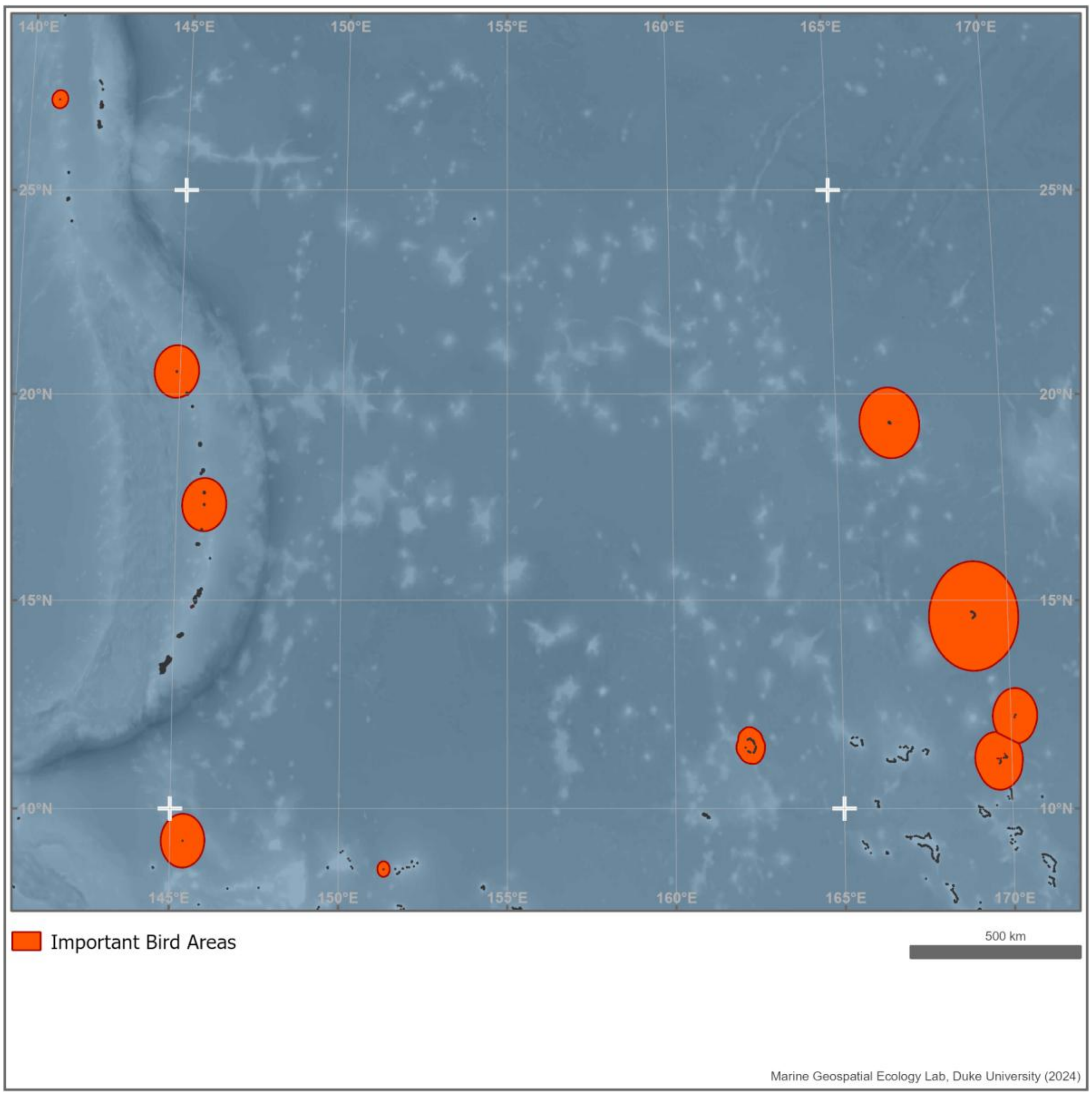


Figure 3.7-1 Important Bird Areas (BirdLife)

3.8 NOAA Capstone Cruise Tracks & Deep-Sea Coral Observations

“In July 2015, a team of NOAA and partners initiated the ‘Campaign to Address Pacific monument Science, Technology, and Ocean NEeds (CAPSTONE)’. CAPSTONE is a major multi-year foundational science effort focused on deepwater areas of U.S. marine protected areas in the central and western Pacific. The investment provides timely, actionable information to support decision making based on reliable and authoritative science. It also serves as an opportunity for the nation to highlight the uniqueness and importance of these national symbols of ocean conservation.”

“This feature layer provides access to NOAA Ocean Exploration data collections managed by NOAA National Center for Environmental Information (NCEI). NOAA Ocean Exploration expeditions and projects archived elsewhere may not be represented within this layer. Expeditions within this layer represent data collected from 1999-present.”

Source:
https://www.ncei.noaa.gov/maps/ocean-exploration-data-atlas/

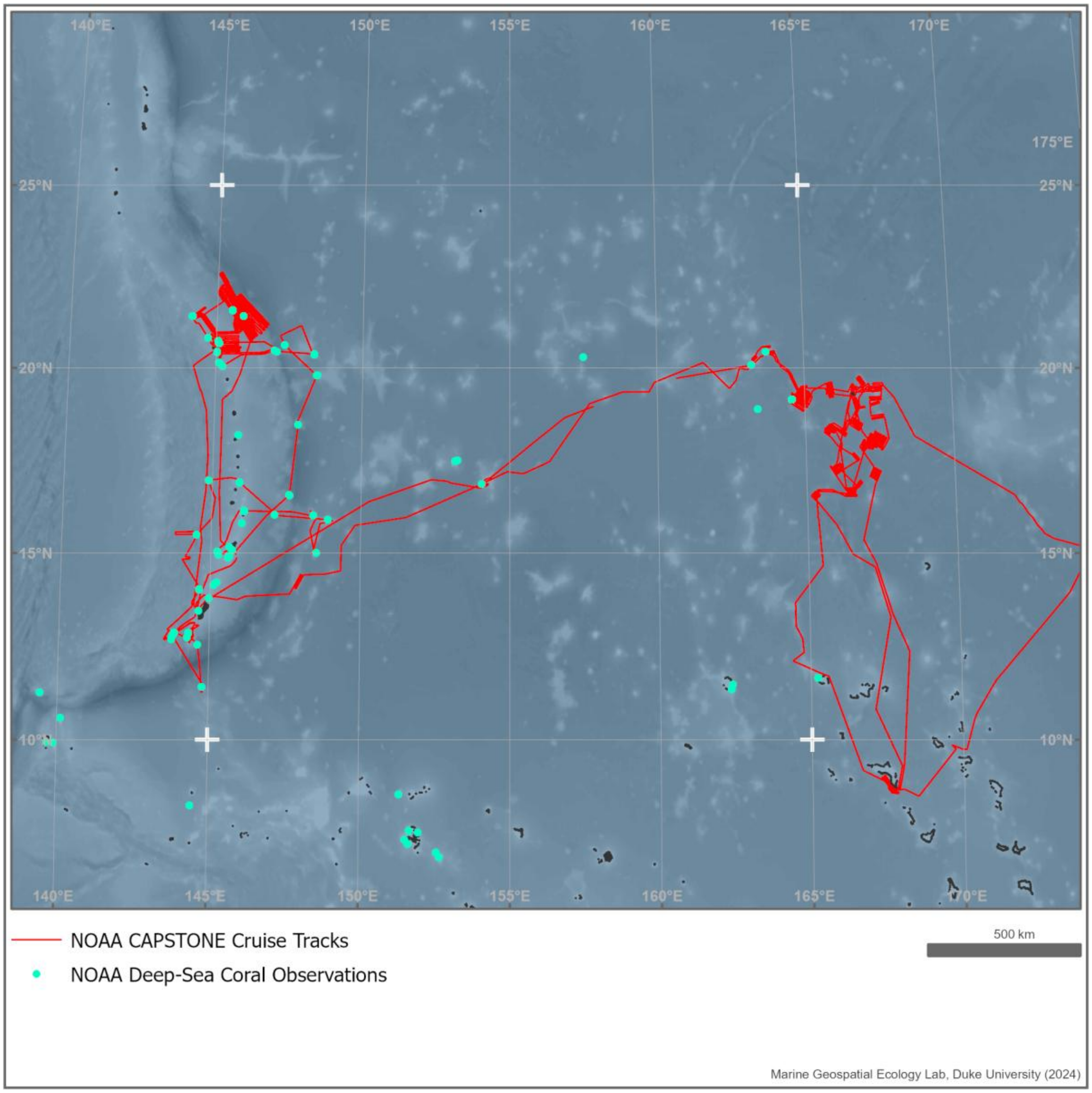


Figure 3.8-1 NOAA CAPSTONE cruise tracks and deep-sea coral observations

3.9 Global Distribution of Deep-Water *Antipatharia* Habitat

Abstract (Yesson et al. 2017)
"Antipatharia are a diverse group of corals with many species found in deep water. Many Antipatharia are habitat for associates, have extreme longevity and some species can occur beyond 8500 m depth. As they are major constituents of 'coral gardens', which are Vulnerable Marine Ecosystems (VMEs), knowledge of their distribution and environmental requirements is an important pre-requisite for informed conservation planning particularly where the expense and difficulty of deep-sea sampling prohibits comprehensive surveys.

This study uses a global database of Antipatharia distribution data to perform habitat suitability modelling using the Maxent methodology to estimate the global extent of black coral habitat suitability. The model of habitat suitability is driven by temperature but there is notable influence from other variables of topography, surface productivity and oxygen levels.

This model can be used to predict areas of suitable habitat, which can be useful for conservation planning. The global distribution of Antipatharia habitat suitability shows a marked contrast with the distribution of specimen observations, indicating that many potentially suitable areas have not been sampled, and that sampling effort has been disproportionate to shallow, accessible areas inside marine protected areas (MPAs). Although 25% of Antipatharia observations are located in MPAs, only 7-8% of predicted suitable habitat is protected, which is short of the Convention on Biological Diversity target to protect 10% of ocean habitats by 2020."

Reference:
Yesson, C., F. Bedford, A. Rogers, and M. Taylor. 2017. "The Global Distribution of Deep-Water Antipatharia Habitat." *Deep Sea Research Part II: Topical Studies in Oceanography*, Towards ecosystem based management and monitoring of the deep Mediterranean, North-East Atlantic and Beyond, 145 (November): 79–86. https://doi.org/10.1016/j.dsr2.2015.12.004.

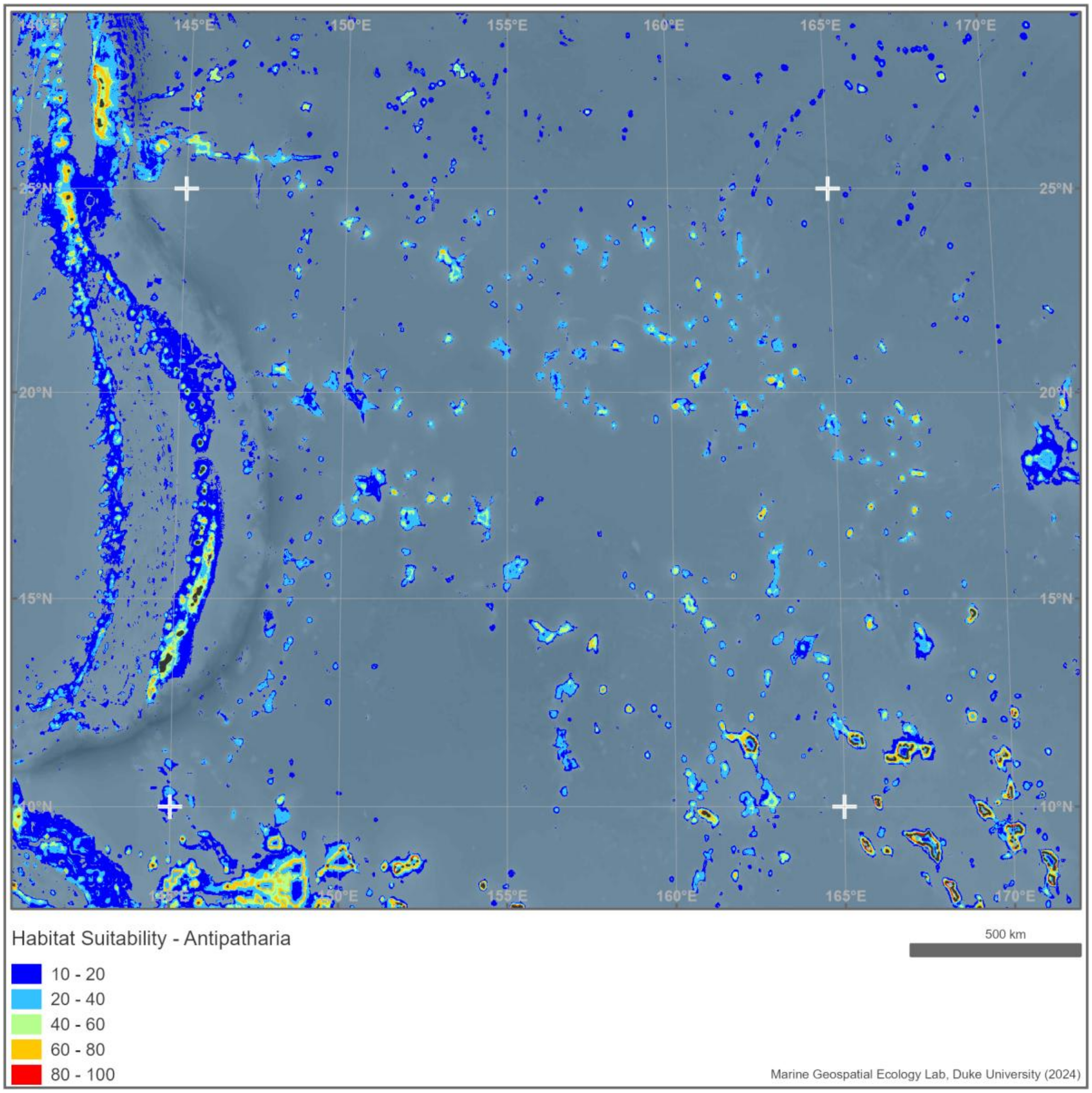


Figure 3.9-1 Deep-Water *Antipatharia* Habitat

3.10 Predictions of Habitat Suitability for Cold-Water Octocorals

Abstract (Yesson et al. 2012):
"Three-quarters of Octocorallia species are found in deep waters. These cold- water octocoral colonies can form a major constituent of structurally complex habitats. The global distribution and the habitat requirements of deep-sea octocorals are poorly understood given the expense and difficulties of sampling at depth. Habitat suitability models are useful tools to extrapolate distributions and provide an understanding of ecological requirements. Here, we present global habitat suitability models and distribution maps for seven suborders of Octocorallia: Alcyoniina, Calcaxonia, Holaxonia, Scleraxonia, Sessiliflorae, Stolonifera and Subselliflorae."

Reference:

Yesson C, Taylor ML, Tittensor DP, Davies AJ, Guinotte J, Baco A, Black J, Hall-Spencer JM, Rogers AD (2012) Global habitat suitability of cold-water octocorals. Journal of Biogeography 39:1278–1292. Doi: 10.1111/j.1365-2699.2011.02681.x

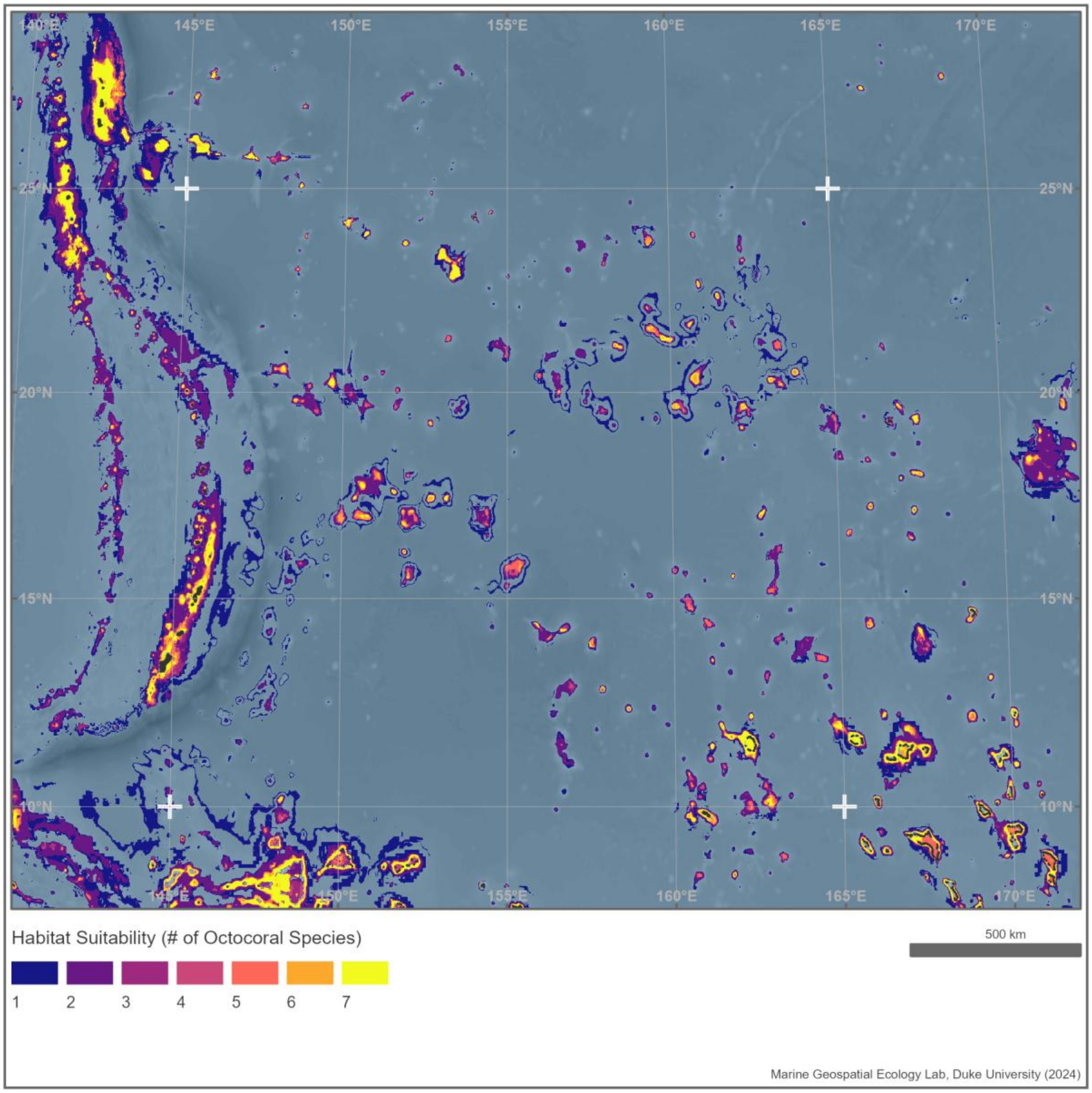


Figure 3.10-1 Deep-Sea octocoral habitat suitability – consensus

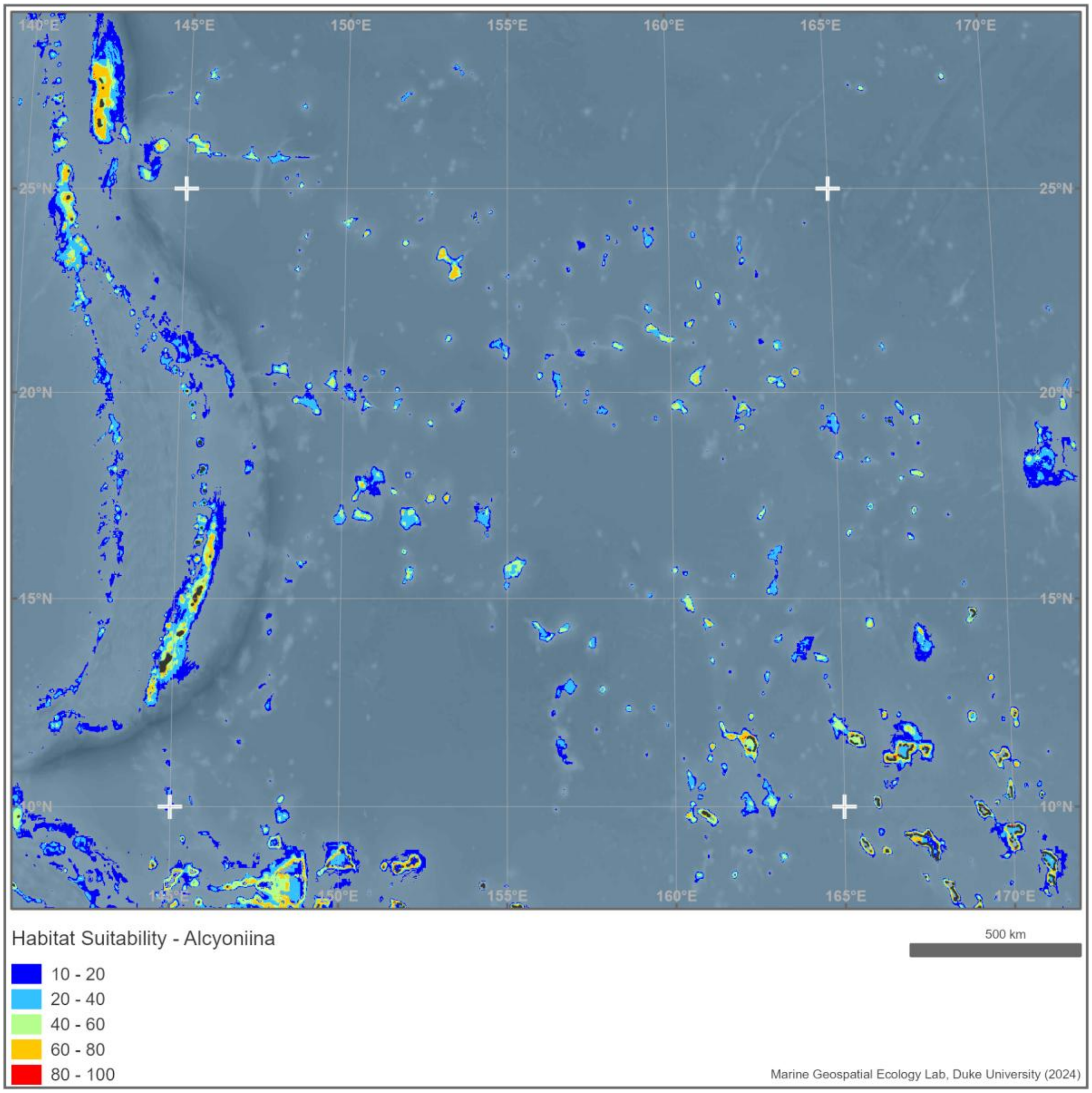


Figure 3.10-2 Deep-Sea octocoral habitat suitability - *Alcyoniina*

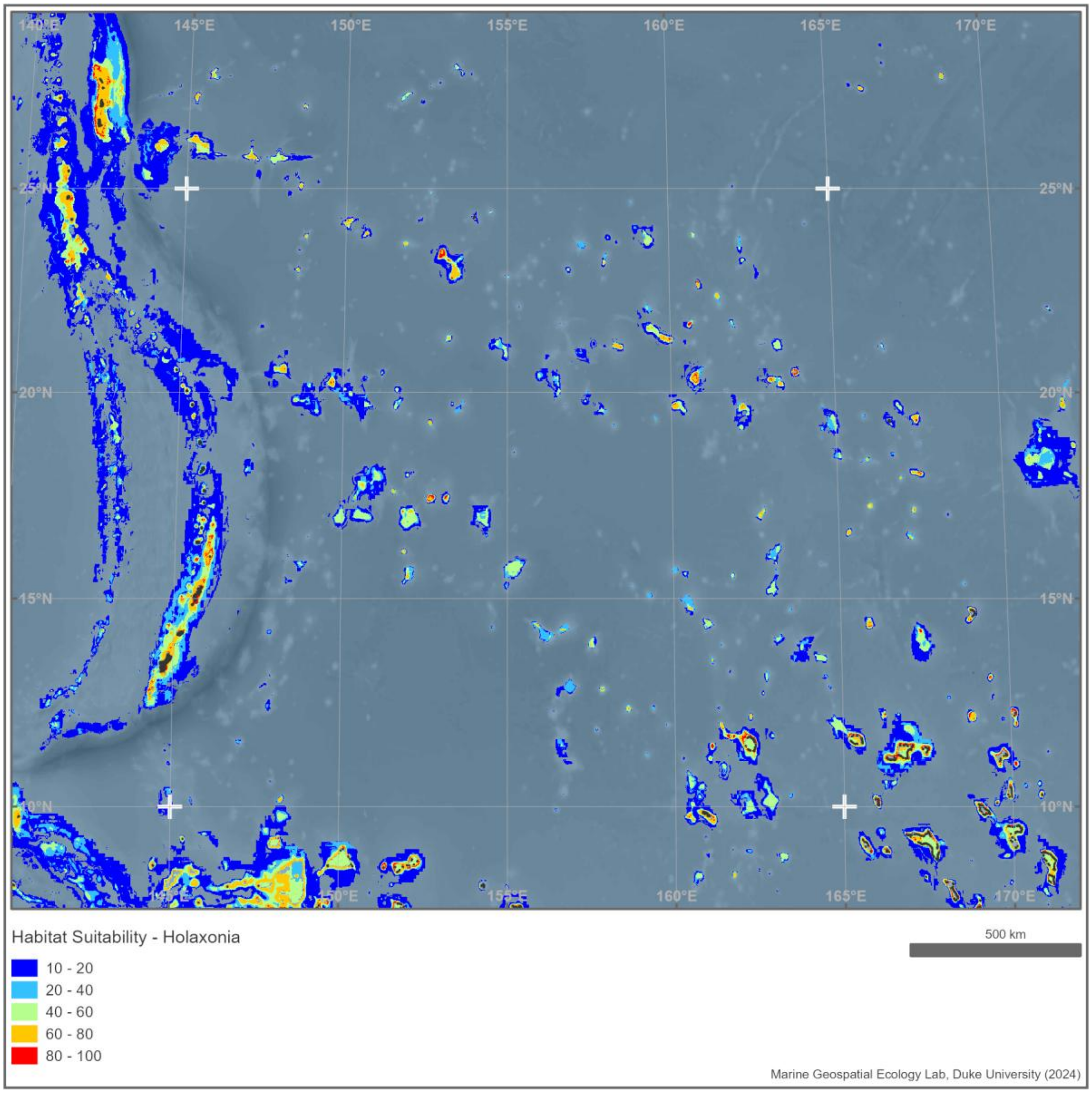


Figure 3.10-3 Deep-Sea octocoral habitat suitability - *Holaxonia*

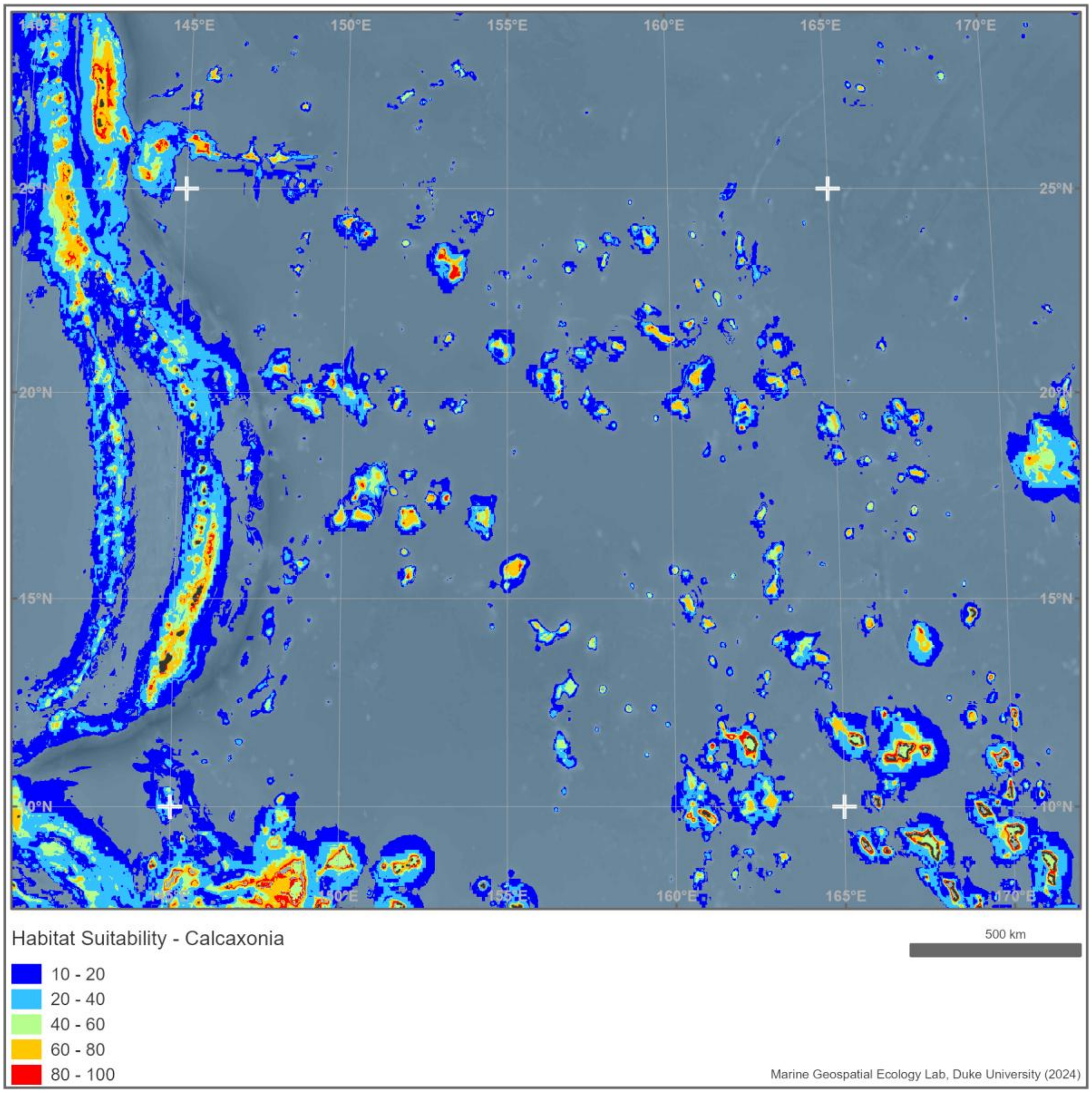


Figure 3.10-4 Deep-Sea octocoral habitat suitability - *Calcaxonia*

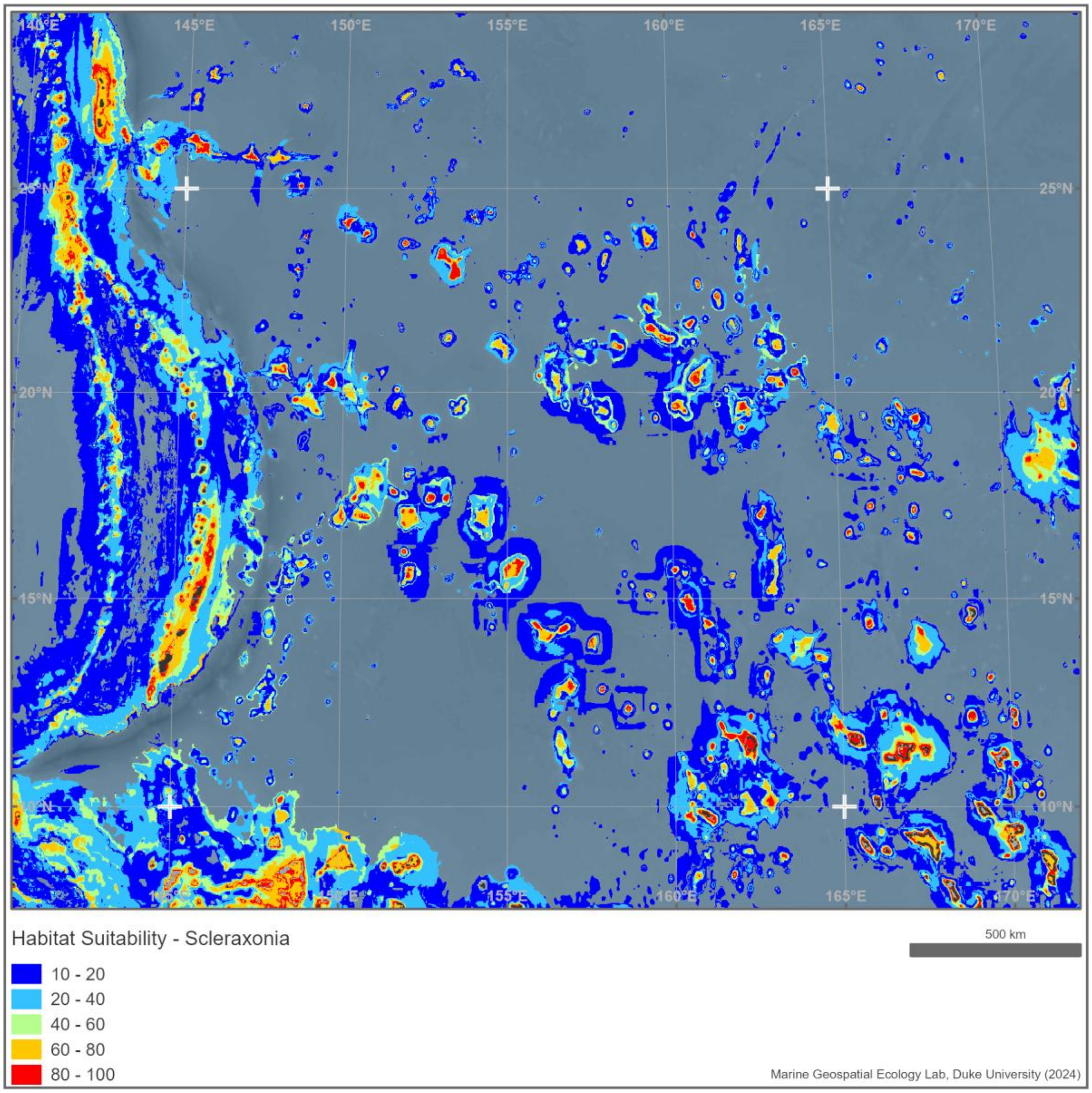


Figure 3.10-5 Deep-Sea octocoral habitat suitability - *Scleraxonia*

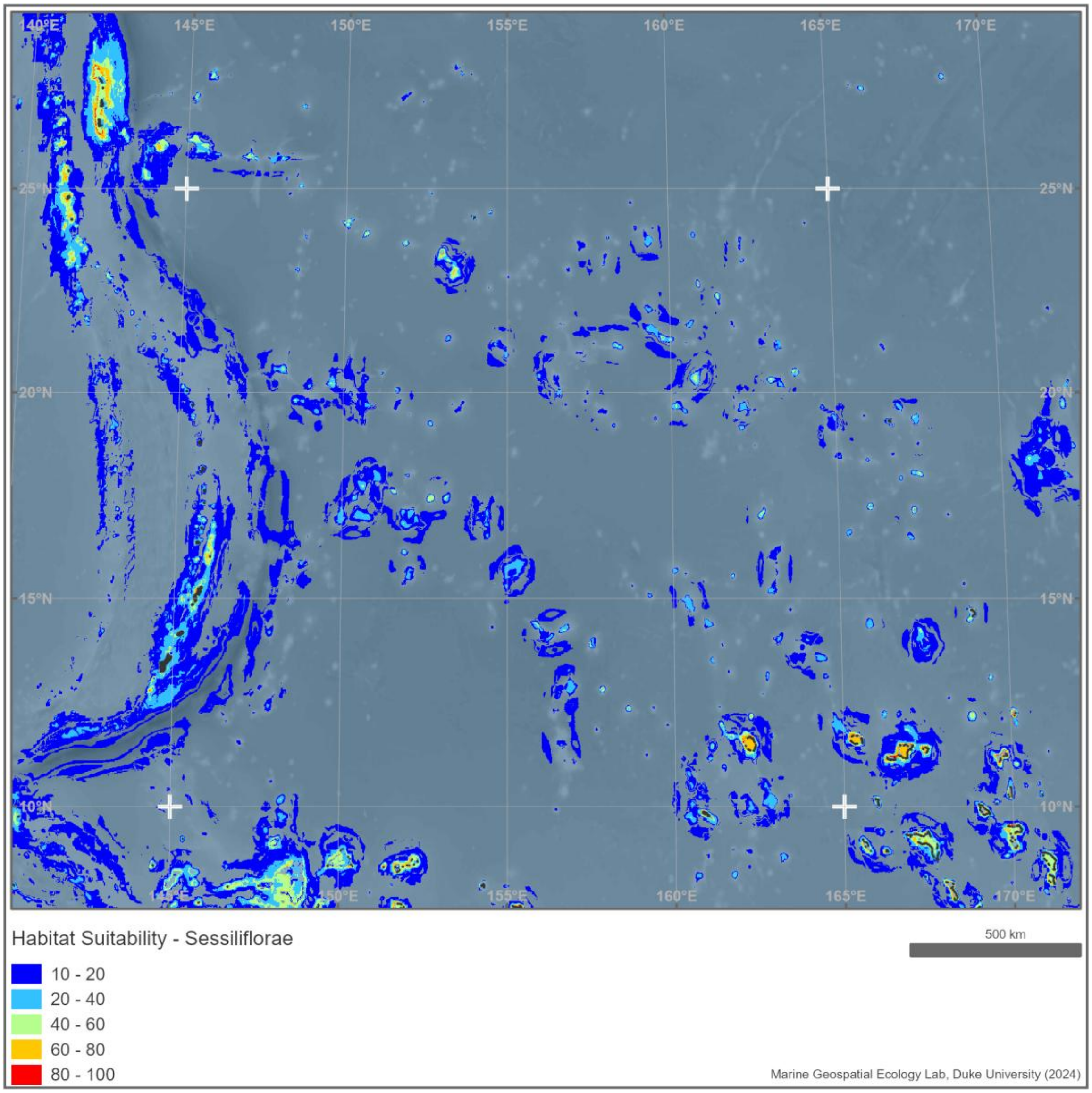


Figure 3.10-6 Deep-Sea octocoral habitat suitability - *Sessiliflorae*

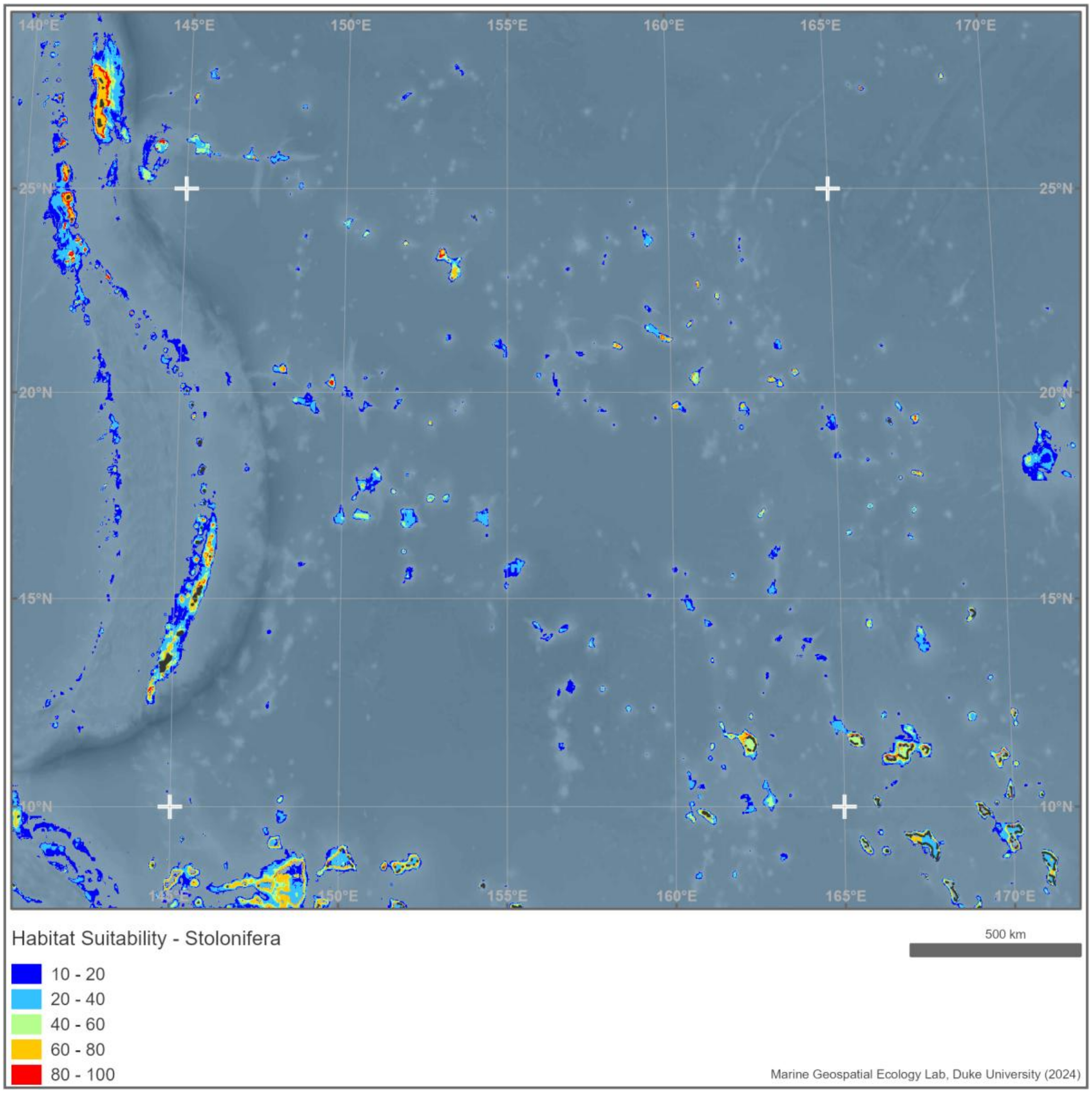


Figure 3.10-7 Deep-Sea octocoral habitat suitability - *Stolonifera*

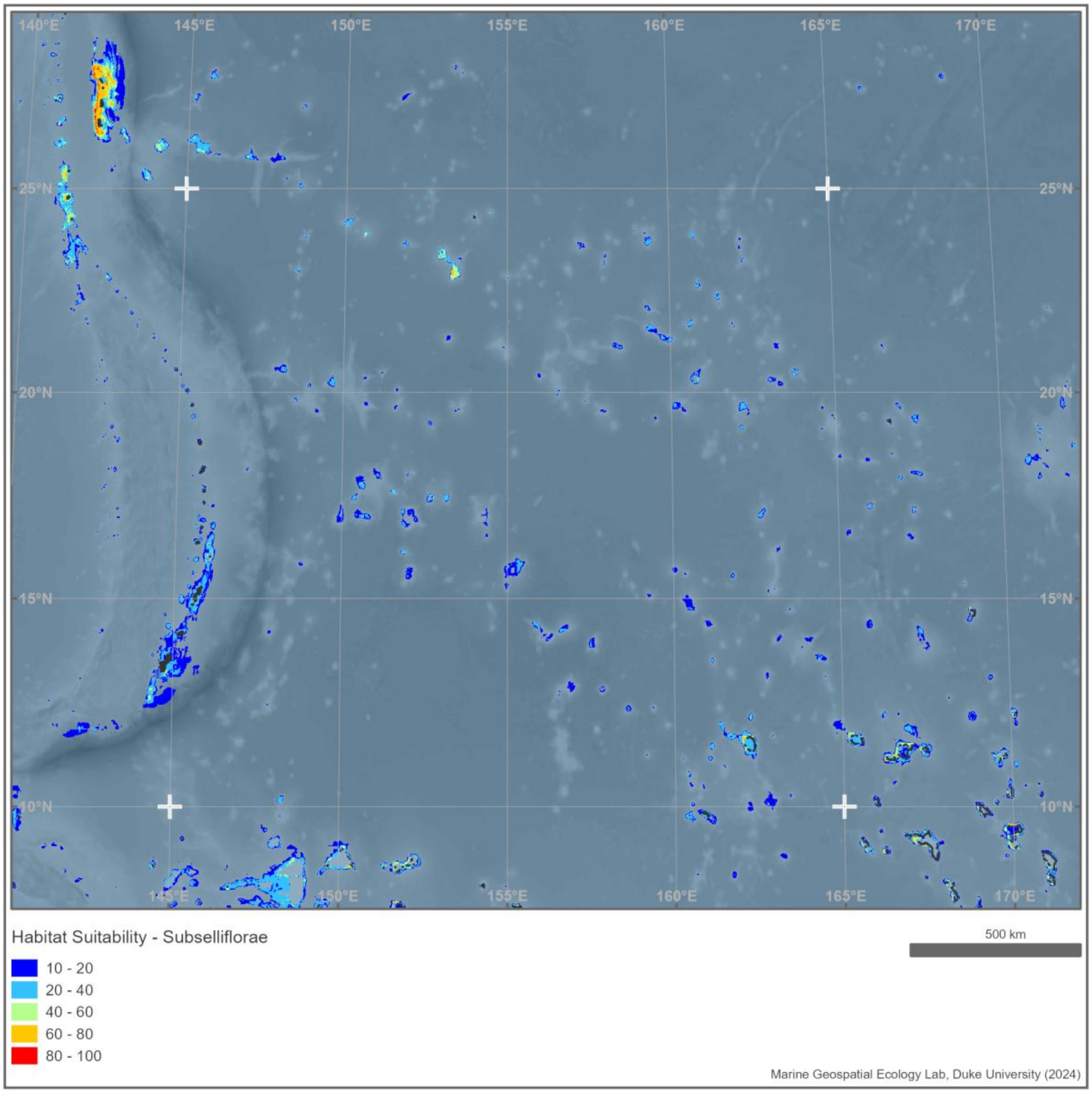


Figure 3.10-8 Deep-Sea octocoral habitat suitability - *Subselliflorae*

3.11 Predictions of Habitat Suitability for Framework-Forming Scleractinian Corals

Abstract (Davies & Guinotte 2011):
"Predictive habitat models are increasingly being used by conservationists, researchers and governmental bodies to identify vulnerable ecosystems and species' distributions in areas that have not been sampled. However, in the deep sea, several limitations have restricted the widespread utilisation of this approach. These range from issues with the accuracy of species presences, the lack of reliable absence data and the limited spatial resolution of environmental factors known or thought to control deep-sea species' distributions. To address these problems, global habitat suitability models have been generated for five species of framework-forming scleractinian corals by taking the best available data and using a novel approach to generate high resolution maps of seafloor conditions. High-resolution global bathymetry was used to resample gridded data from sources such as World Ocean Atlas to produce continuous 30-arc second (1 km^2) global grids for environmental, chemical and physical data of the world's oceans. The increased area and resolution of the environmental variables resulted in a greater number of coral presence records being incorporated into habitat models and higher accuracy of model predictions. The most important factors in determining cold-water coral habitat suitability were depth, temperature, aragonite saturation state and salinity. Model outputs indicated the majority of suitable coral habitat is likely to occur on the continental shelves and slopes of the Atlantic, South Pacific and Indian Oceans. The North Pacific has very little suitable scleractinian coral habitat. Numerous small scale features (i.e., seamounts), which have not been sampled or identified as having a high probability of supporting cold-water coral habitat were identified in all ocean basins. Field validation of newly identified areas is needed to determine the accuracy of model results, assess the utility of modeling efforts to identify vulnerable marine ecosystems for inclusion in future marine protected areas and reduce coral bycatch by commercial fisheries."

Reference:
Davies AJ, Guinotte JM (2011) Global Habitat Suitability for Framework-Forming Cold-Water Corals. PLoS ONE 6(4): e18483. doi:10.1371/journal.pone.0018483

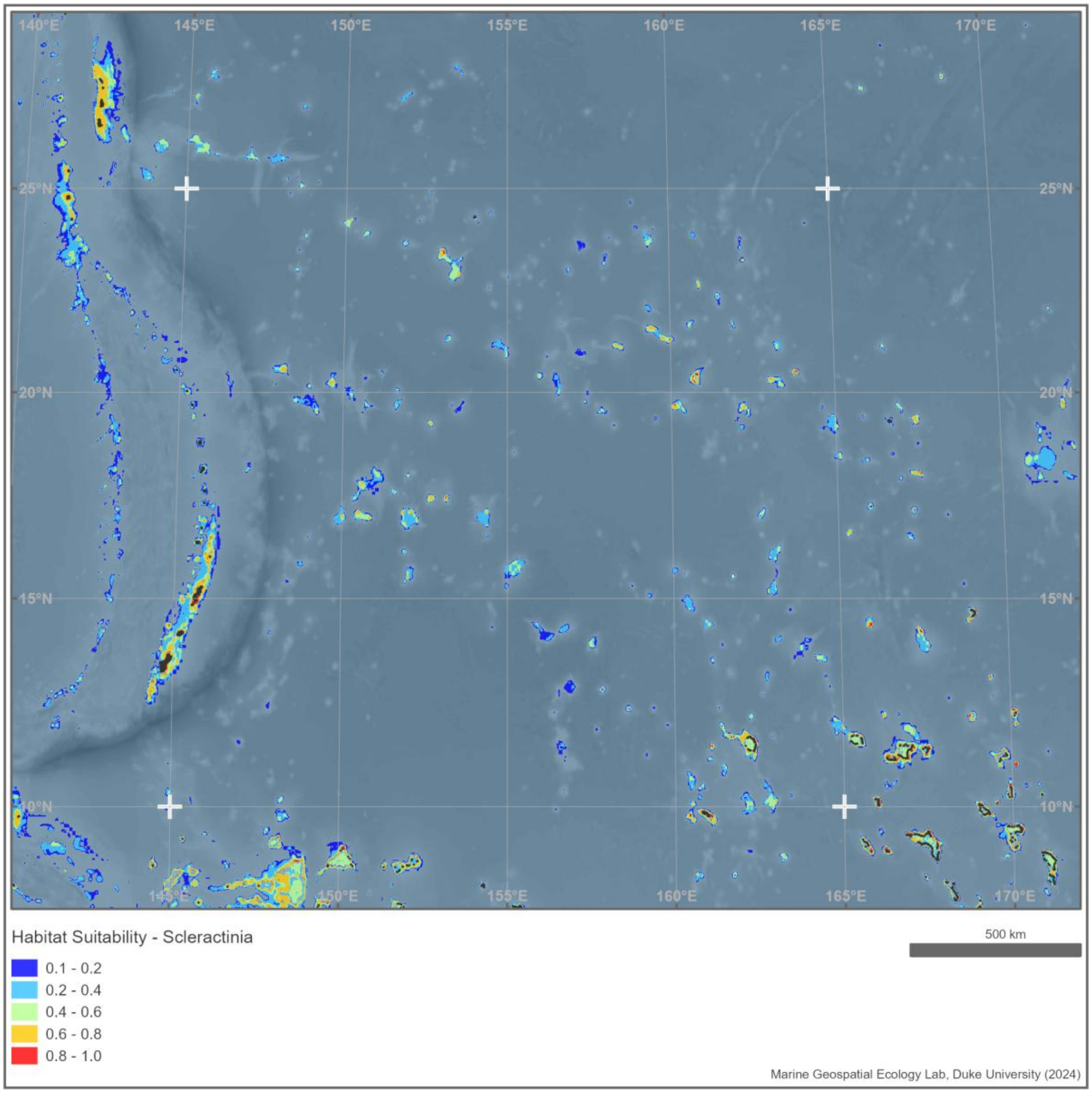


Figure 3.11-1 Deep-Sea *Scleractinia* habitat suitability – all five framework forming species

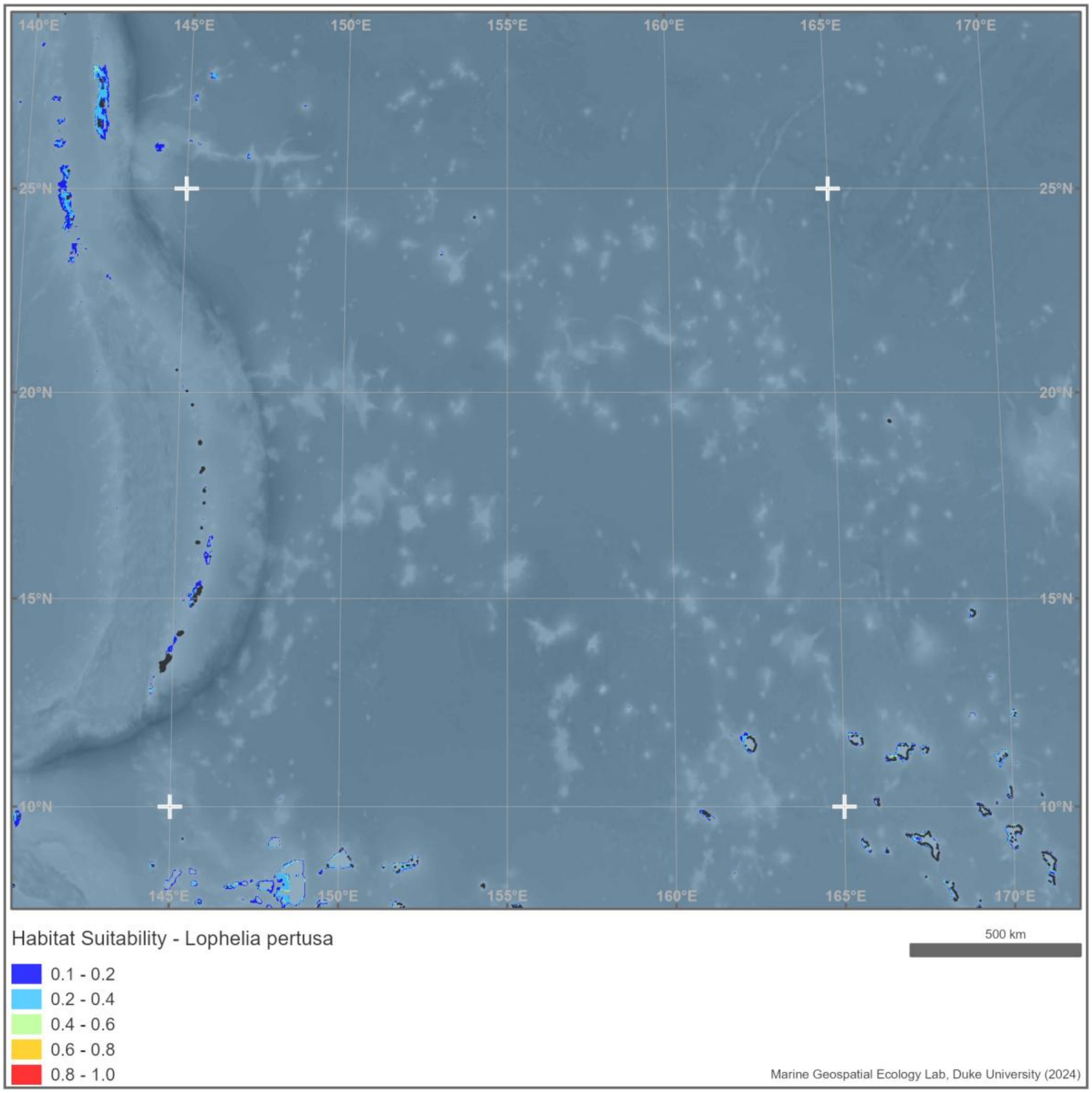


Figure 3.11-2 Deep-Sea *Scleractinia* habitat suitability – *Lophelia pertusa*

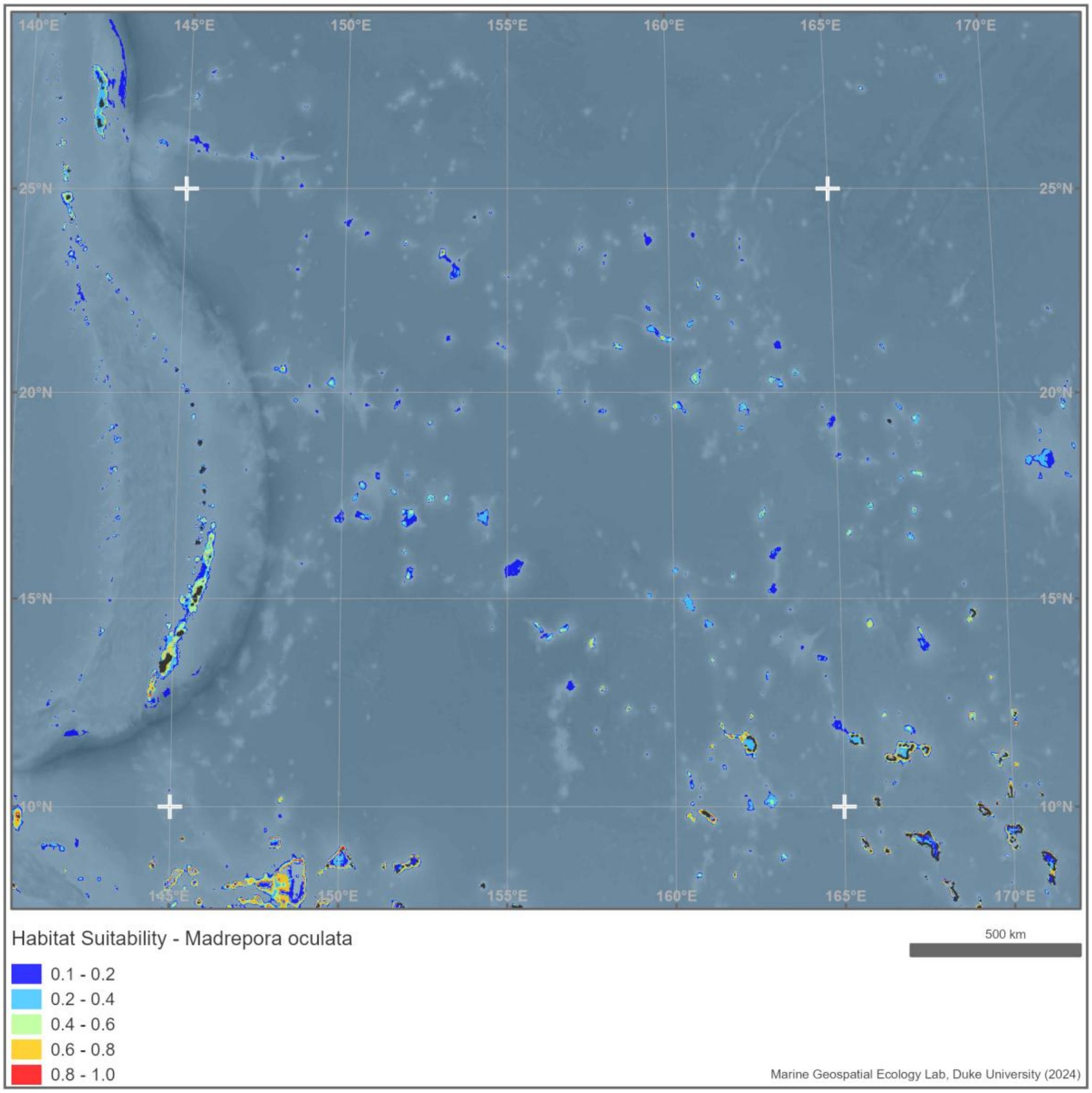


Figure 3.11-3 Deep-Sea *Scleractinia* habitat suitability – *Madrepora oculata*

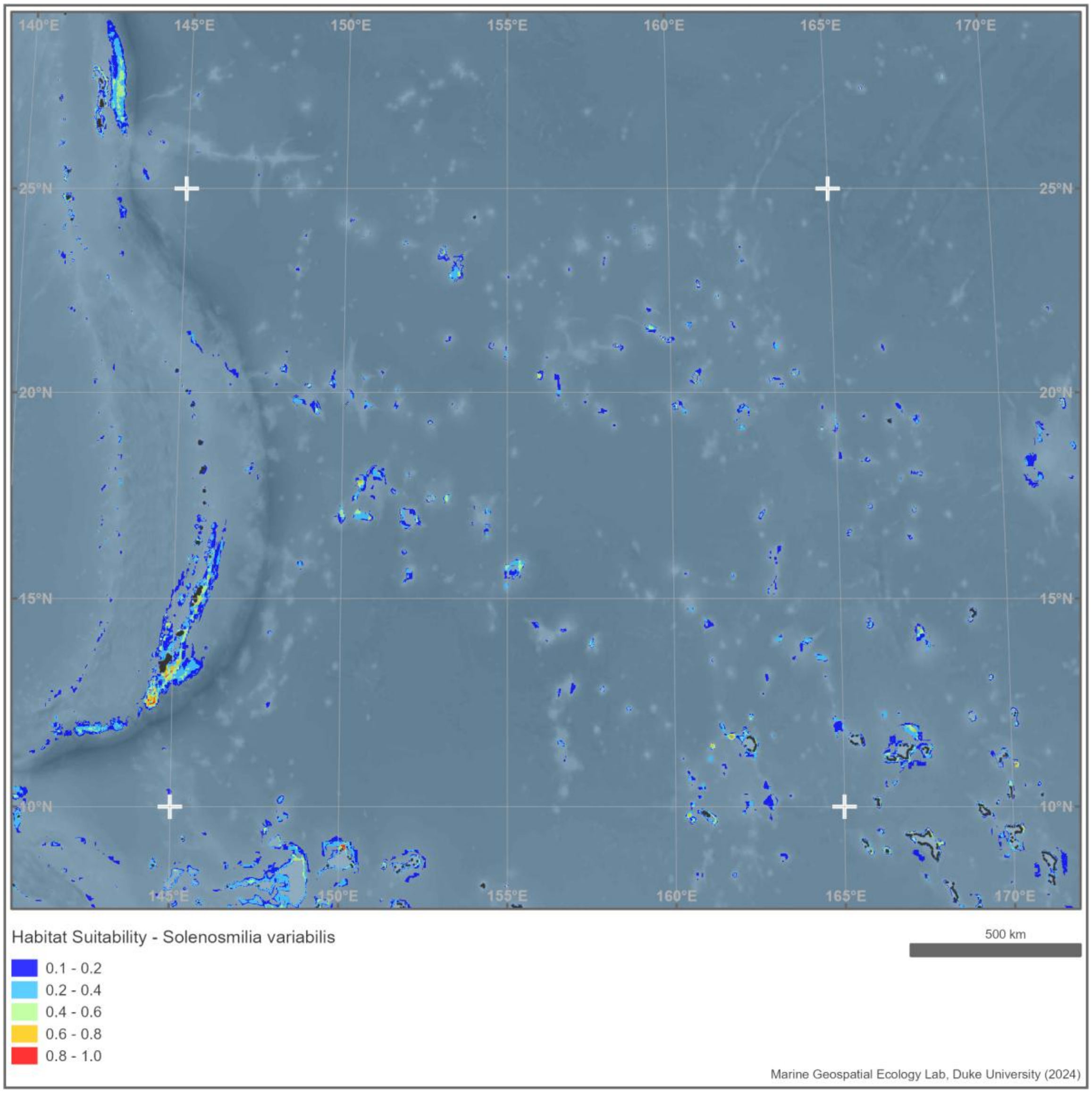


Figure 3.11-4 Deep-Sea *Scleractinia* habitat suitability – *Solenosmilia variabilis*

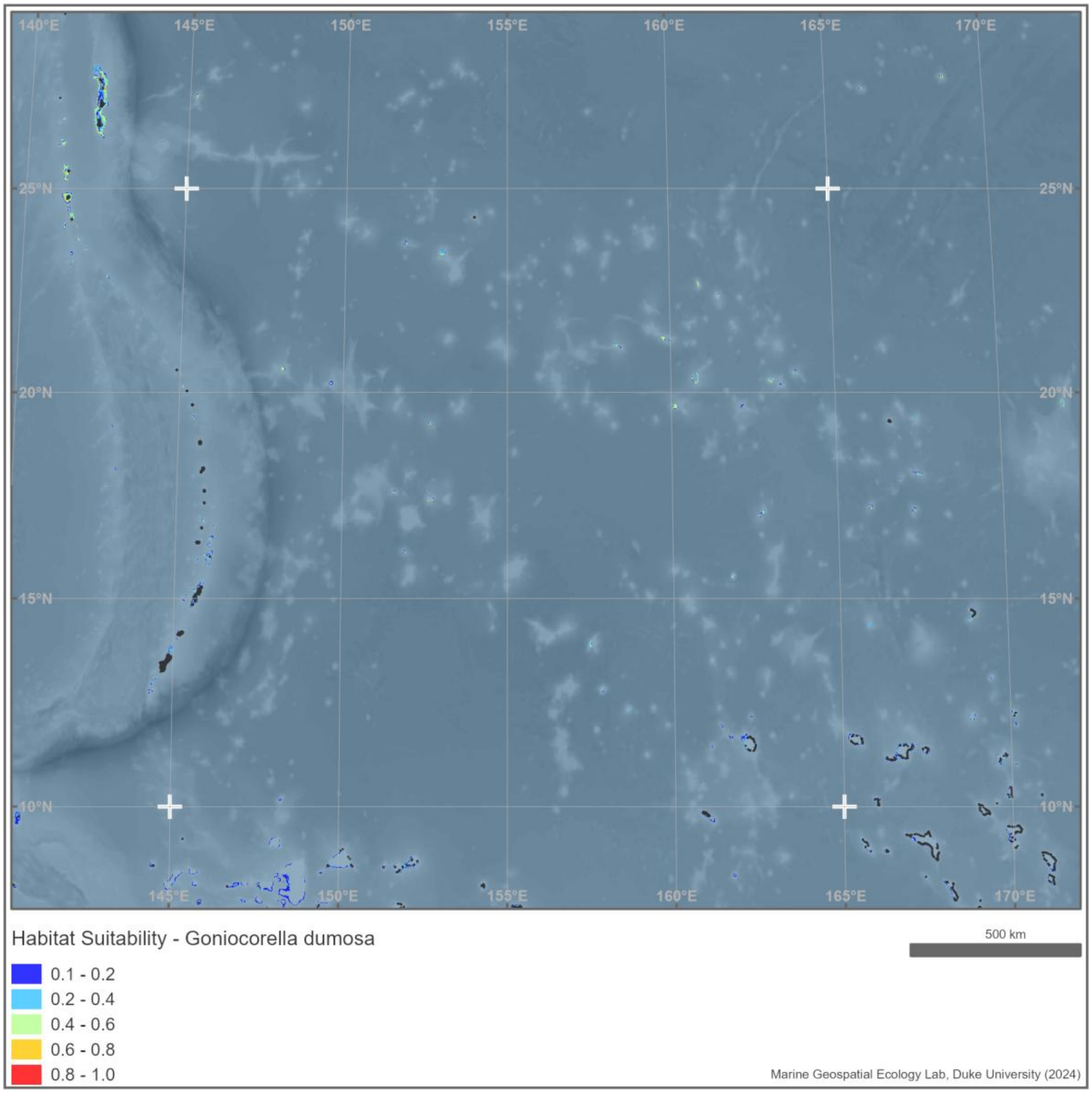


Figure 3.11-5 Deep-Sea *Scleractinia* habitat suitability – *Goniocorella dumosa*

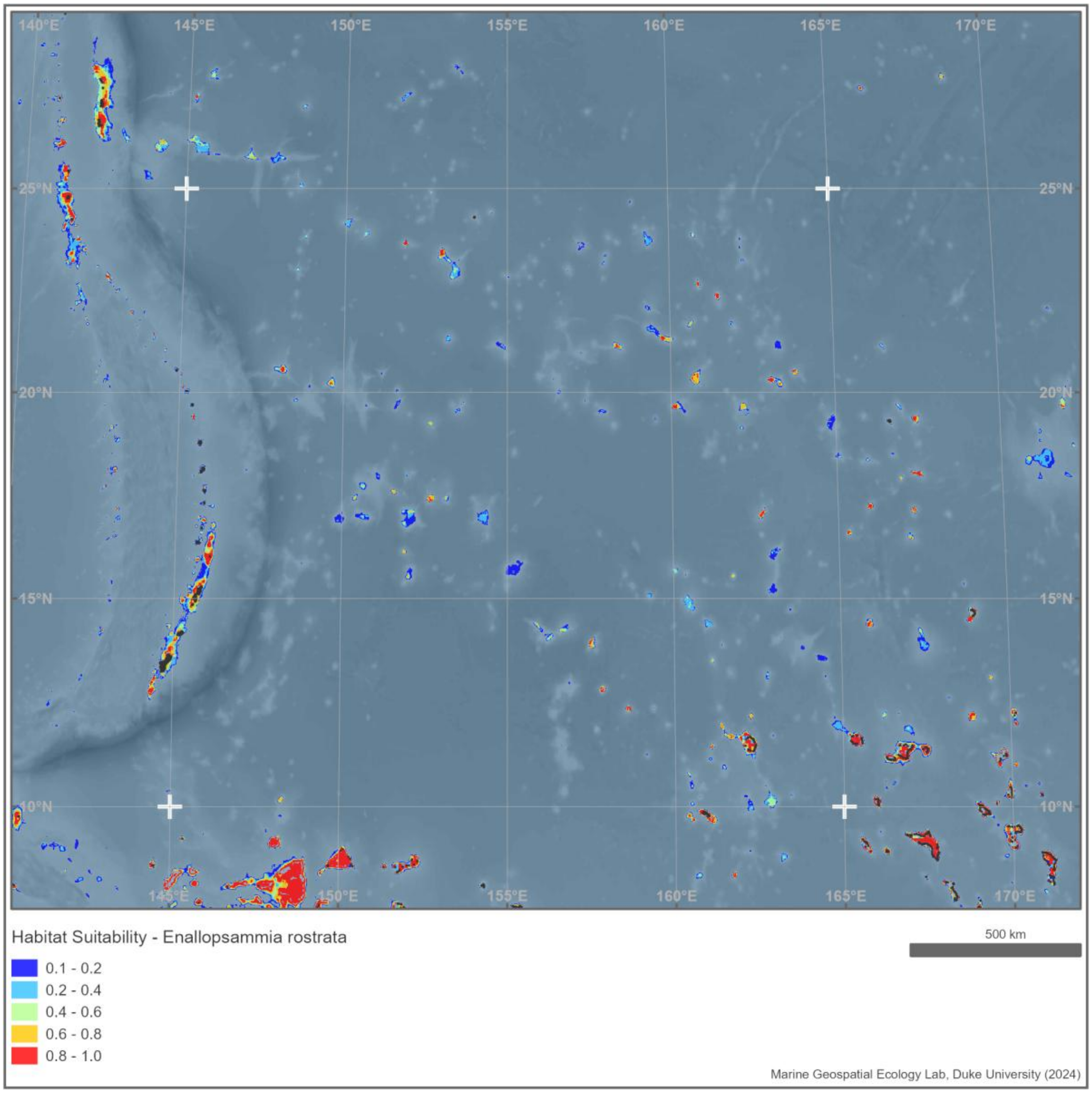


Figure 3.11-6 Deep-Sea *Scleractinia* habitat suitability – *Enallopsammia rostrata*

3.12 Global Patterns in Benthic Biomass

Abstract (Yool et al. 2017):
"Deep-water benthic communities in the ocean are almost wholly dependent on near-surface pelagic ecosystems for their supply of energy and material resources. Primary production in sunlit surface waters is channelled through complex food webs that extensively recycle organic material, but lose a fraction as particulate organic carbon (POC) that sinks into the ocean interior. This exported production is further rarefied by microbial breakdown in the abyssal ocean, but a residual ultimately drives diverse assemblages of seafloor heterotrophs. Advances have led to an understanding of the importance of size (body mass) in structuring these communities. Here we force a size-resolved benthic biomass model, BORIS, using seafloor POC flux from a coupled ocean-biogeochemistry model, NEMO-MEDUSA, to investigate global patterns in benthic biomass. BORIS resolves 16 size classes of metazoans, successively doubling in mass from approximately 1 μg to 28 mg. Simulations find a wide range of seasonal responses to differing patterns of POC forcing, with both a decline in seasonal variability, and an increase in peak lag times with increasing body size. However, the dominant factor for modelled benthic communities is the integrated magnitude of POC reaching the seafloor rather than its seasonal pattern. Scenarios of POC forcing under climate change and ocean acidification are then applied to investigate how benthic communities may change under different future conditions. Against a backdrop of falling surface primary production (-6.1%), and driven by changes in pelagic remineralization with depth, results show that while benthic communities in shallow seas generally show higher biomass in a warmed world (+3.2%), deep-sea communities experience a substantial decline (-32%) under a high greenhouse gas emissions scenario. Our results underscore the importance for benthic ecology of reducing uncertainty in the magnitude and seasonality of seafloor POC fluxes, as well as the importance of studying a broader range of seafloor environments for future model development."

Reference:
Yool, Andrew, Adrian P. Martin, Thomas R. Anderson, Brian J. Bett, Daniel OB Jones, and Henry A. Ruhl. "Big in the benthos: Future change of seafloor community biomass in a global, body size-resolved model." Global change biology 23, no. 9 (2017): 3554-3566.doi: 10.1111/gcb.13680

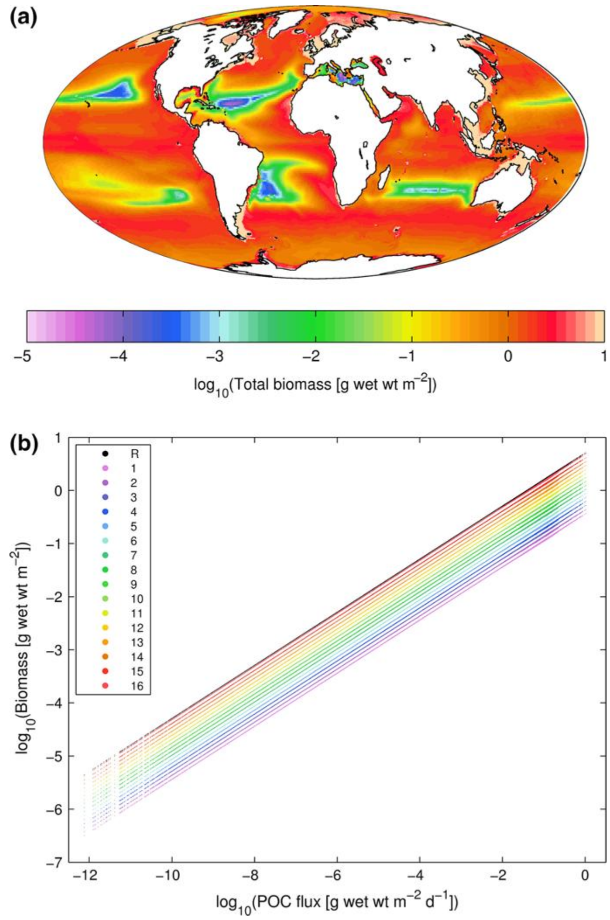


Figure 3.12-1 Mean annual field of total modelled seafloor biomass

4 Biogeographic Classification

4.1 Global Open Ocean and Deep Seabed (GOODS) biogeographic classification

"GOODS is the first attempt at comprehensively classifying the open-ocean and deep seafloor into distinct biogeographic regions (UNESCO, 2009). The classification was produced by an international and multidisciplinary group of experts under the auspices of a number of international and intergovernmental organizations as well as governments, and under the ultimate umbrella of the United Nations Educational, Scientific and Cultural Organization (UNESCO) and its Intergovernmental Oceanographic Commission (IOC). The maps shown below include the updates made by Watling et al. (2013).

The biogeographic classification classifies specific ocean regions using environmental features and – to the extent data are available – their species composition. GOODS is hypothesis-driven and still preliminary, and will thus require further refinement and peer review in the future. However, parts of it have already been published (e.g. pelagic provinces; Spalding et al. 2012). Watling et al. (2013) tried to refine the GOODS bathyal and abyssal provinces including some new variables. Physical and chemical proxies thought to be good predictors of the distributions of organisms at the deep-sea floor, and thus used for the definition of biogeographic provinces, were: depth, temperature (T), salinity (S), dissolved oxygen (O), and particulate organic carbon flux (POC) to the seafloor.

The major open ocean pelagic and deep sea benthic zones presented by the GOODS report and by Watling et al. (2013) are considered by their authors a reasonable basis for advancing efforts towards the conservation and sustainable use of biodiversity in marine areas beyond the limits of national jurisdiction in line with a precautionary approach."

References:

UNESCO. 2009. Global Open Oceans and Deep Seabed (GOODS) – Biogeographic Classification. Paris, UNESCO-IOC. (IOC Technical Series, 84.)

Watling, L., Guinotte, J., Clark, M. R., and Smith, C. R. (2013) A proposed biogeography of the deep ocean floor. Progress in Oceanography, 11, 91-112.

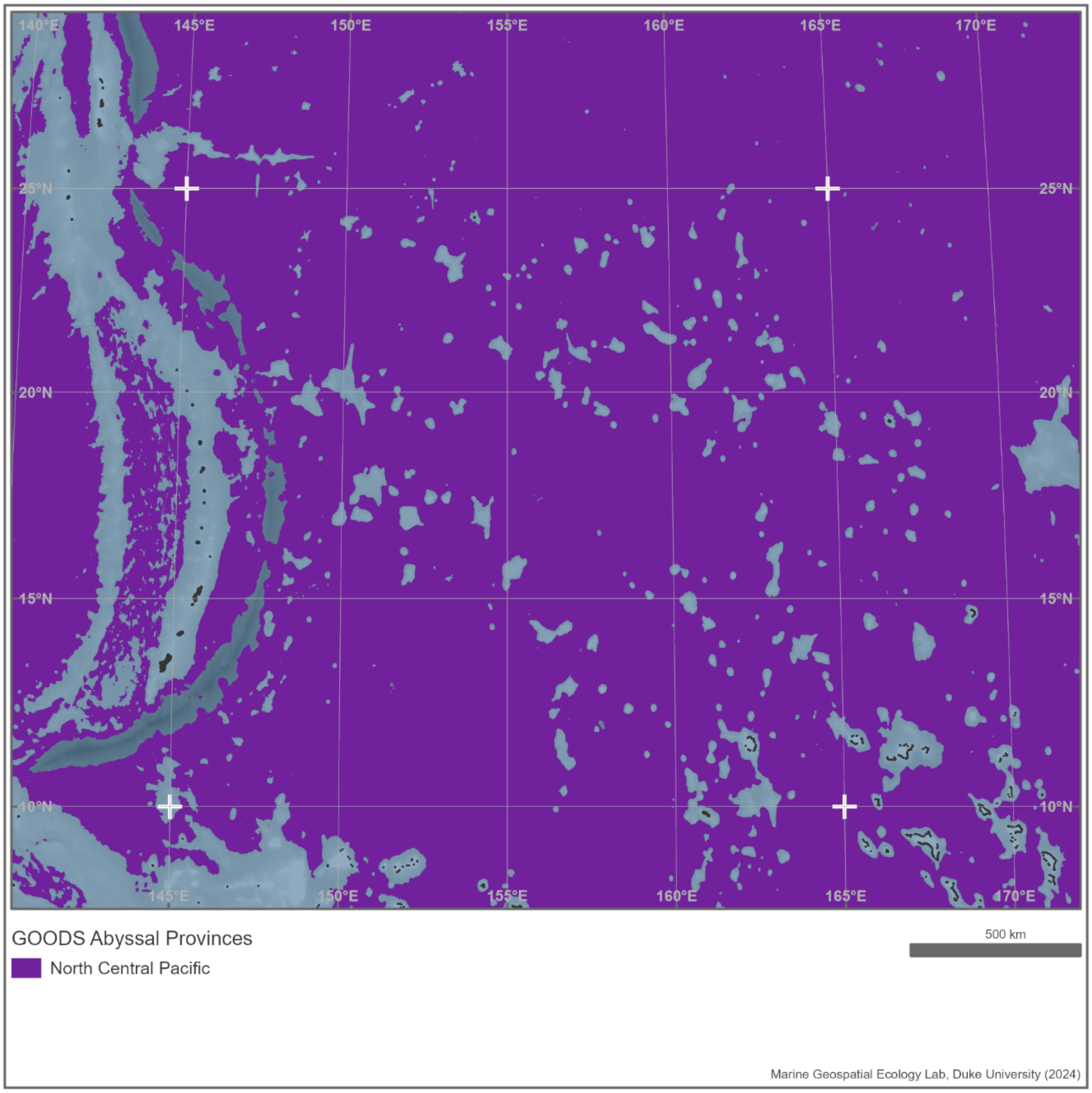


Figure 4.1-1 GOODS abyssal provinces

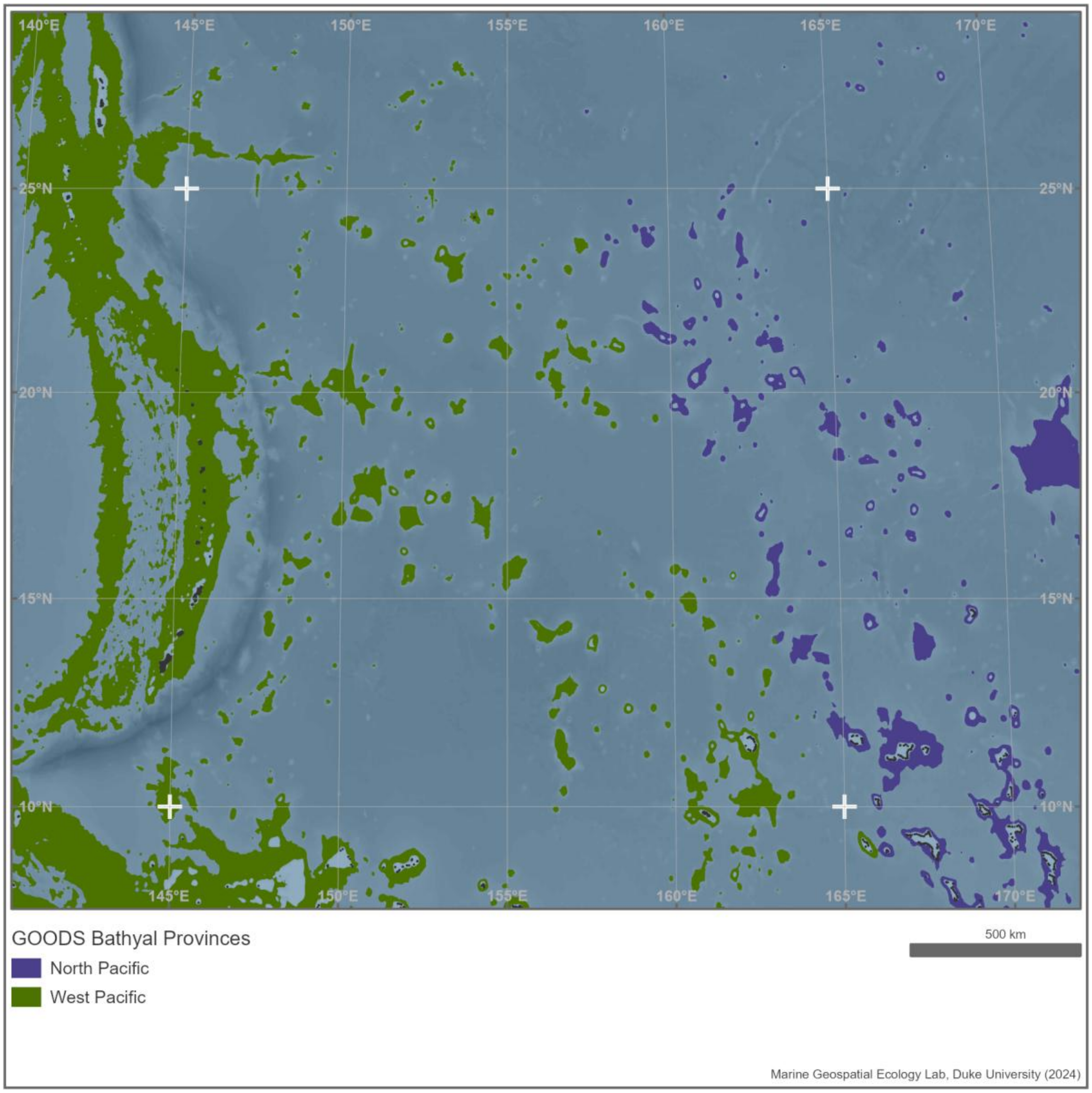


Figure 4.1-2 GOODS bathyal provinces

4.2 Global Mesopelagic Biogeography

Abstract (Sutton et al. 2017):
"We have developed a global biogeographic classification of the mesopelagic zone to reflect the regional scales over which the ocean interior varies in terms of biodiversity and function. An integrated approach was neces- sary, as global gaps in information and variable sampling methods preclude strictly statistical approaches. A panel combining expertise in oceanography, geospatial mapping, and deep-sea biology convened to collate expert opinion on the distributional patterns of pelagic fauna relative to environmental proxies (temperature, salinity, and dissolved oxygen at mesopelagic depths). An iterative Delphi Method integrating additional bio- logical and physical data was used to classify biogeographic ecoregions and to identify the location of ecoregion boundaries or inter-regions gradients. We define 33 global mesopelagic ecoregions. Of these, 20 are oceanic while 13 are 'distant neritic.' While each is driven by a complex of controlling factors, the putative primary driver of each ecoregion was identified. While work remains to be done to produce a comprehensive and robust mesopelagic biogeography (i.e., reflecting temporal variation), we believe that the classification set forth in this study will prove to be a useful and timely input to policy planning and management for conservation of deep- pelagic marine resources. In particular, it gives an indication of the spatial scale at which faunal communities are expected to be broadly similar in composition, and hence can inform application of ecosystem-based management approaches, marine spatial planning and the distribution and spacing of network of representative protected areas."

Reference:
Sutton, T.T., Clark, M.R., Dunn, D.C., Halpin, P.N., Rogers, A.D., Guinotte, J., Bograd, S.J., Angel, M.V., Perez, J.A.A., Wishner, K. and Haedrich, R.L., (2017). A global biogeographic classification of the mesopelagic zone. Deep Sea Research Part I: Oceanographic Research Papers, 126, pp.85-102.

Dataset downloaded from Marine Regions (August 2019)
http://www.marineregions.org/gazetteer.php?p=details&id=50384

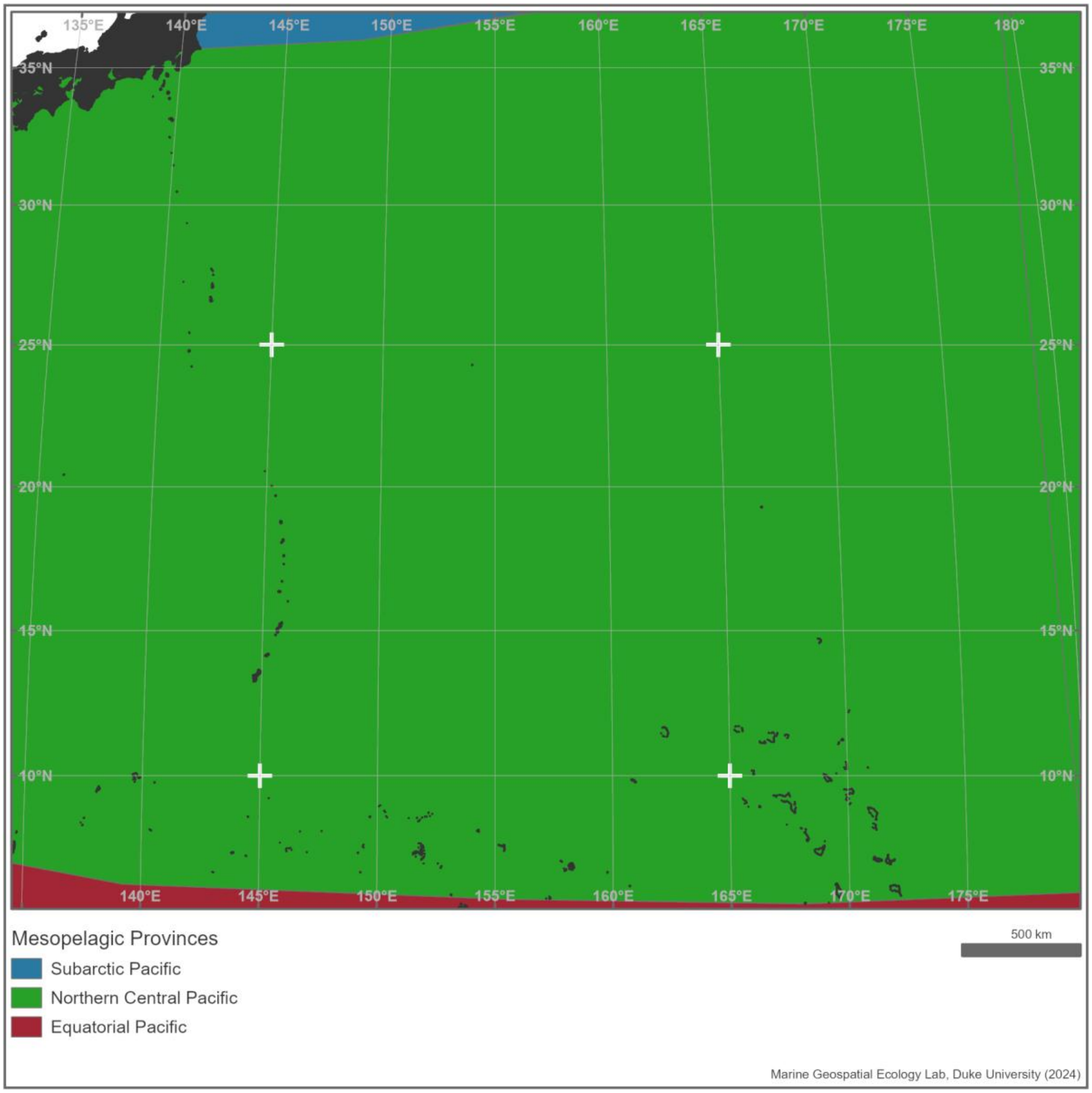


Figure 4.2-1 Mesopelagic provinces

4.3 Pelagic Provinces of the World

Abstract (Spalding et al. 2012):
Off-shelf waters cover 66% of the planet. Growing concerns about the state of natural resources in these waters, and of future threats have led to a growing movement to improve management and conservation of natural resources. However, efforts to assess progress and to further plan and prioritise management interventions have been held back in part by the lack of a comprehensive biogeographic classification for the high seas. In this work we review existing efforts at classifying the surface pelagic waters of the world's oceans and we present a synthesis classification which draws both on known taxonomic biogeography and on the oceanographic forces which are major drivers of ecological patterns. We describe a nested system of 37 pelagic provinces of the world, nested into a system of four broad realms. Ecologically we have also differentiated a system of 7 biomes which are spatially disjoint but united by common abiotic conditions creating physiognomically similar communities. This system builds on existing work and is further intended to align closely with the coastal biogeographic regionalisation provided by the Marine Ecoregions of the World classification. It is hoped that it will provide a valuable tool in supporting threat analysis, priority setting, policy development and active management of the world's pelagic oceans.

Reference:
Spalding MD, Agostini VN, Rice J, Grant SM (2012). Pelagic provinces of the world): a biogeographic classification of the world's surface pelagic waters. Ocean and Coastal Management 60: 19-30. DOI: 10.1016/j.ocecoaman.2011.12.016. Data URL: http://data.unep-wcmc.org/datasets/38

Dataset downloaded from:
The Nature Conservancy (2012). Marine Ecoregions and Pelagic Provinces of the World. GIS layers developed by The Nature Conservancy with multiple partners, combined from Spalding et al. (2007) and Spalding et al. (2012). Cambridge (UK): The Nature Conservancy. DOIs: 10.1641/B570707; 10.1016/j.ocecoaman.2011.12.016. Data URL: http://data.unep-wcmc.org/datasets/38

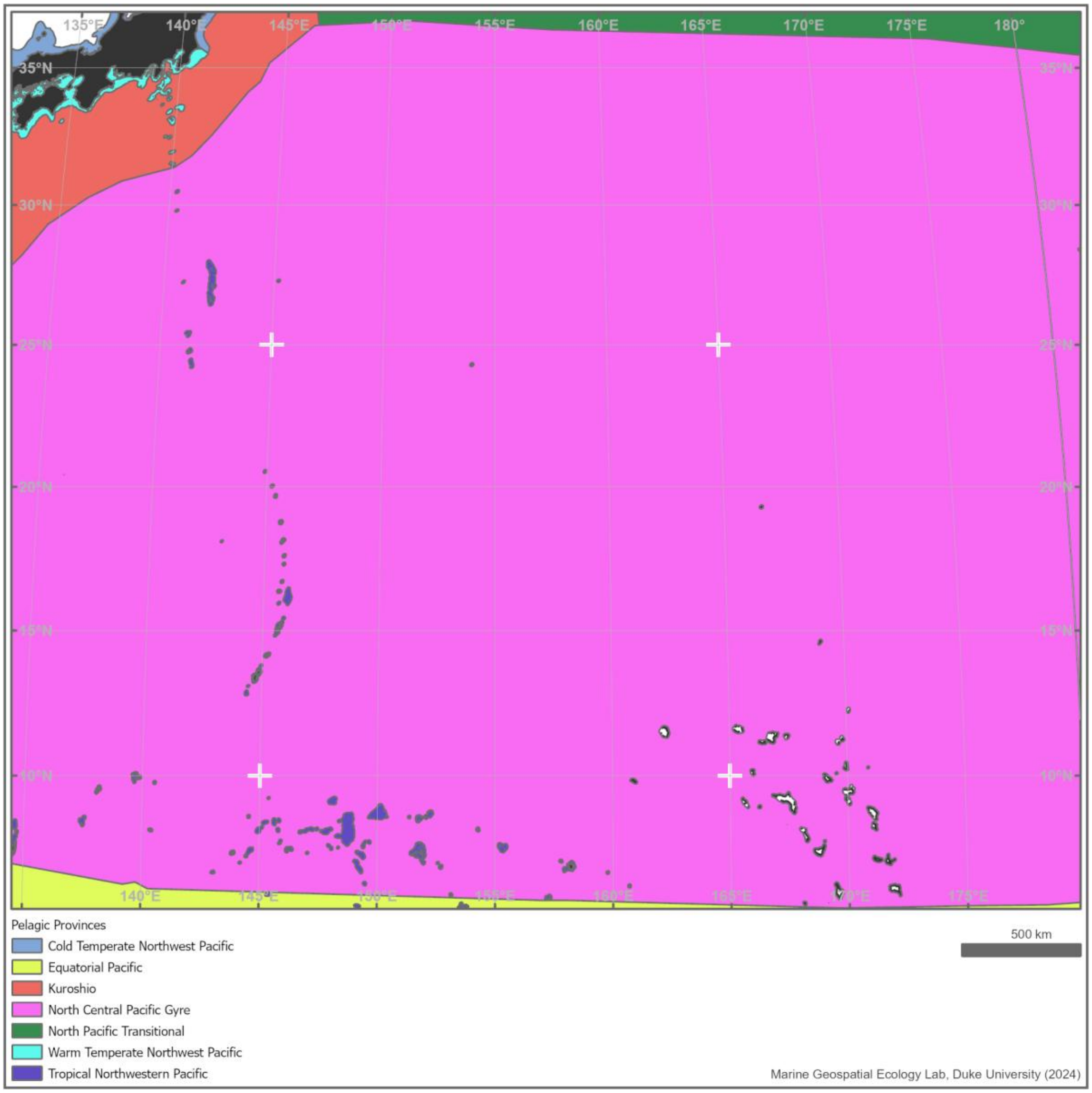


Figure 4.3-1 Pelagic provinces

4.4 Longhurst Marine Provinces

Abstract (Longhurst 2006):
"This dataset represents a partition of the world oceans into provinces as defined by Longhurst (1995; 1998; 2006), and are based on the prevailing role of physical forcing as a regulator of phytoplankton distribution. The dataset represents the initial static boundaries developed at the Bedford Institute of Oceanography, Canada. Note that the boundaries of these provinces are not fixed in time and space, but are dynamic and move under seasonal and interannual changes in physical forcing. At the first level of reduction, Longhurst recognized four principal biomes (also referred to as domains in earlier publications): the Polar Biome, the Westerlies Biome, the Trade-Winds Biome, and the Coastal Boundary Zone Biome. These four Biomes are recognizable in every major ocean basin. At the next level of reduction, the ocean basins are partitioned into provinces, roughly ten for each basin. These partitions provide a template for data analysis or for making parameter assignments on a global scale."

Source: VLIZ (2009). Longhurst Biogeographical Provinces. Available online at http://www.marineregions.org/. Consulted on 2013-01-14.

Reference:

Longhurst, A.R. (2006). Ecological Geography of the Sea. 2nd Edition. Academic Press, San Diego, 560p.

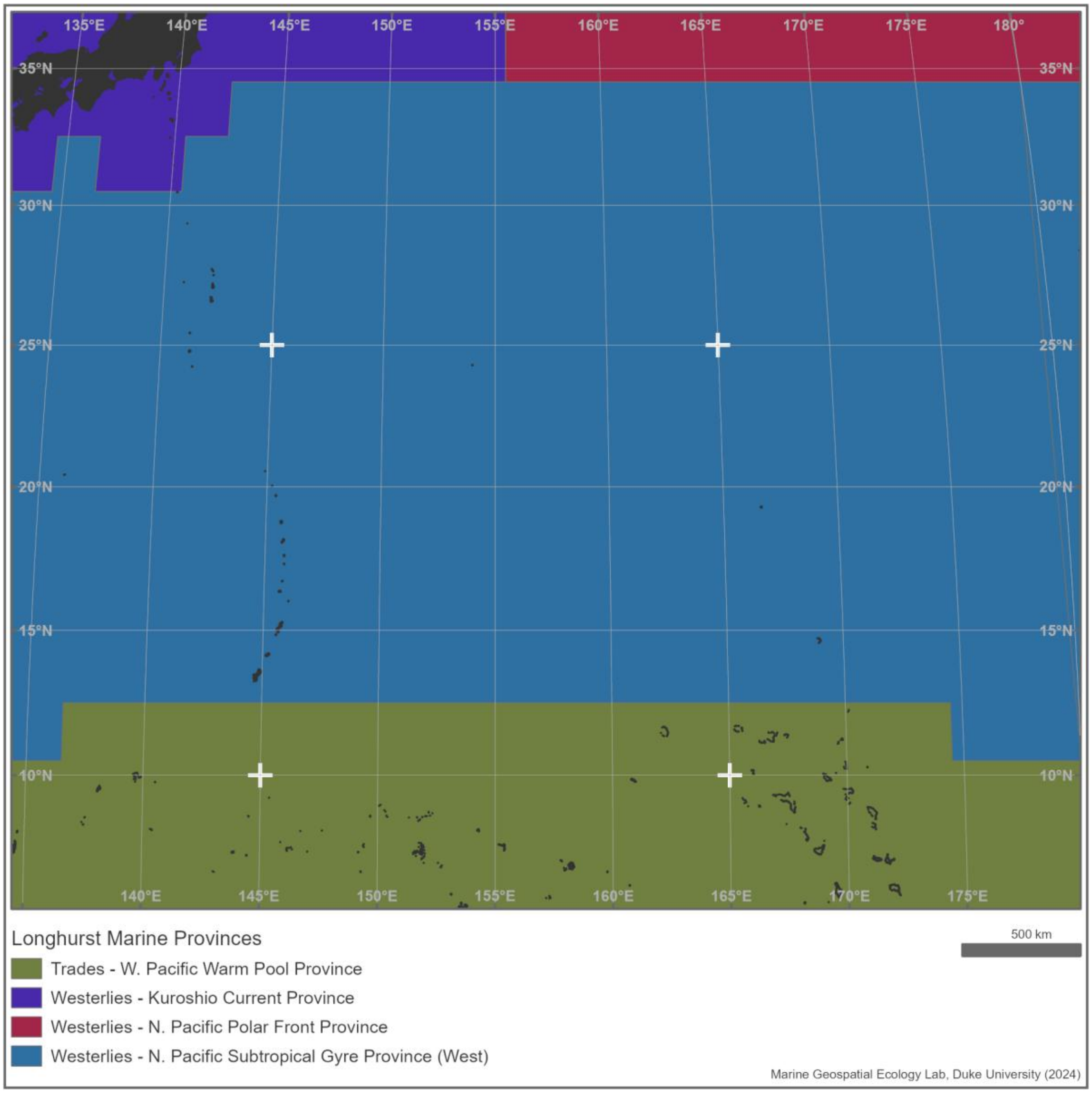


Figure 4.4-1 Longhurst marine provinces

4.5 Global Seascapes

Abstract (Harris & Whiteway 2009):
"Designing a representative network of high seas marine protected areas (MPAs) requires an acceptable scheme to classify the benthic (as well as the pelagic) bioregions of the oceans. Given the lack of sufficient biological information to accomplish this task, we used a multivariate statistical method with 6 biophysical variables (depth, seabed slope, sediment thickness, primary production, bottom water dissolved oxygen and bottom temperature) to objectively classify the ocean floor into 53,713 separate polygons comprising 11 different categories, that we have termed seascapes. A cross-check of the seascape classification was carried out by comparing the seascapes with existing maps of seafloor geomorphology and seabed sediment type and by GIS analysis of the number of separate polygons, polygon area and perimeter/area ratio. We conclude that seascapes, derived using a multivariate statistical approach, are biophysically meaningful subdivisions of the ocean floor and can be expected to contain different biological associations, in as much as different geomorphological units do the same. Less than 20% of some seascapes occur in the high seas while other seascapes are largely confined to the high seas, indicating specific types of environment whose protection and conservation will require international cooperation. Our study illustrates how the identification of potential sites for high seas marine protected areas can be accomplished by a simple GIS analysis of seafloor geomorphic and seascape classification maps. Using this approach, maps of seascape and geomorphic heterogeneity were generated in which heterogeneity hotspots identify themselves as MPA candidates. The use of computer aided mapping tools removes subjectivity in the MPA design process and provides greater confidence to stakeholders that an unbiased result has been achieved."

Reference:
Harris, P.T. & Whiteway, T. (2009) High seas marine protected areas: Benthic environmental conservation priorities from a GIS analysis of global ocean biophysical data. *Ocean and Coastal Management*, **52**, 22–38.

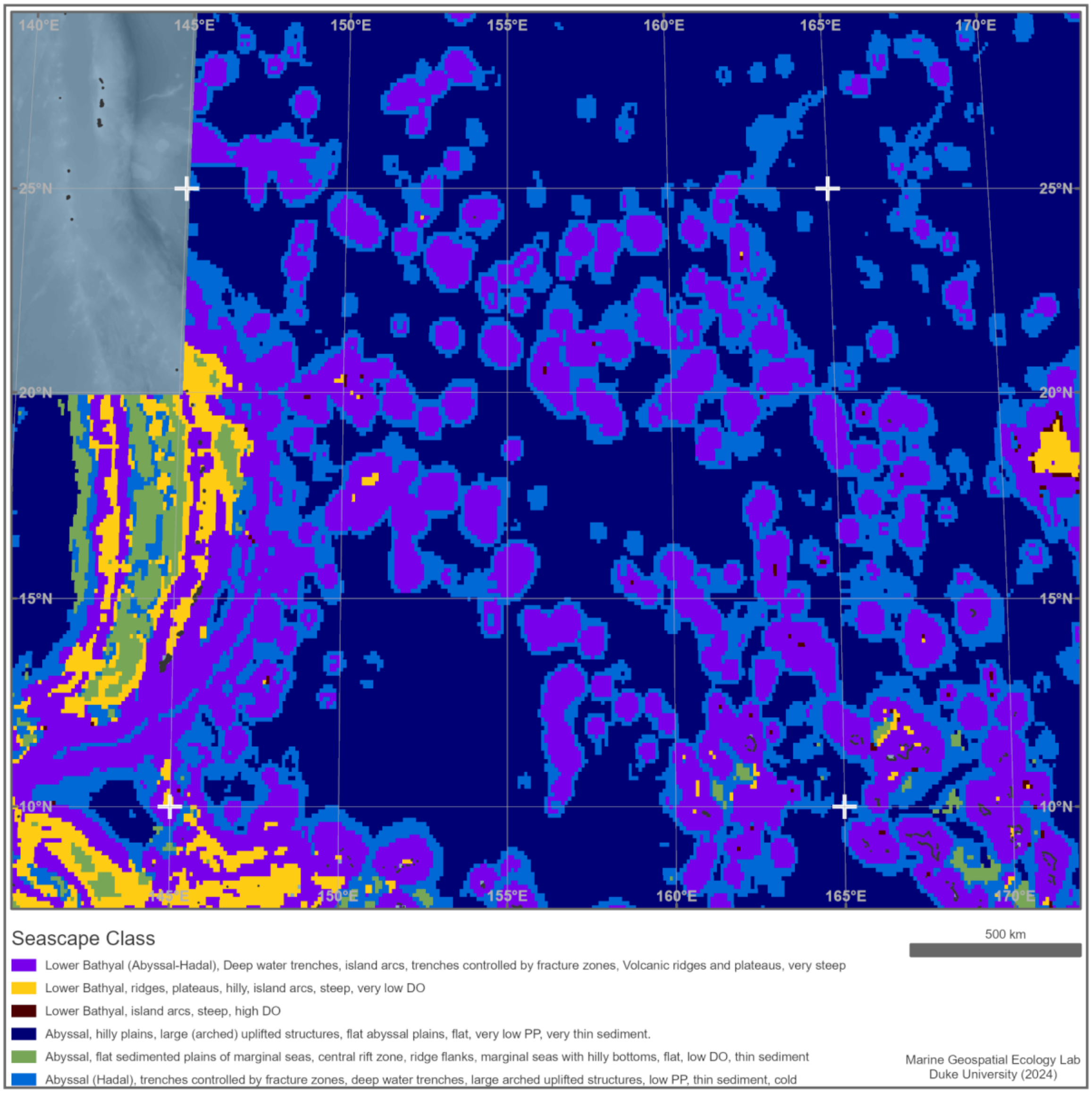
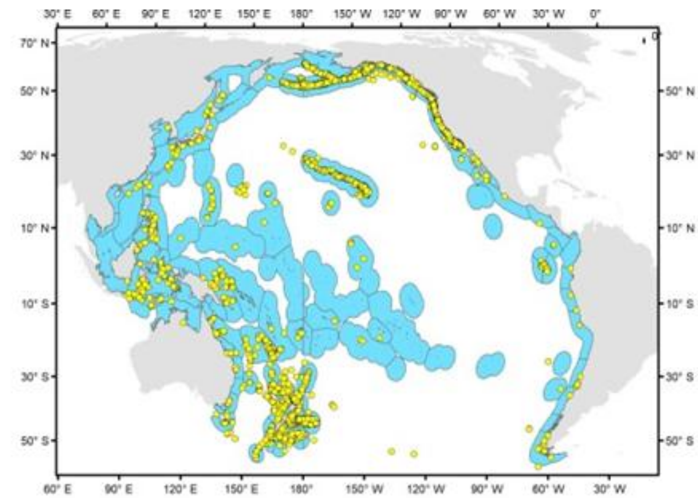


Figure 4.5-1 Global seascapes

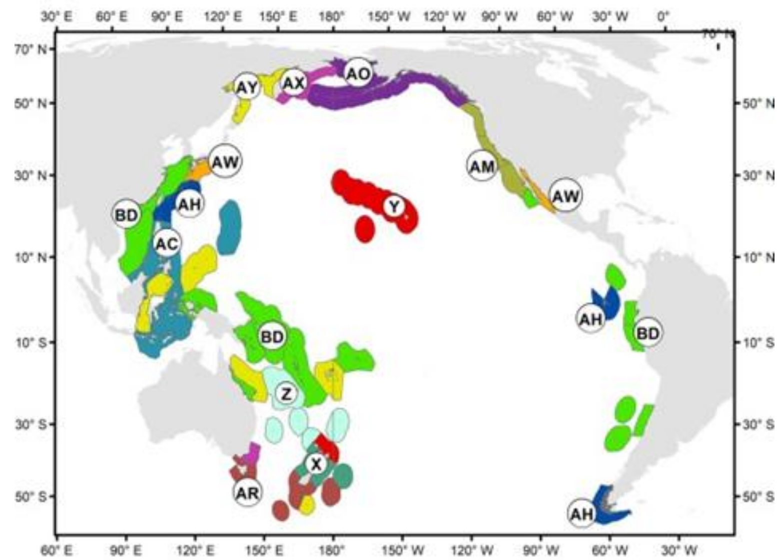
4.6 Upper Bathyal Pacific Ocean biogeographic provinces from octocoral distributions

Abstract (Summers and Watling 2021):
“Biogeographical classification schemes such as the Marine Ecoregions of the World (MEOW) have been developed for continental shelf depths. The lack of faunal data in the deep sea has led to the development of biogeographical units based on oceanographic characteristics. The aim of this study was to propose biogeographical schemes for the Upper Bathyal (200–1000 m) across the Pacific Ocean using octocoral distributions. We retrieved over 200 000 octocoral data records from the Deep Sea Coral Data Portal (DSCDP), Ocean Biogeographic Information System (OBIS), Tropical Deep-Sea Benthos program (French National Museum of Natural History), Queensland Museum from the CIDARIS expeditions, and records retrieved from the Siboga expedition reports. We used cluster analysis to examine octocoral distributions against four different biogeographical classification schemes. The classification schemes produced mostly concordant patterns with three major faunal distribution barriers: the North Pacific Current isolates the subarctic units by creating a steep temperature gradient; the Subantarctic Front separates the Subantarctic from the rest of the Pacific; and the East Pacific Barrier separates the East Pacific from the Central and West Pacific. Two other smaller but distinct provinces are the Indo-Pacific where Lower Bathyal genera are found in the Upper Bathyal, and Torres Strait/Coral Sea characterised by mesophotic genera. We propose 12 biogeographic provinces across the Pacific Ocean Upper Bathyal region from 200 to 1000 m depth based on octocoral distributions. The main driver for these units seems to be temperature, a defining feature of water masses. These units could potentially be subdivided into smaller regions based on habitat. Additionally, the clustering of Ecological Marine Units (EMUs) provides evidence that the Upper Bathyal should in certain regions be divided vertically into two depth zones based on water masses.”

Reference:
Summers, Natalie, and Les Watling. "Upper Bathyal Pacific Ocean biogeographic provinces from octocoral distributions." Progress in Oceanography 191 (2021): 102509. https://doi.org/10.1016/j.pocean.2020.102509



(a)



(b)

Figure 4.6-1 Originally Figure 3

Original caption: Fig. 3. a) Distribution of Upper Bathyal octocoral records plotted over the MEOW ecoregions. b) The location of the resulting groups. Abbreviated groups contain more than one region. MEOW cluster groups are as follows: *BD:Vanuatu + Central and Southern Great Barrier Reef + Guayaquil + Magdalena Transition + Juan Fernandez and Desventuradas + Southern China + Cocos Islands + South China Sea Oceanic Islands + Solomon Sea + Solomon Archipelago + Papua + Samoa Islands + East China Sea + Central Peru + Central Chile AY:Campbell Island + Sea of Okhotsk + Sulawesi Sea/Makassar Strait + Coral Sea + Fiji Islands + West Caroline Islands AX:Cape Howe + Kamchatka Shelf and Coast AW:Central Kuroshio Current + Cortezian AR:Auckland Island + Bounty and Antipodes Islands + South New Zealand + Snares Island + Bassian + Macquarie Island AO:Gulf of Alaska + North American Pacific Fijordland + Eastern Bering Sea + Aleutian Islands AM:Oregon, Washington, Vancouver Coast and Shelf + Southern California Bight + Northern California AH:Channels and Fjords of Southern Chile + South Kuroshio + Western Galapagos Islands + Eastern Galapagos Islands AC:Lesser Sunda + Mariana Islands +*

Palawan/North Borneo + Halmahera + Banda Sea + Eastern Philippines Z:Kermadec Island + New Caledonia + Lord Howe and Norfolk Islands + Three Kings-North Cape Y:Northeastern New Zealand + Hawaii X:Central New Zealand + Chatham Island.

5 Human Uses

5.1 Demersal Destructive Fishing

Here we include a map of demersal destructive fishing from Halpern et al. (2015). These data were created as an input for an analysis of the global impact of human uses on the marine ecosystem.

Reference:
Halpern, B. S. et al. 2015. Spatial and temporal changes in cumulative human impacts on the world's ocean. - Nat Commun 6: 1–7.

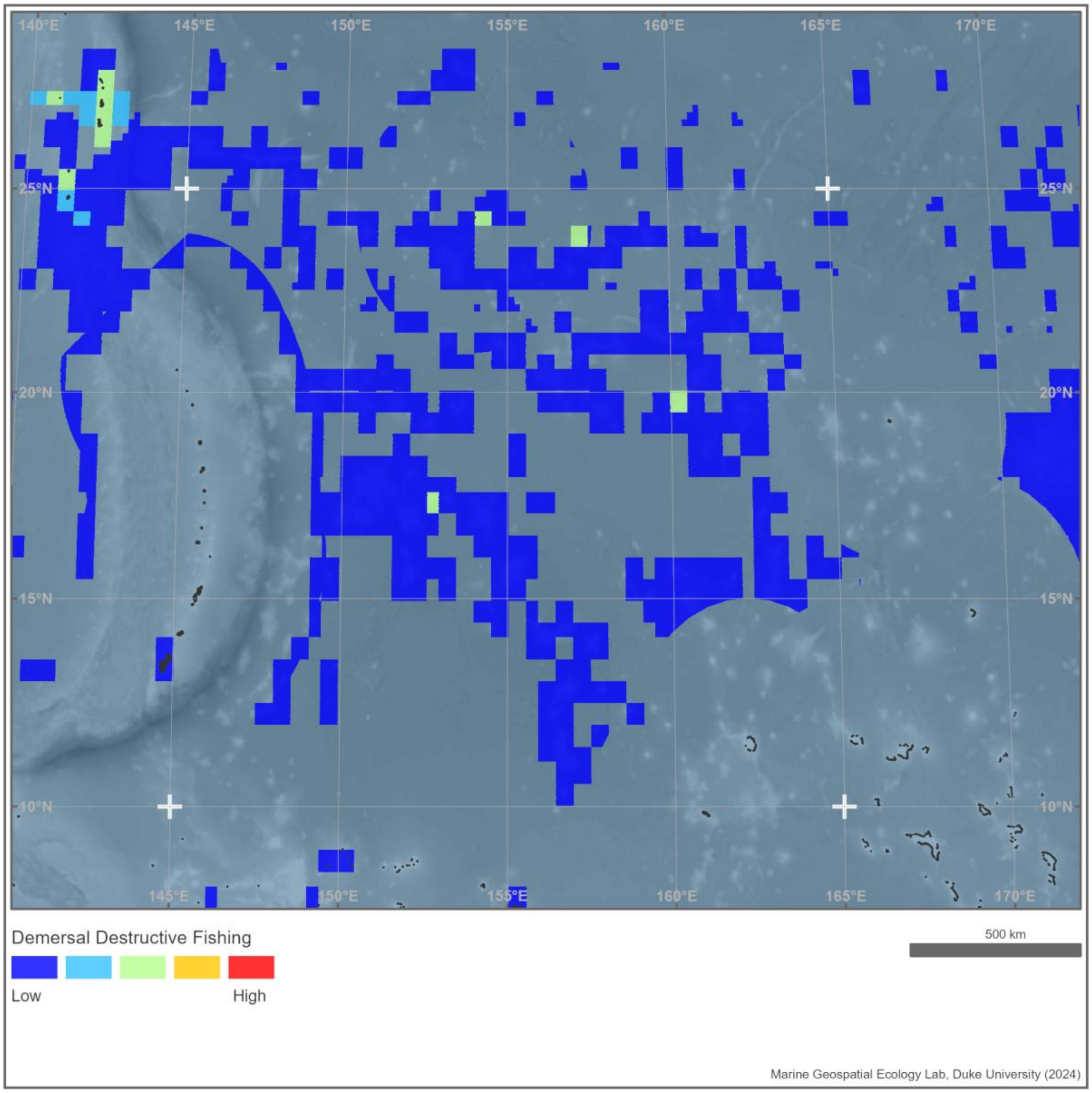


Figure 5.1-1 Demersal destructive bottom fishing

5.2 Fishing Effort by Gear Type, Global Fishing Watch

Abstract
"Although fishing is one of the most widespread activities by which humans harvest natural resources, its global footprint is poorly understood and has never been directly quantified. We processed 22 billion automatic identification system messages and tracked >70,000 industrial fishing vessels from 2012 to 2016, creating a global dynamic footprint of fishing effort with spatial and temporal resolution two to three orders of magnitude higher than for previous data sets. Our data show that industrial fishing occurs in >55% of ocean area and has a spatial extent more than four times that of agriculture. We find that global patterns of fishing have surprisingly low sensitivity to short-term economic and environmental variation and a strong response to cultural and political events such as holidays and closures."

Reference:
Kroodsma, David A., Juan Mayorga, Timothy Hochberg, Nathan A. Miller, Kristina Boerder, Francesco Ferretti, Alex Wilson, et al. 2018. "Tracking the Global Footprint of Fisheries." *Science* 359 (6378): 904–8. https://doi.org/10.1126/science.aao5646.

"This dataset contains the Global Fishing Watch AIS-based fishing effort and vessel presence datasets. Data is based on fishing detections of >114,000 unique AIS devices on fishing vessels, of which ~70,000 are active each year. Fishing vessels are identified via a neural network classifier, vessel registry databases, and manual review by GFW and regional experts. Data are binned into grid cells 0.01 (or 0.1) degrees on a side and measured in units of hours. The time is calculated by assigning an amount of time to each AIS detection (which is the time to the previous position), and then summing all positions in each grid cell."

Source: https://globalfishingwatch.org/datasets-and-code/fishing-effort/

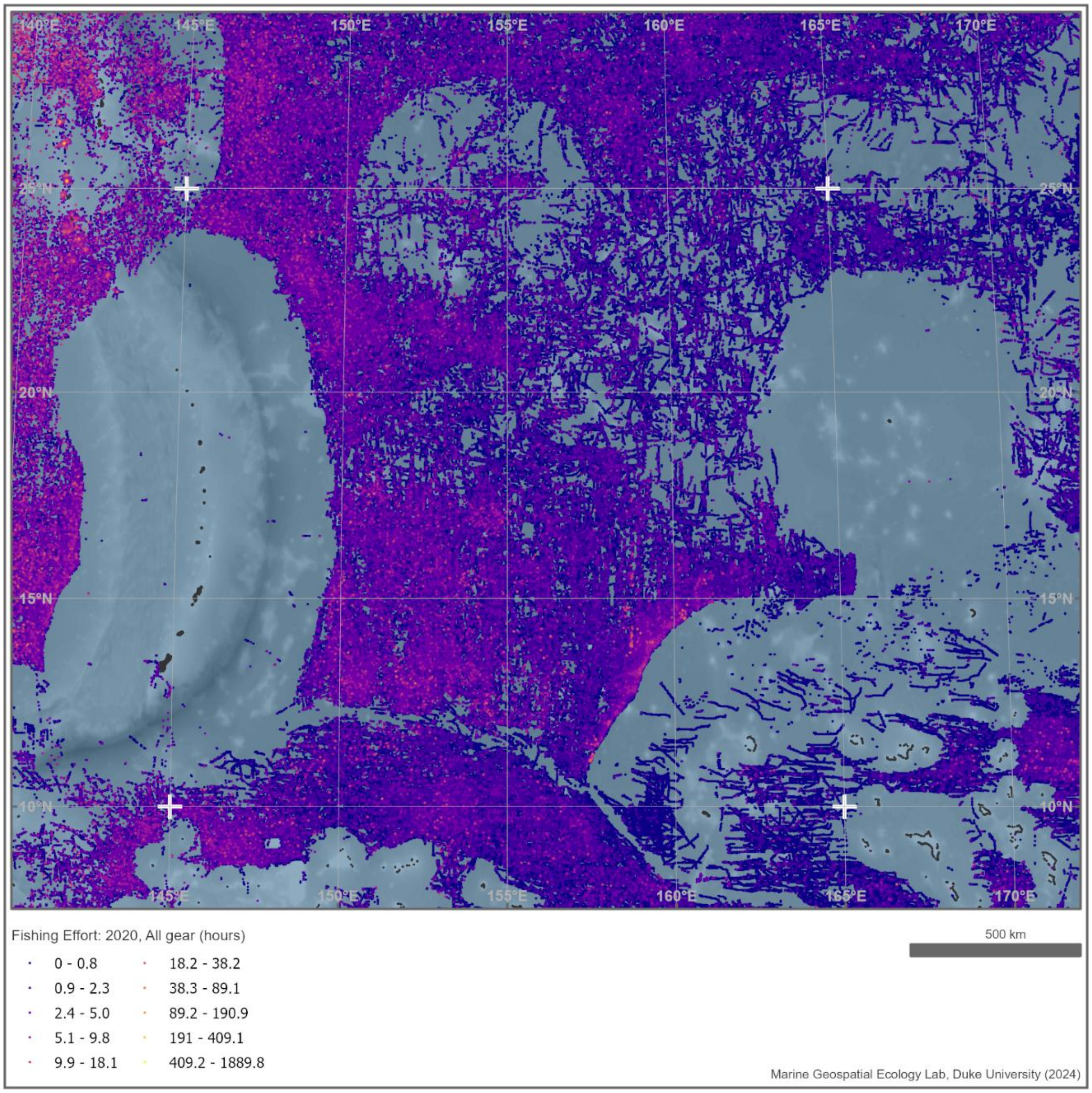


Figure 5.2-1 Fishing effort in 2020, all gear types

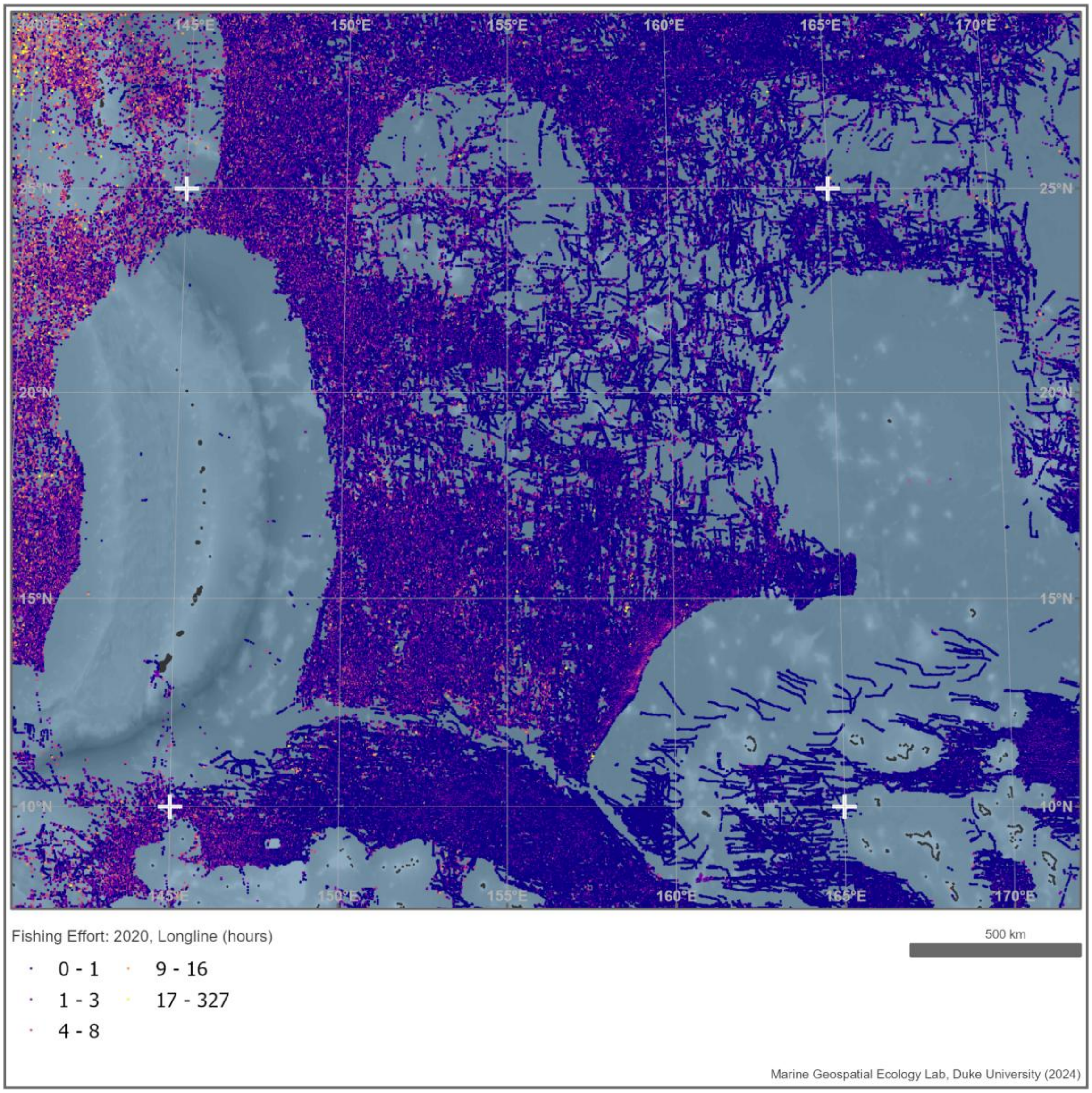


Figure 5.2-2 Fishing effort in 2020, Longline

5.3 Global Fishing Reconstruction

"The reconstructed data we present combine official reported catch data and reconstructed estimates of unreported catches (including major discards), with reference to individual EEZs. Officially reported catch data are mainly extracted from the Food and Agriculture Organization of the United Nations (FAO) FishStat database. For background information on reconstruction data, download the .pdf associated with each relevant EEZ. The taxon distributions represent the most up-to-date information on biological distribution of taxa, as assembled by FishBase and SeaLifeBase. Users of *Sea Around Us* catch maps and the associated ½ x ½ degree data should be aware that the spatial precision implied by our global use of ½ degree lat./long. cells, which is appropriate for coastal cells, is likely problematic for offshore and High Seas cells. This is due to the catches they contain having been derived from spatially reported catch data provided by Regional Fisheries Management Organizations (RFMOs) in much larger spatial cells (1, 5, 10 or even 20 degree lat./long.). Our subsequent allocation of these data to ½ degree cells *within* each of the RFMO cells is based on our standard allocation approach, as described in Zeller *et al*. (2016, *Marine Policy* 70: 145-152). This allocation is not likely to reflect the precise location of catches being taken from each ½ degree cell within each RFMO cell in each year. Thus, users of these data need to evaluate carefully their use of our spatially allocated data, as the spatial scale at which one analyses these data needs to be driven by the type of question one asks (see Amoroso *et al*. 2018, *Science* 361(6404): eaat6713; and Kroodsma *et al*. 2018, *Science* 361(6404): eaat7789 on appropriate scaling). The *Sea Around Us*, in collaboration with the Global Fishing Watch, is developing improvements in spatial allocations of catch data that address this and related issues."

Source: http://www.seaaroundus.org/data/#/spatial-catch

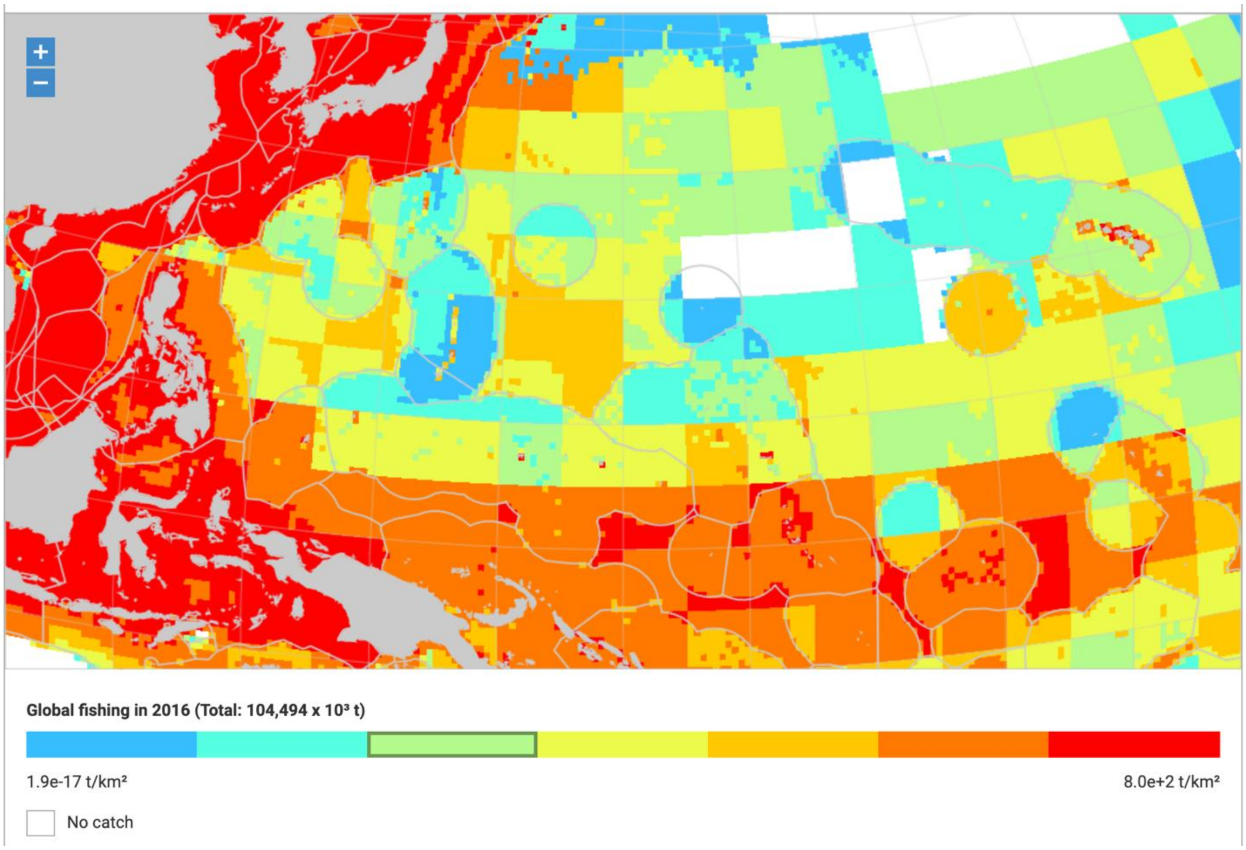


Figure 5.3-1 Global fishing reconstruction, 2016

5.4 Commercial Shipping

“This data was obtained through a partnership with IMF, as part of IMF's World Seaborne Trade Monitoring System (Cerdeiro, Komaromi, Liu and Saeed, 2020). The data analysis was supported by the World Bank’s ESMAP and PROBLUE programs.

The dataset contains 6 density layers, with vessel types aggregated to suit the needs of the WBG Offshore Wind Development Program:
1) Commercial ships
2) Fishing ships
3) Oil & Gas [note: this is just platforms, rigs, and FPSOs]
4) Passenger ships
5) Leisure vessels
6) GLOBAL ship density layers of all ship categories combined

The raster layers were created using IMF's analysis of hourly AIS positions received between Jan-2015 and Feb-2021 and represent the total number of AIS positions that have been reported by ships in each grid cell with dimensions of 0.005 degree by 0.005 degree (approximately a 500m x 500m grid at the Equator).

The AIS positions may have been transmitted by both moving and stationary ships within each grid cell, therefore the density is analogous to the general intensity of shipping activity.”

Reference:
IMF’s World Seaborne Trade monitoring system (Cerdeiro, Komaromi, Liu and Saeed, 2020)

Source:
https://datacatalog.worldbank.org/search/dataset/0037580

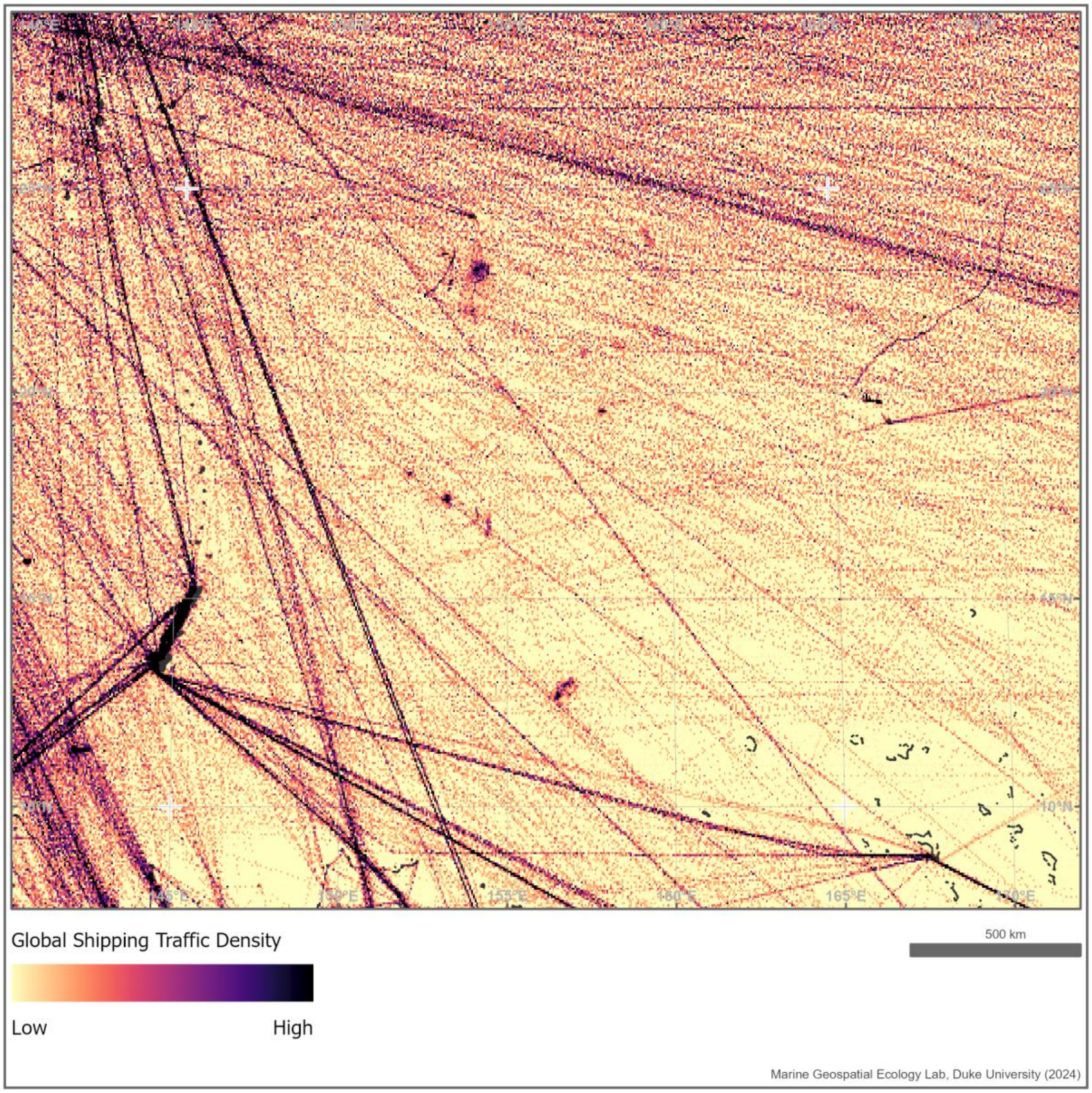


Figure 5.4-1 Commercial shipping density

5.5 Undersea Telecommunications Cables

"This dataset is an attempt to consolidate all the available information about the undersea communications infrastructure. The initial data was harvested from Wikipedia, and further information was gathered by simply googling and transcribing as much data as possible into a useful format, namely a rich geocoded format."

Source:
https://koordinates.com/layer/3722-undersea-telecommunication-cables/

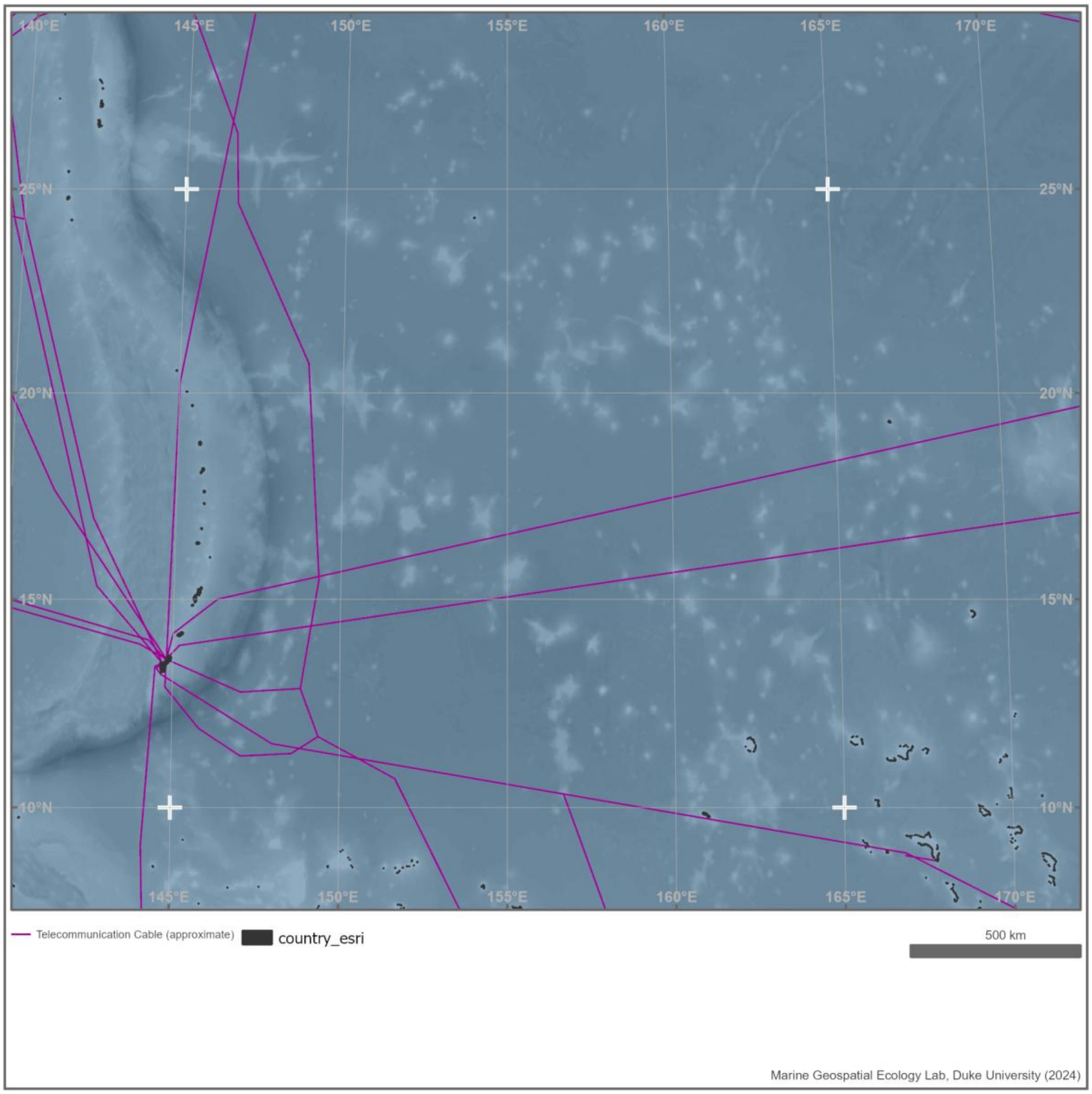


Figure 5.5-1 Undersea telecommunications cables

5.6 LITTERBASE: Distribution of Litter and Microplastic

"LITTERBASE currently comprises 1,036 scientific publications on the amount, distribution and composition of litter in the ocean and other watercourses. This information is continuously updated and visualised in global distribution maps. However, litter has been quantified in many different units by different workers, which hampers direct comparison. Therefore, users can select subsets of data with the same unit for direct comparison in addition to global maps with all litter quantities. Furthermore, the information on display can be filtered according to size category of the litter (macro: > 5 mm, micro: ≤ 5 mm, nano: ≤ 100 nm) and habitat considered (beach, sea surface, water column, seabed).

The global map shows that there is already a lot of information available on litter pollution from certain areas, for example, the Mediterranean Sea. By contrast, much less is known about litter pollution in the tropics, around Africa or the Polar Regions. The map also shows that litter quantities vary strongly within certain regions (e.g. in the Southwest Pacific and East Asia)."

Source: https://litterbase.awi.de/litter_detail

Reference:
Tekman MB, Gutow L, Macario A, Haas A, Walter A, Bergmann M: Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung

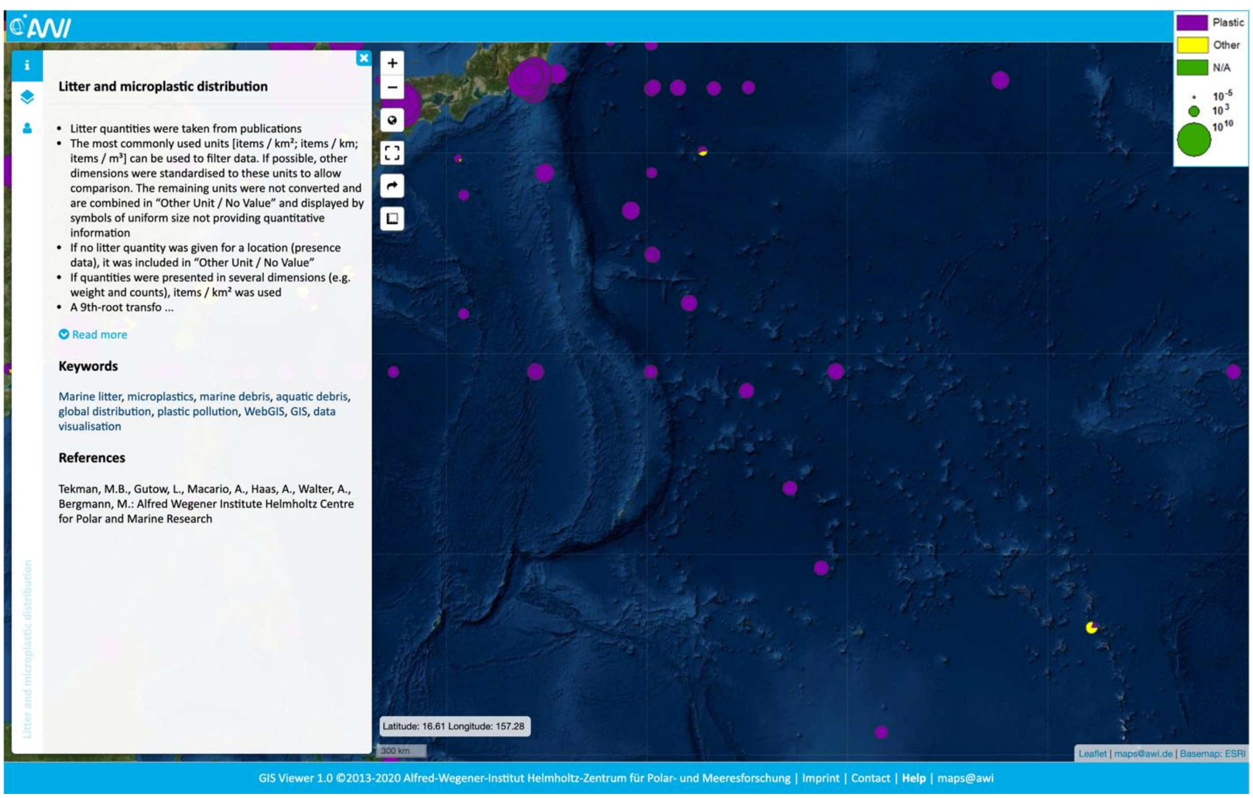


Figure 5.6-1 Litter and microplastic distribution

5.7 Cumulative Human Impacts on the World's Ocean

Abstract (Halpern 2015):
"Human pressures on the ocean are thought to be increasing globally, yet we know little about their patterns of cumulative change, which pressures are most responsible for change, and which places are experiencing the greatest increases. Managers and policymakers require such information to make strategic decisions and monitor progress towards management objectives. Here we calculate and map recent change over 5 years in cumulative impacts to marine ecosystems globally from fishing, climate change, and ocean- and land-based stressors. Nearly 66% of the ocean and 77% of national jurisdictions show increased human impact, driven mostly by climate change pressures. Five percent of the ocean is heavily impacted with increasing pressures, requiring management attention. Ten percent has very low impact with decreasing pressures. Our results provide large-scale guidance about where to prioritize management efforts and affirm the importance of addressing climate change to maintain and improve the condition of marine ecosystems."

Reference:
Halpern, B. S. et al. 2015. Spatial and temporal changes in cumulative human impacts on the world's ocean. - Nat Commun 6: 1–7.doi:10.1038/ncomms8615

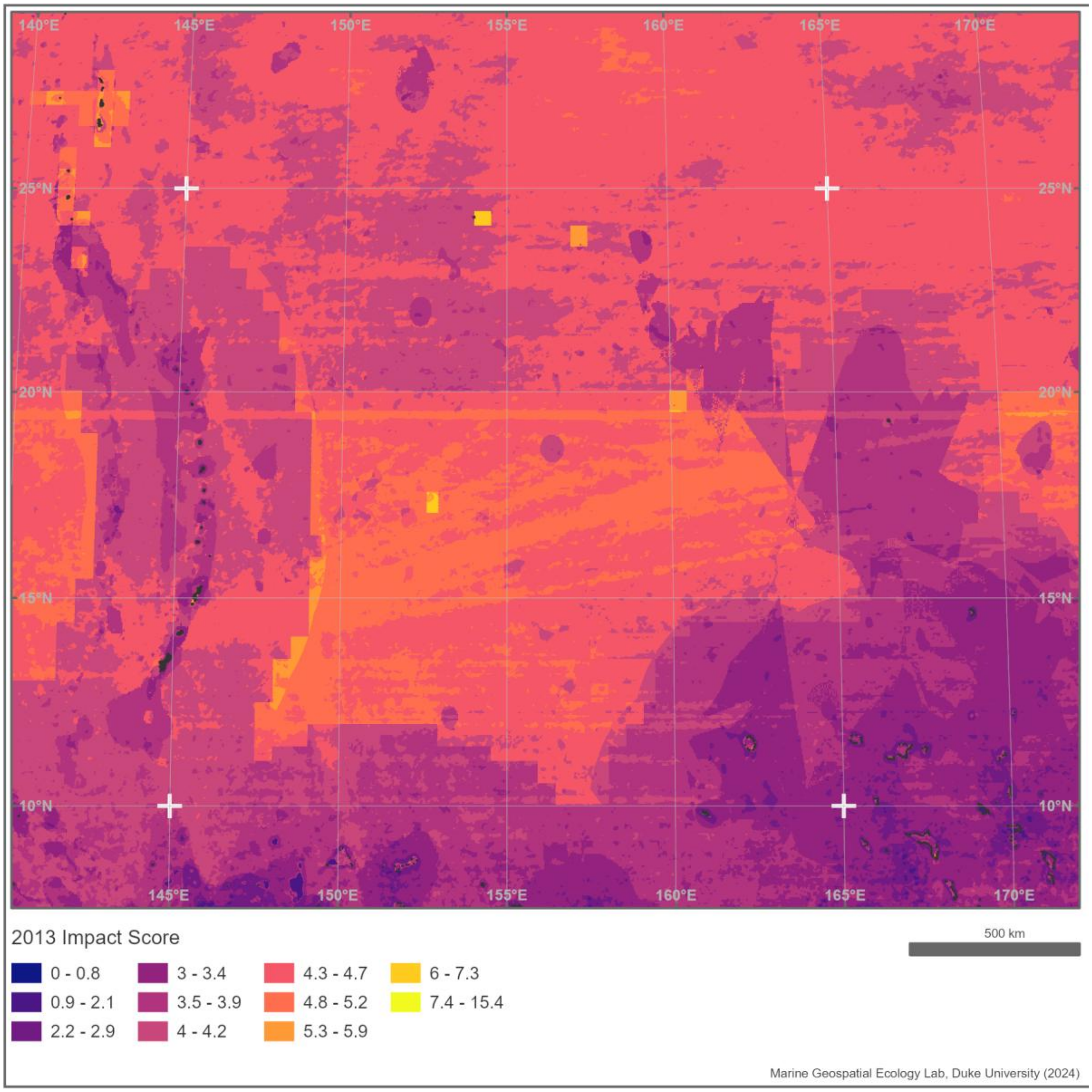


Figure 5.7-1 Cumulative human impact, 2013

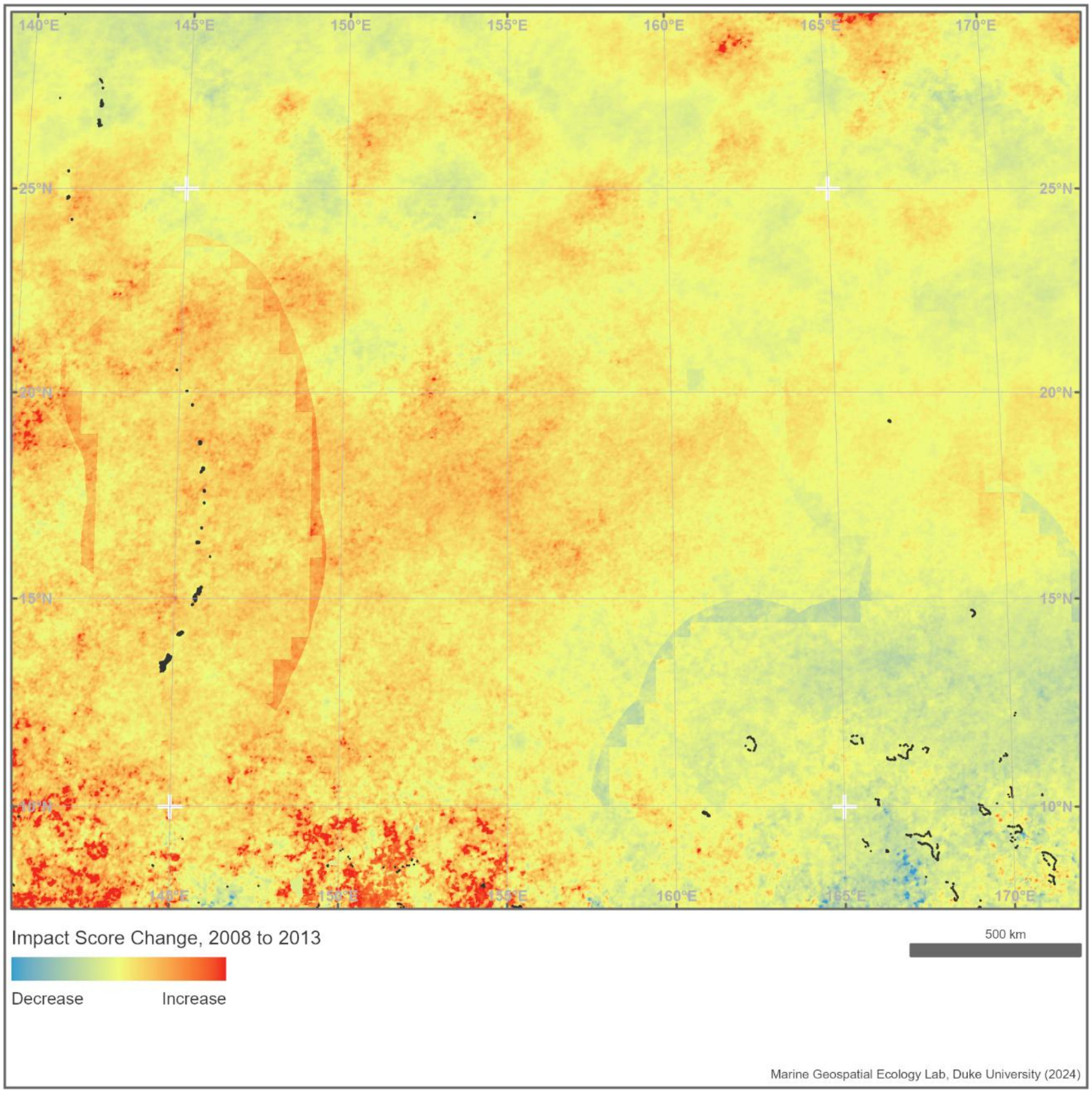


Figure 5.7-2 Change in cumulative human impact, 2008 to 2013

5.8 Exploration Areas for Mineral Resources in the Area

The International Seabed Authority (ISA; https://www.isa.org.jm/) provides the location of all contract areas for exploration for mineral resources in the Area.

The International Seabed Authority has entered into 15-year contracts for exploration for polymetallic nodules (19 contracts), polymetallic sulphides (8 contracts) and cobalt-rich ferromanganese crusts (4 contracts) in the deep seabed.

Nineteen of these contracts are for exploration for polymetallic nodules in the Clarion-Clipperton Zone (17), Central Indian Ocean Basin (1) and North-west Pacific (1). There are eight contracts for exploration for polymetallic sulphides in the Indian Ocean Ridges and the Mid-Atlantic Ridge, and four contracts for exploration for cobalt-rich crusts in the North-west Pacific.

Data source for the current exploration areas: https://www.isa.org.jm/maps

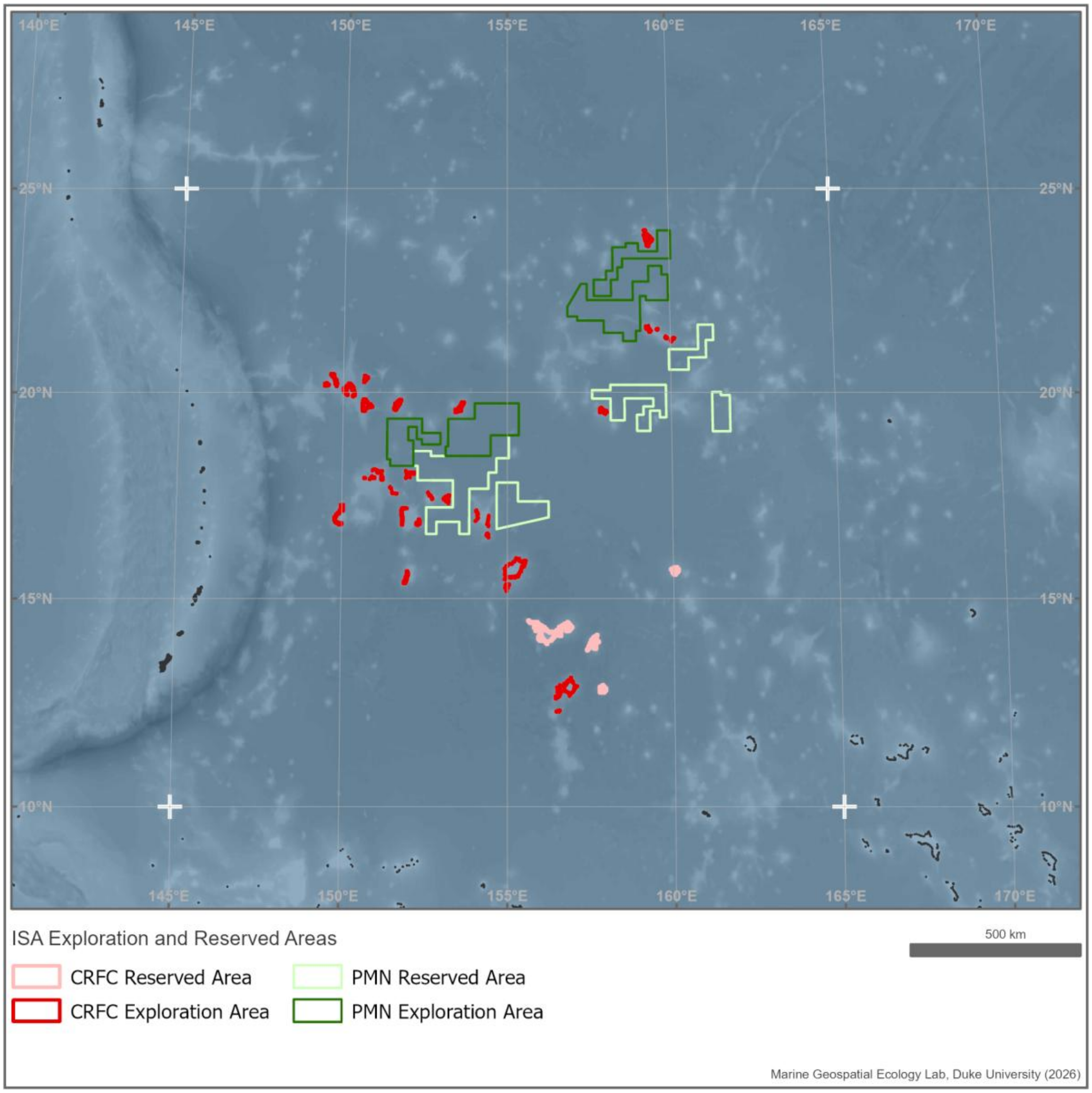


Figure 5.8-1 ISA exploration and reserved areas

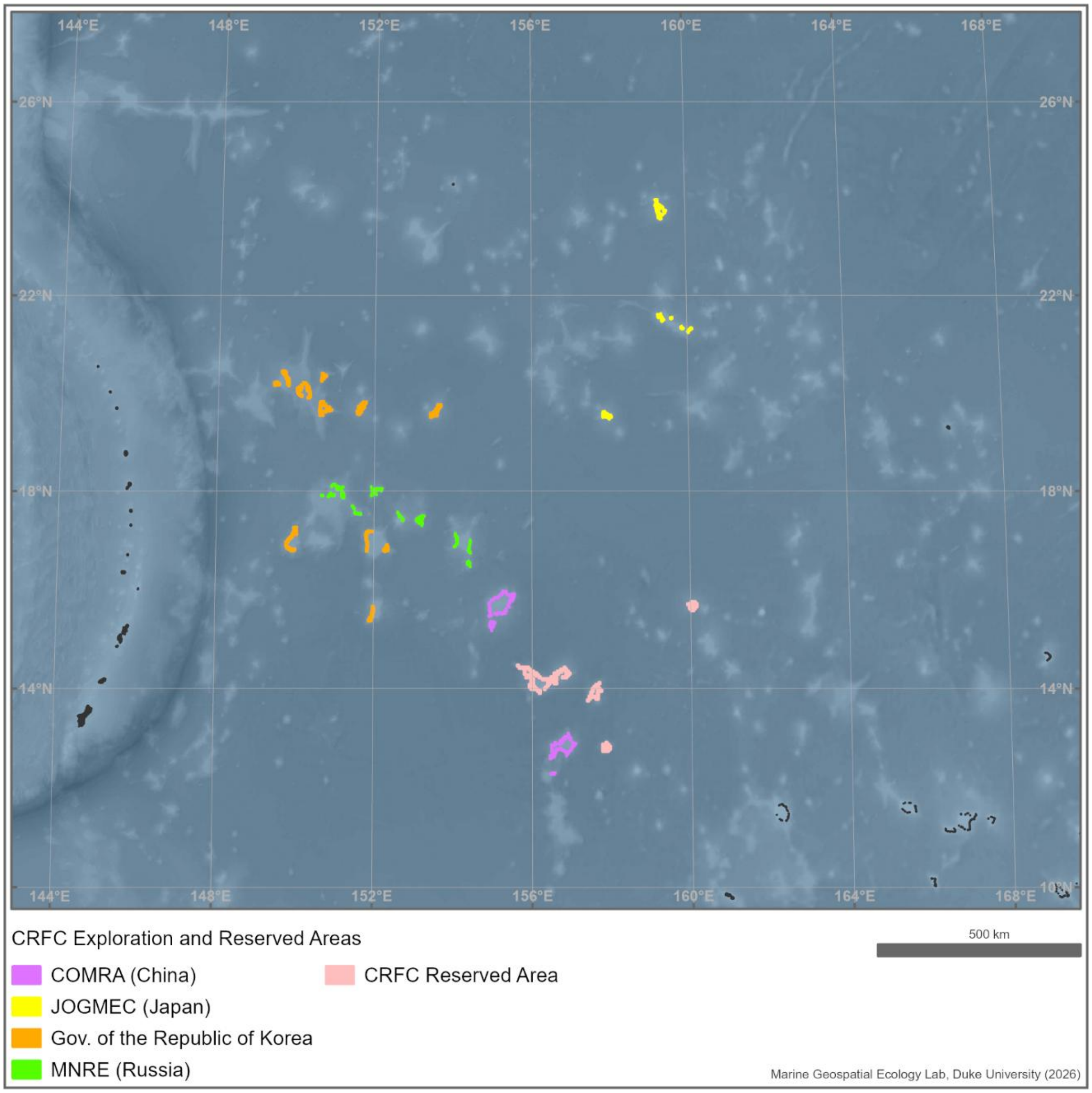


Figure 5.8-2 ISA Cobalt-Rich Ferromanganese Crusts (CRFC) exploration and reserved areas

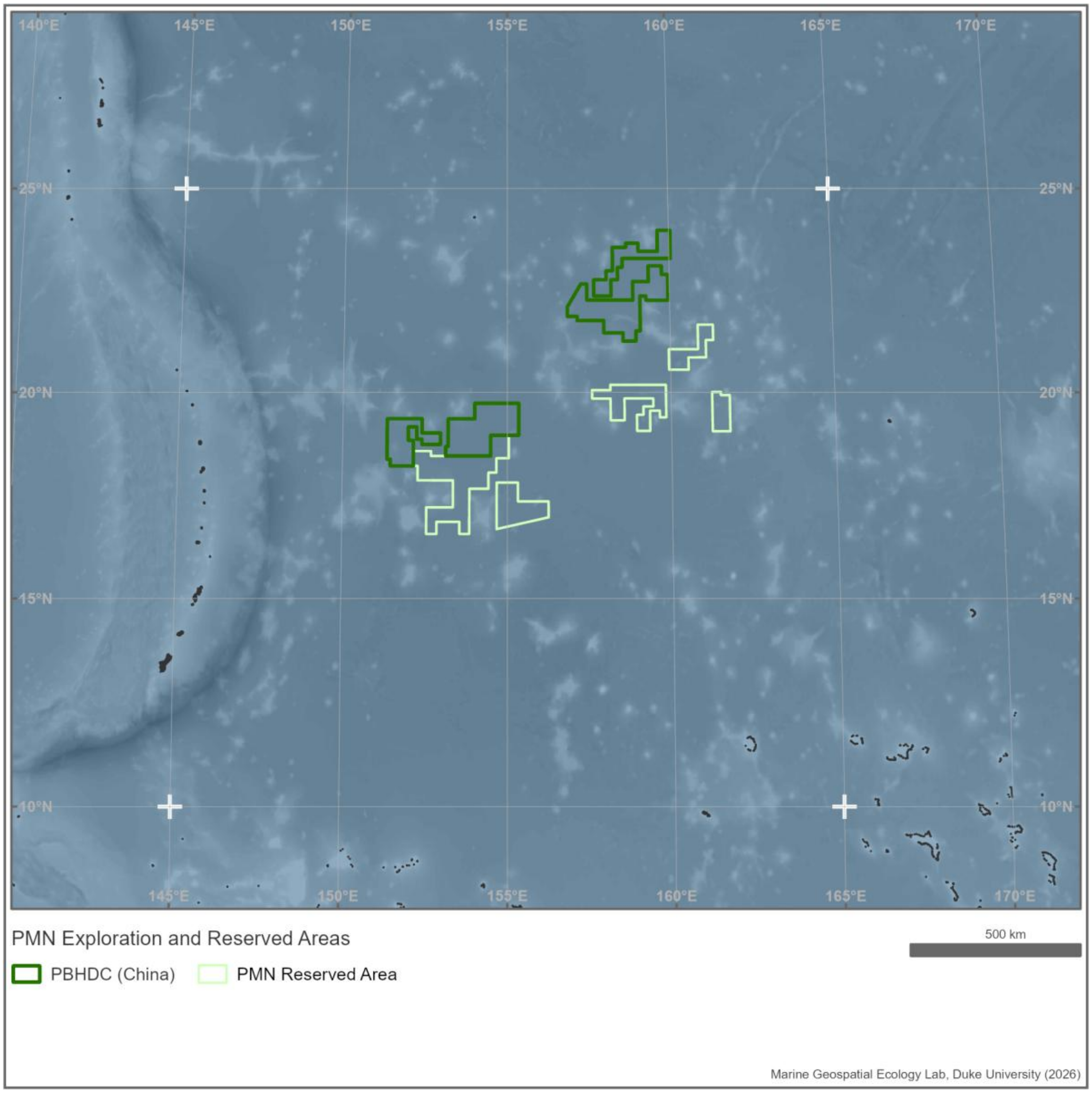


Figure 5.8-3 ISA Polymetallic Nodules (PMN) exploration and reserved areas

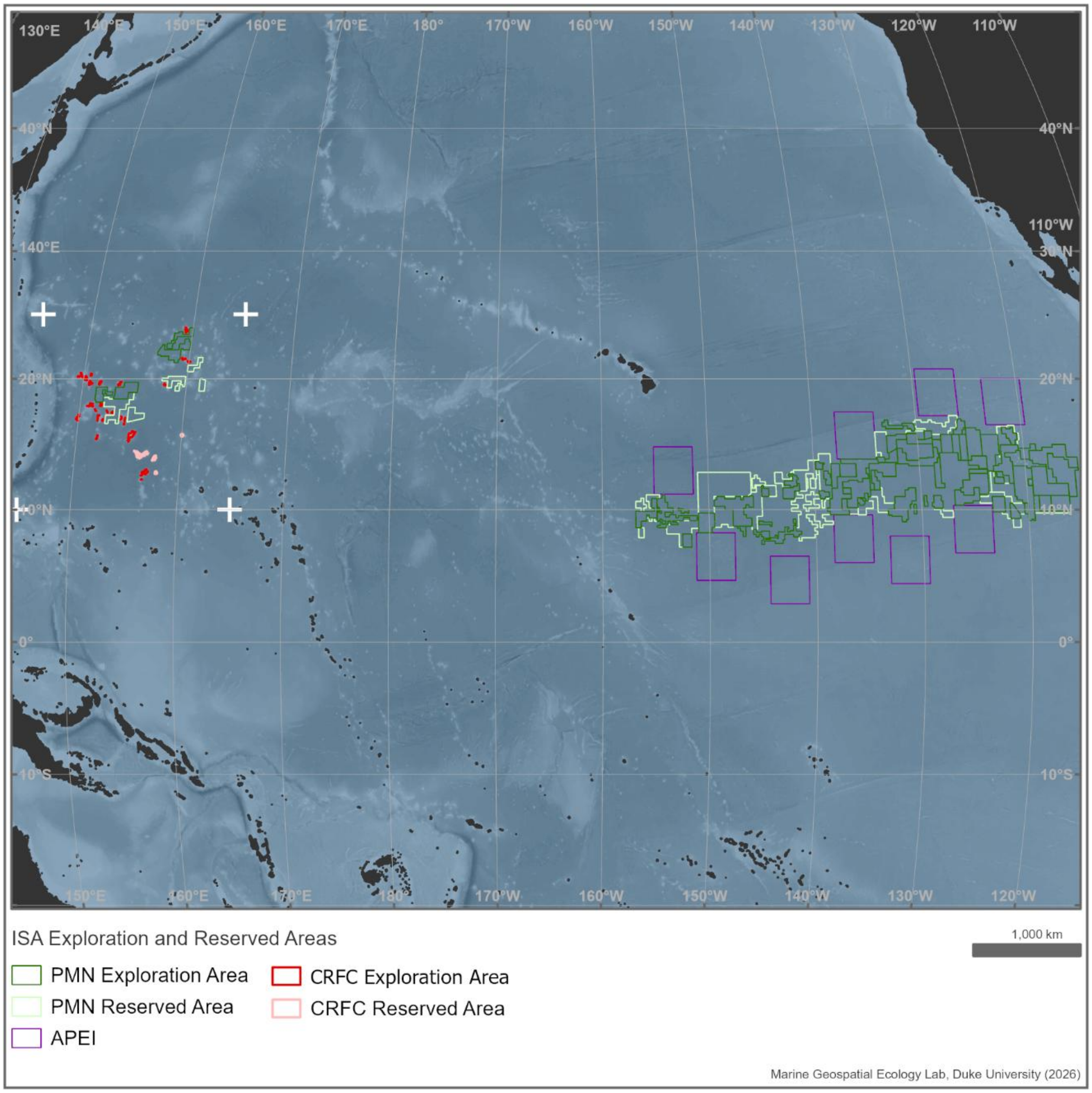


Figure 5.8-4 ISA Pacific exploration and reserved areas

6 Areas Defined for Management and/or Conservation Objectives

6.1 Regional Fishery Bodies (RFB)

Regional Fishery Bodies (RFBs) are a mechanism through which States or organizations that are parties to an international fishery agreement or arrangement work together towards the conservation, management and/or development of fisheries (http://www.fao.org/fishery/topic/16800/en). The mandates of RFBs vary. Some RFBs have an advisory mandate, and provide advice, decisions or coordinating mechanisms that are not binding on their members. Some RFBs have a management mandate – these are called Regional Fisheries Management Organizations (RFMOs). They adopt fisheries conservation and management measures that are binding on their members.

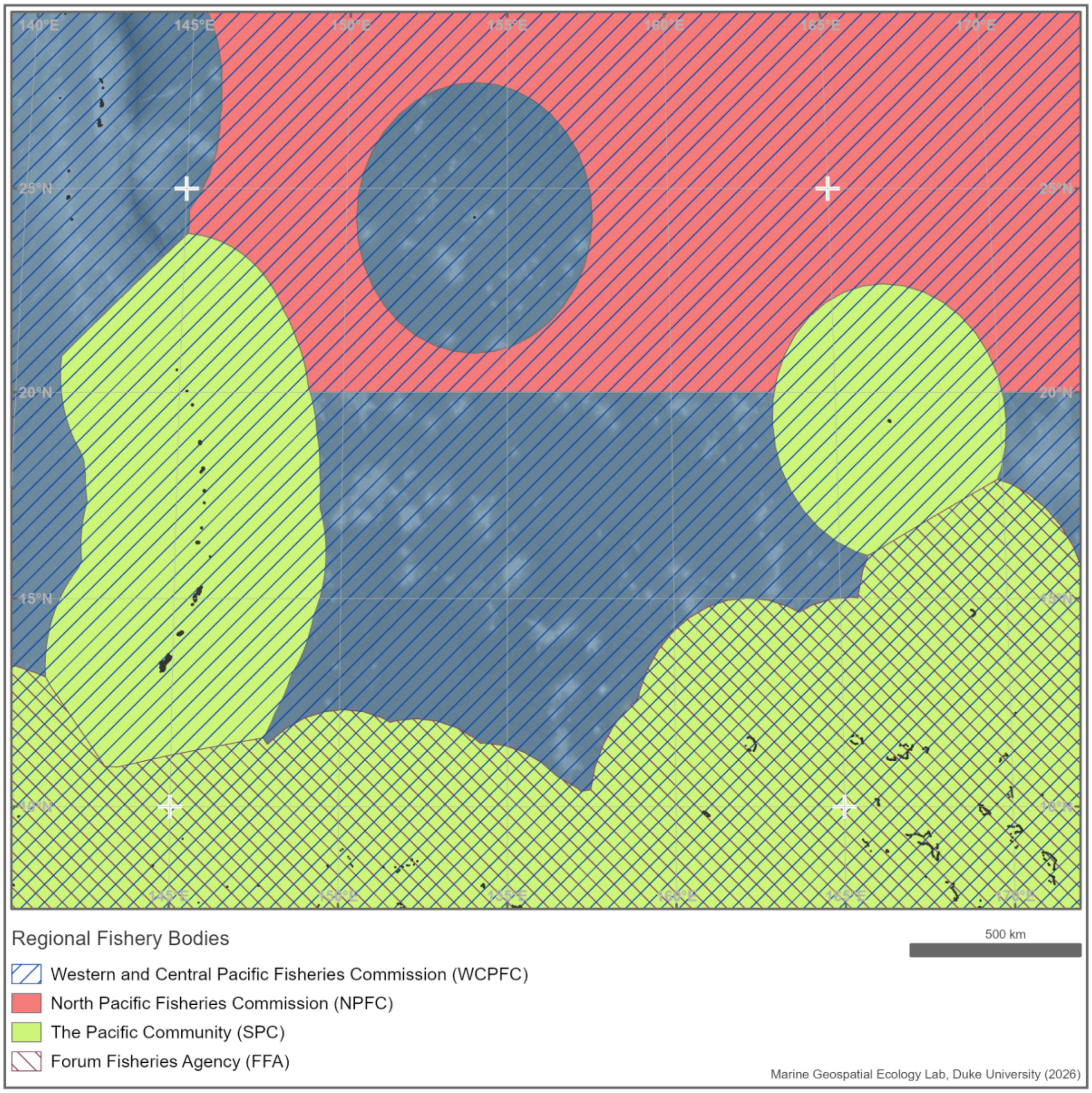


Figure 6.1-1 Regional Fishery Bodies in the Northwest Pacific

6.2 Marine Protected Areas

"Protected Planet is the most up to date and complete source of information on protected areas, updated monthly with submissions from governments, non-governmental organizations, landowners and communities. It is managed by the United Nations Environment Programme's World Conservation Monitoring Centre (UNEP-WCMC) with support from IUCN and its World Commission on Protected Areas (WCPA).
It is a publicly available online platform where users can discover terrestrial and marine protected areas, access related statistics and download data from the World Database on Protected Areas (WDPA)."

Source: https://www.protectedplanet.net/c/world-database-on-protected-areas

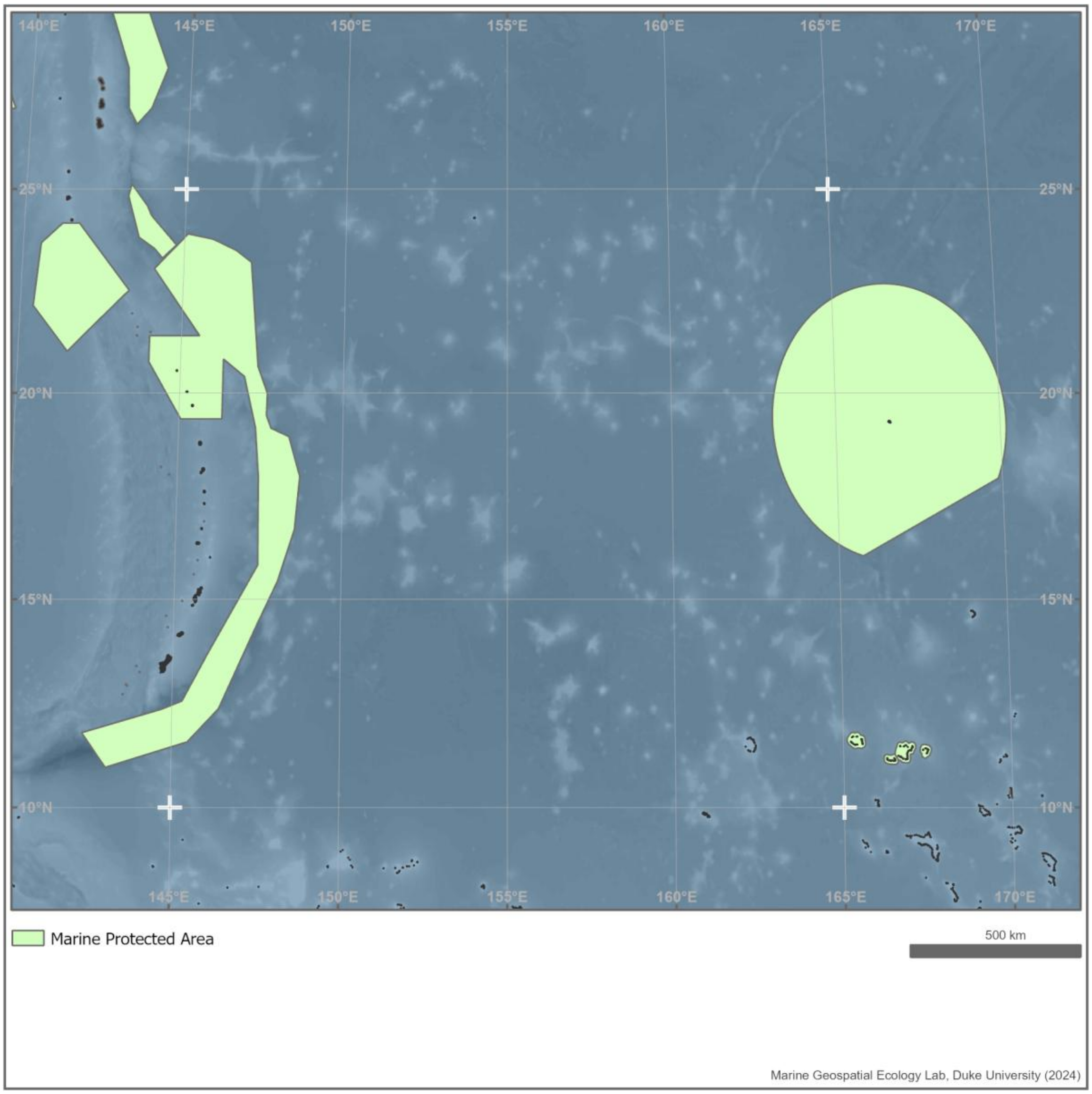


Figure 6.2-1 Marine protected areas

6.3 Convention on Biological Diversity Ecologically or Biologically Significant Areas (EBSAs)

In 2008, the ninth meeting of the Conference of the Parties to the Convention on Biological Diversity (COP 9) adopted the following scientific criteria for identifying ecologically or biologically significant marine areas (EBSAs) in need of protection in open-ocean waters and deep-sea habitats. For more details on the EBSA criteria, please see: wwww.cbd.int/doc/meetings/mar/ebsaws-2014-01/other/ebsaws-2014-01-azores-brochure-en.pdf. CBD scientific criteria for ecologically or biologically significant areas (EBSAs) (annex I, decision IX/20) includes: Uniqueness or Rarity, Special importance for life history stages of species, Importance for threatened, endangered or declining species and/or habitats, Vulnerability, Fragility, Sensitivity, or Slow recovery, Biological Productivity, Biological Diversity, Naturalness. From 2011 to 2019, the CBD convened regional workshops that identified over 300 areas meeting the internationally agreed criteria for Ecologically and Biologically Significant Areas (EBSAs).

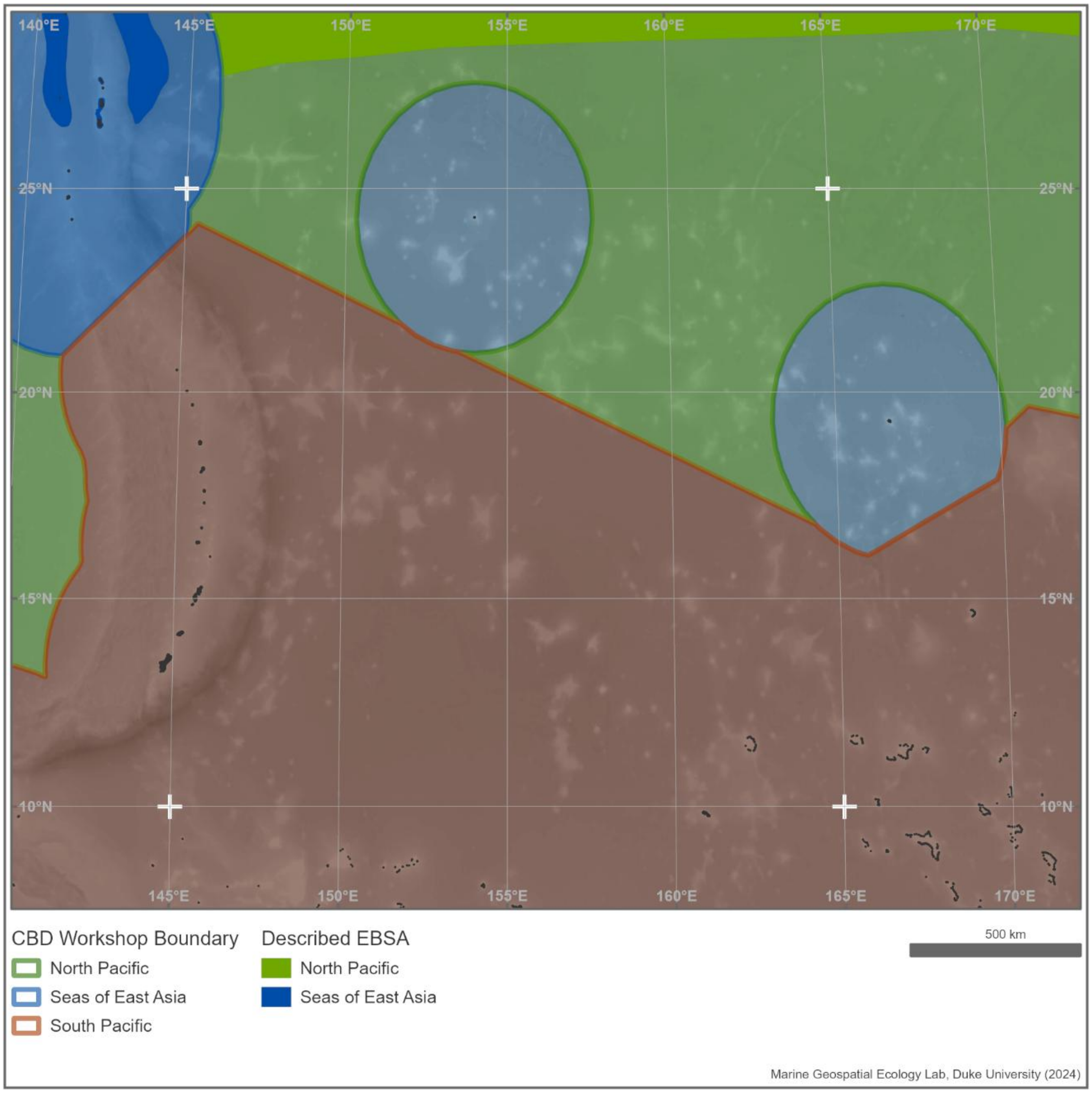


Figure 6.3-1 CBD Ecologically or Biologically Significant Areas and workshop boundaries

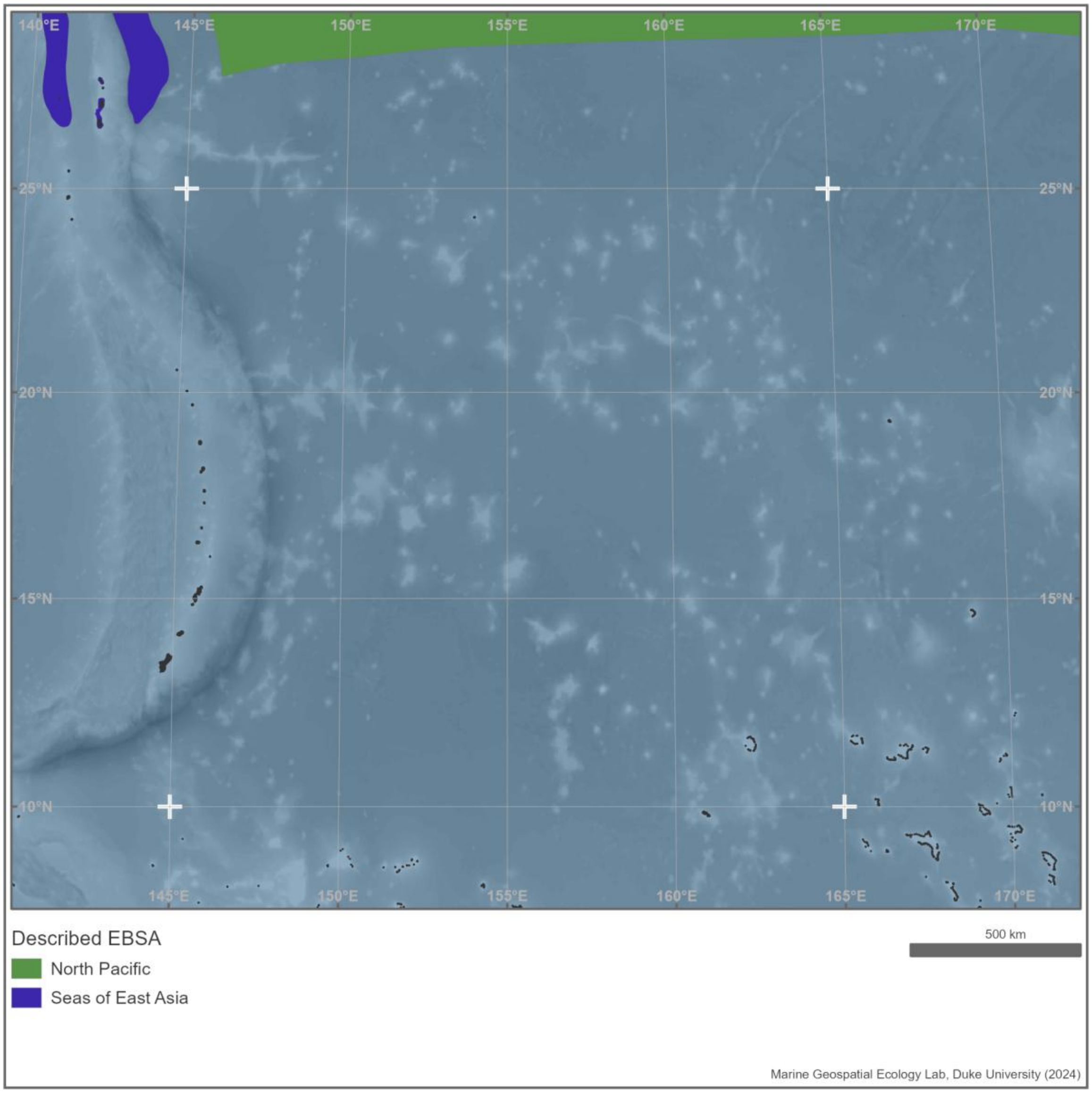


Figure 6.3-2 CBD Ecologically or Biologically Significant Areas

7 Acknowledgments

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The data collection team gratefully acknowledge contributions from:

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Cindy Van Dover - Duke University

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Andrew Sweetman - Heriot-Watt University

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