Myanmar Marine Biodiversity Atlas

UNIVERSITY OF EXETER

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Myanmar Marine Biodiversity Atlas

Edition 1: December 2016

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1. INTRODUCTION

The Republic of the Union of Myanmar possesses an extensive coastline and marine realm, with vast marine resources at its disposal. These natural resources have played an essential role in Myanmar's history and will continue to play an integral part in the country's future. Indeed, Myanmar's rapid social and economic development will bring about greater demands on its marine resources and habitats, along with opportunities for conservation and research and a stronger regulatory environment supported through international co-operation.

The Myanmar Marine Biodiversity Atlas (Edition 1: December 2016) seeks to illustrate the current state of marine resources in Myanmar through spatial information and lay a foundation for future marine spatial planning (MSP) and conservation activities. The maps presented detail Myanmar's physical marine environment, oceanography, marine habitats, biodiversity and fisheries, in addition to important human influences that will play a role in shaping the country's marine environment.

As this Marine Biodiversity Atlas is continually developed, the various data layers will be made available to government departments and stakeholders through a Geographic Information System (GIS) and an online portal. Each map will be made available electronically as an ArcMap map package, forming a living database, so that new data layers can be added as and when they become available. It is anticipated that these data will greatly facilitate informed decision-making by regulators, inform Initial Environmental Examinations and Environmental Impact Assessments, and provide the platform for marine spatial planning. It is our goal that the Atlas will serve to benefit biodiversity, the economy and citizens of Myanmar, and its regional neighbours long into the future.

The data sources used for the maps are listed in the bibliography at the end of the atlas.

2. GEOPOLITICAL CONTEXT

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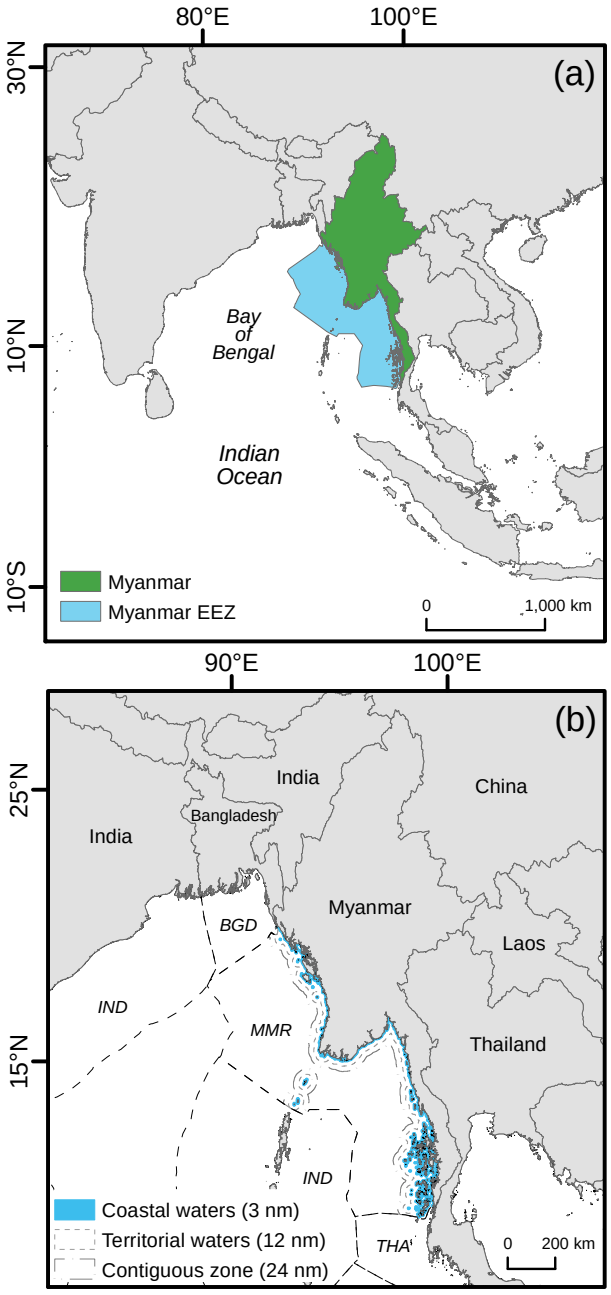
This section details Myanmar's geopolitical context, including its global location and national coastline. The area within which Myanmar has exclusive national rights over mineral and biological resources within its maritime boundaries is defined. Socio-economic information detailing the distribution of important population settlements and infrastructure is presented, in addition to protected areas and the distribution of important assets associated with the petrochemical exploration industry, which can be used to help inform targeted conservation efforts on the ground. Map parts of each figure are drawn to the same spatial scale unless otherwise stated. Maps are drawn to Projected Coordinate System: Asia North Albers Equal Area Conic (ANAEC) unless otherwise stated.



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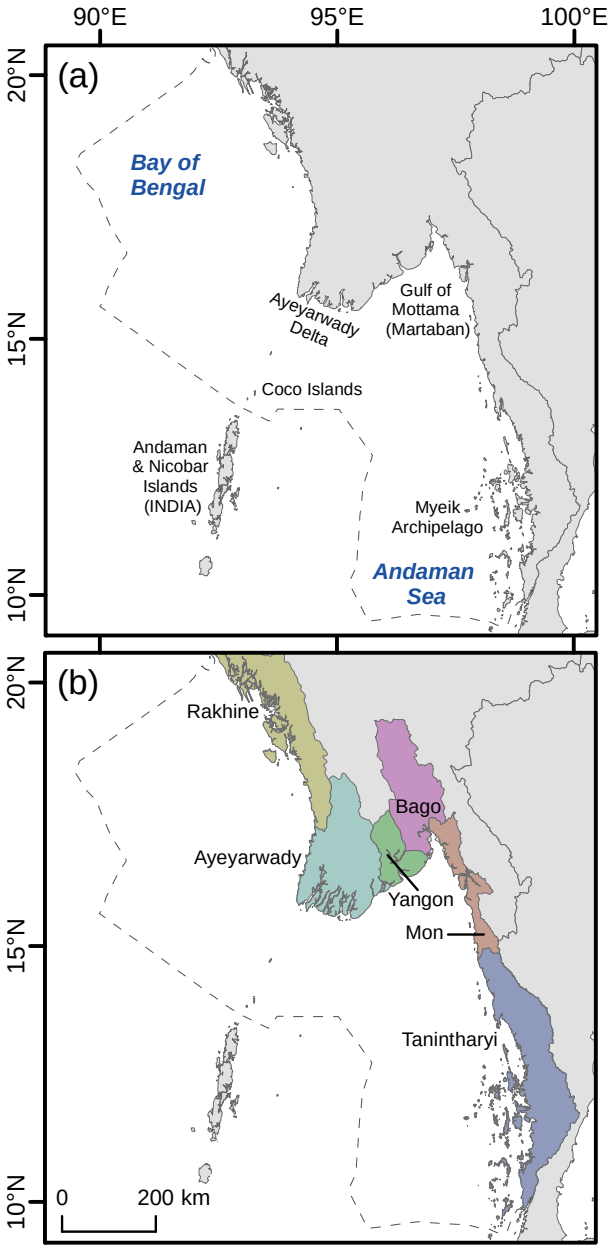

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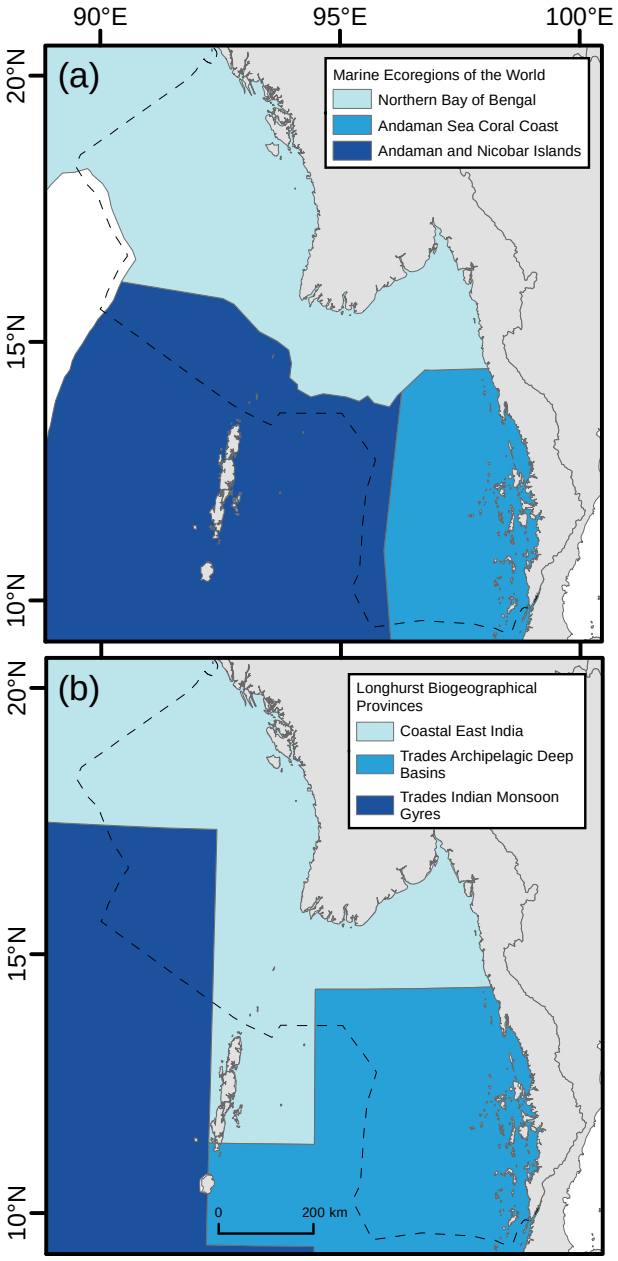

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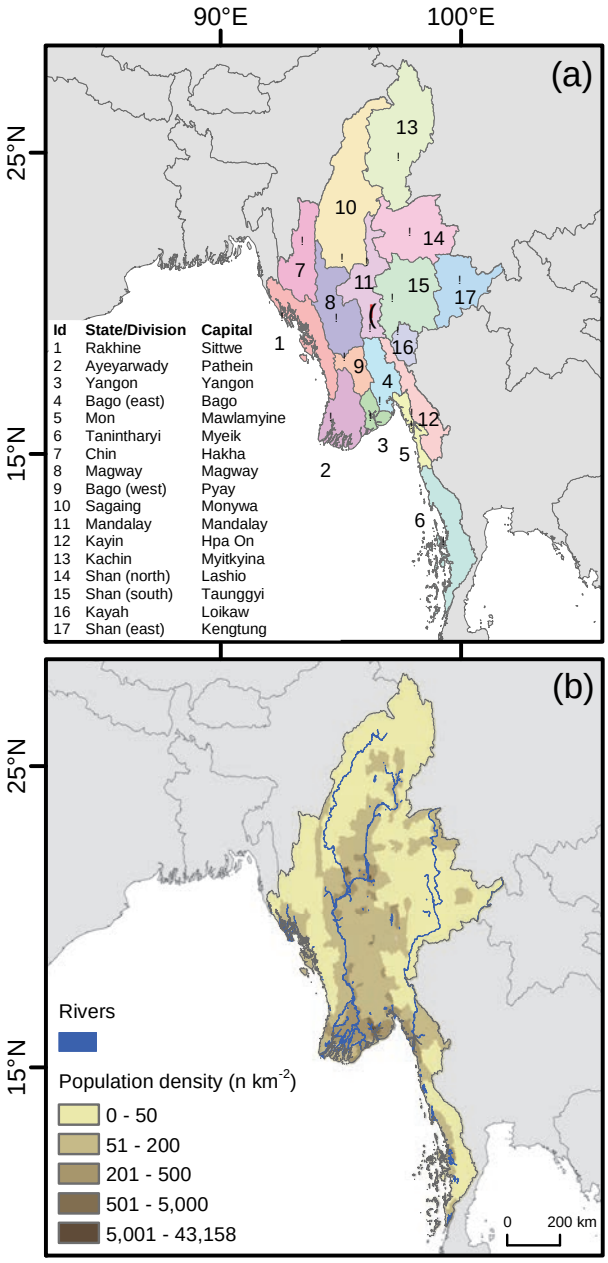

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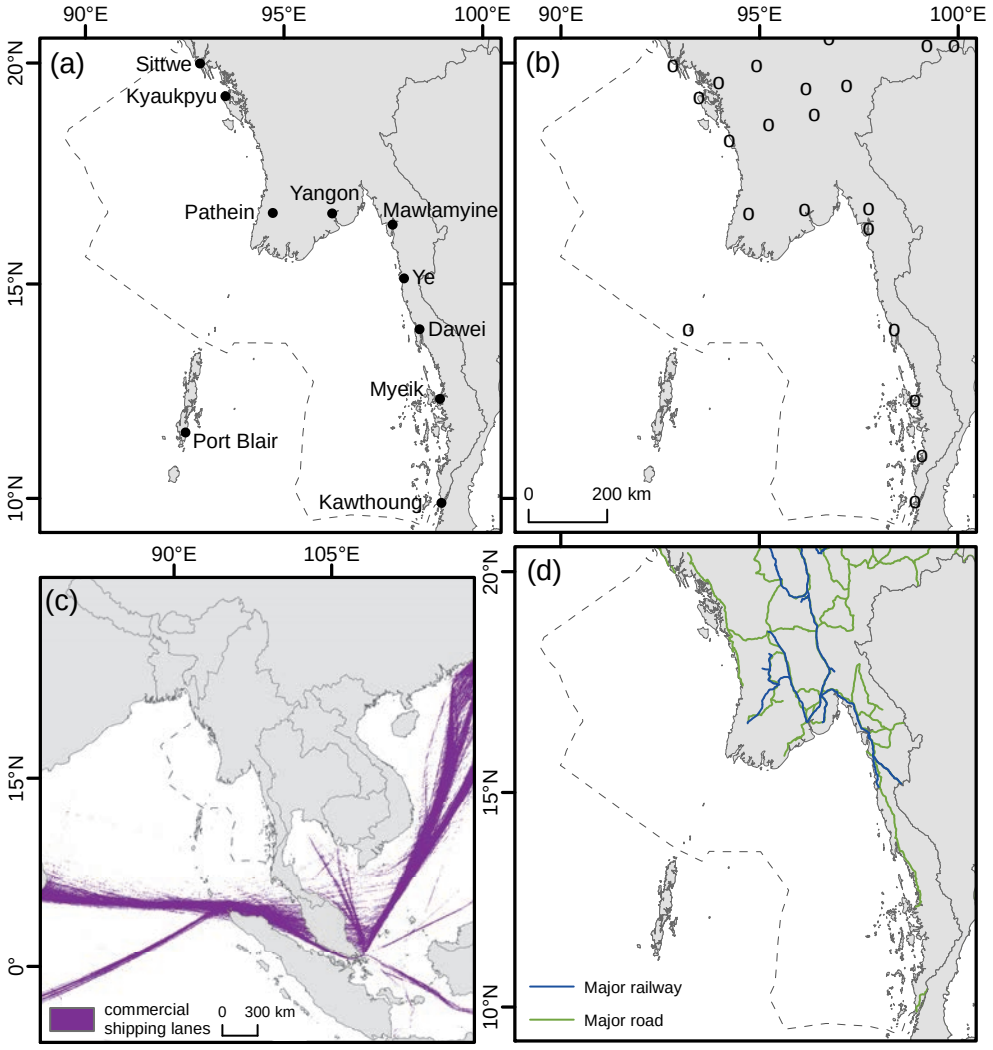

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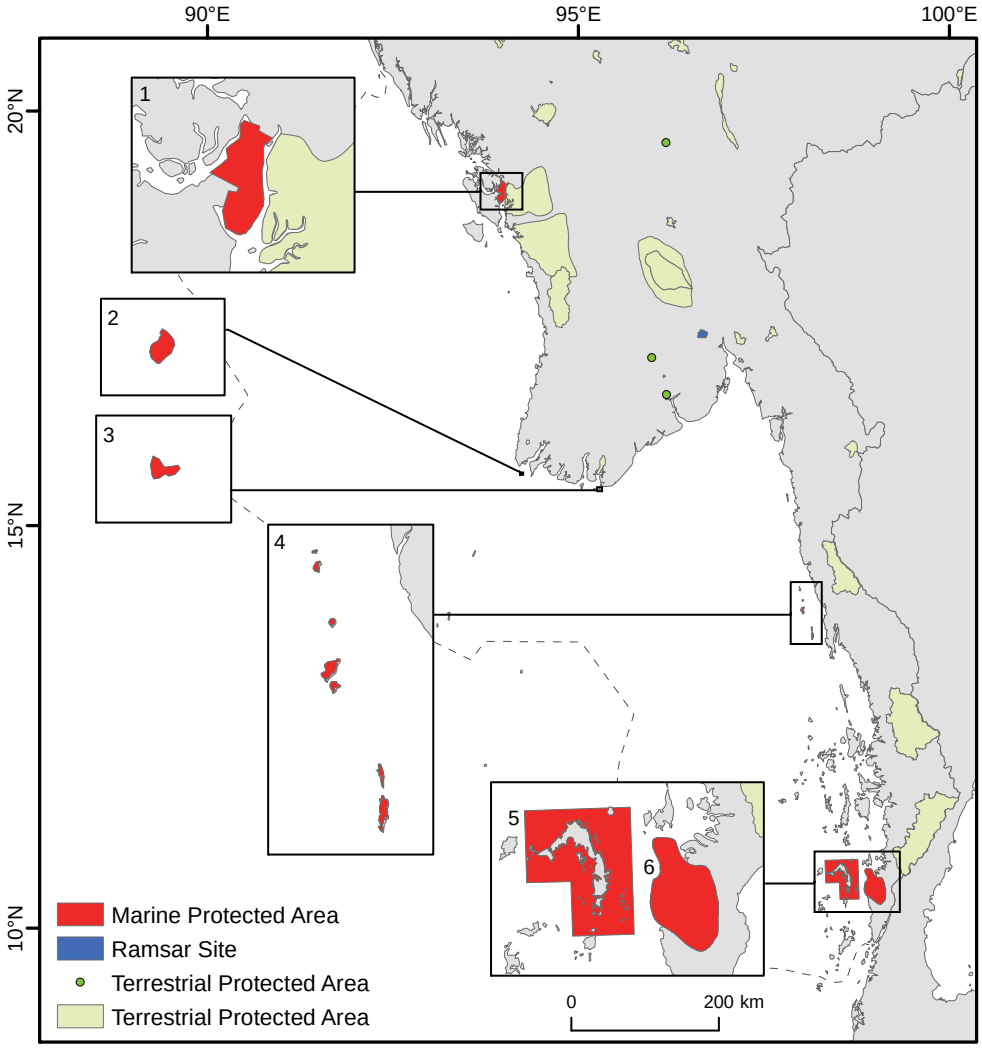

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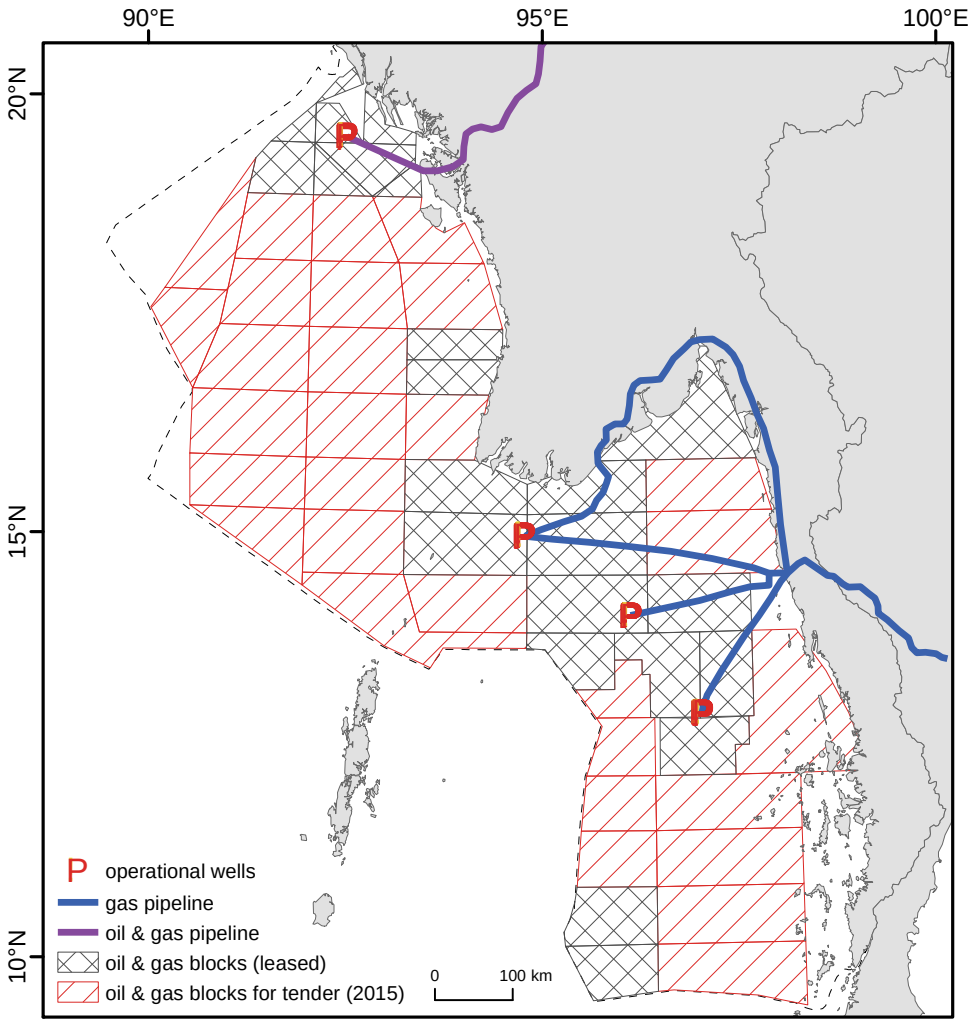

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3. PHYSICAL ENVIRONMENT

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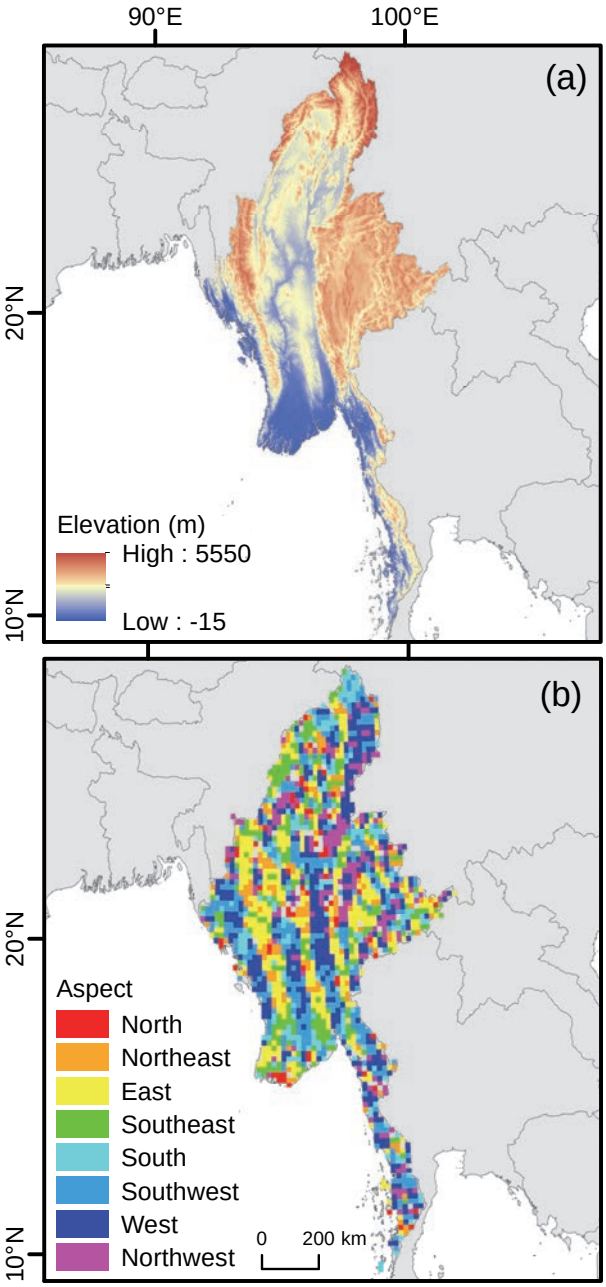
This section details the characteristics of the physical environment, both on land and within Myanmar's maritime limits, from its depth zones to seabed slope and undersea features that are regionally important**.** Map parts of each figure are drawn to the same spatial scale unless otherwise stated. Maps are drawn to Projected Coordinate System: Asia North Albers Equal Area Conic (ANAEC) unless otherwise stated.



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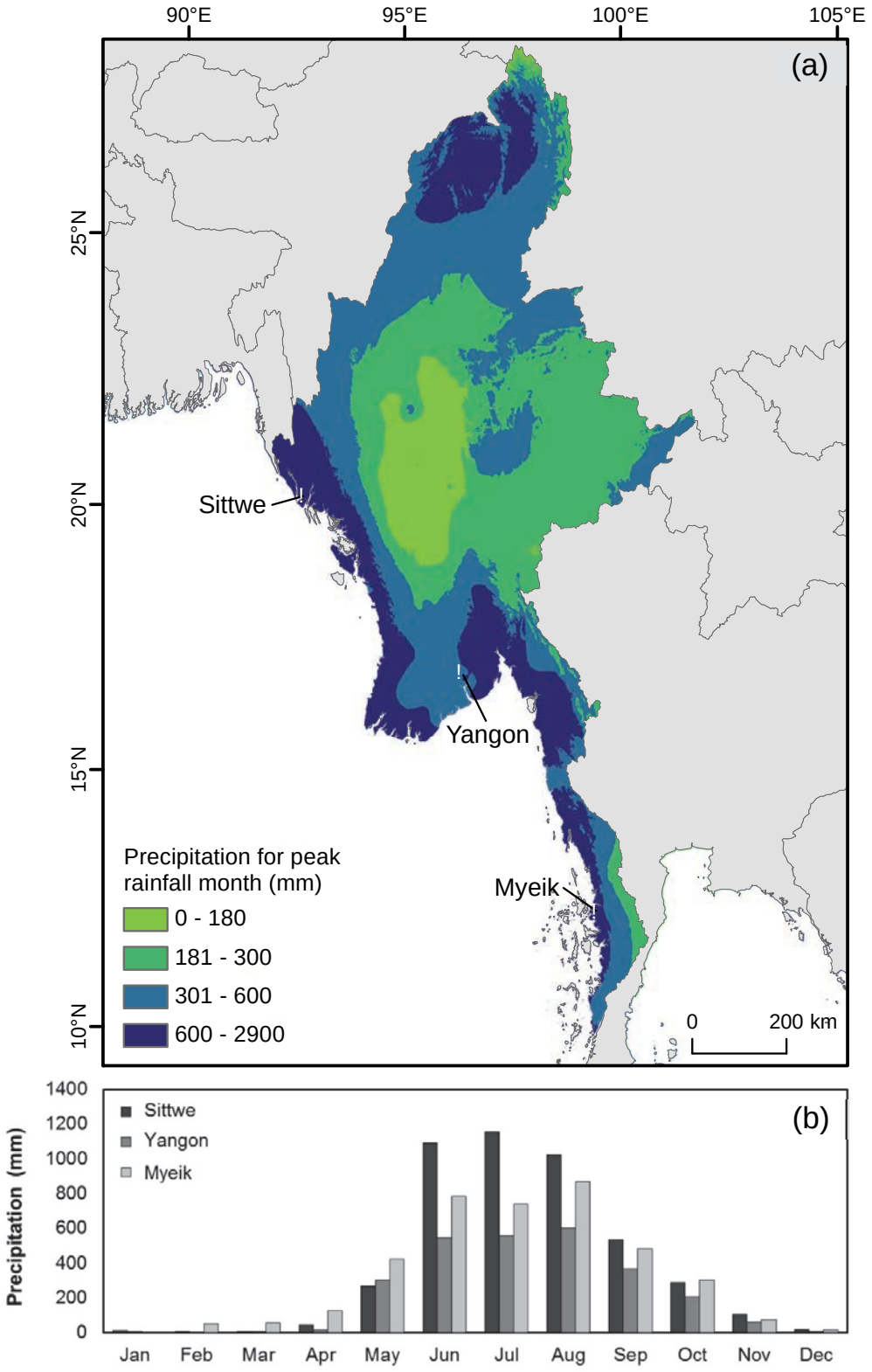

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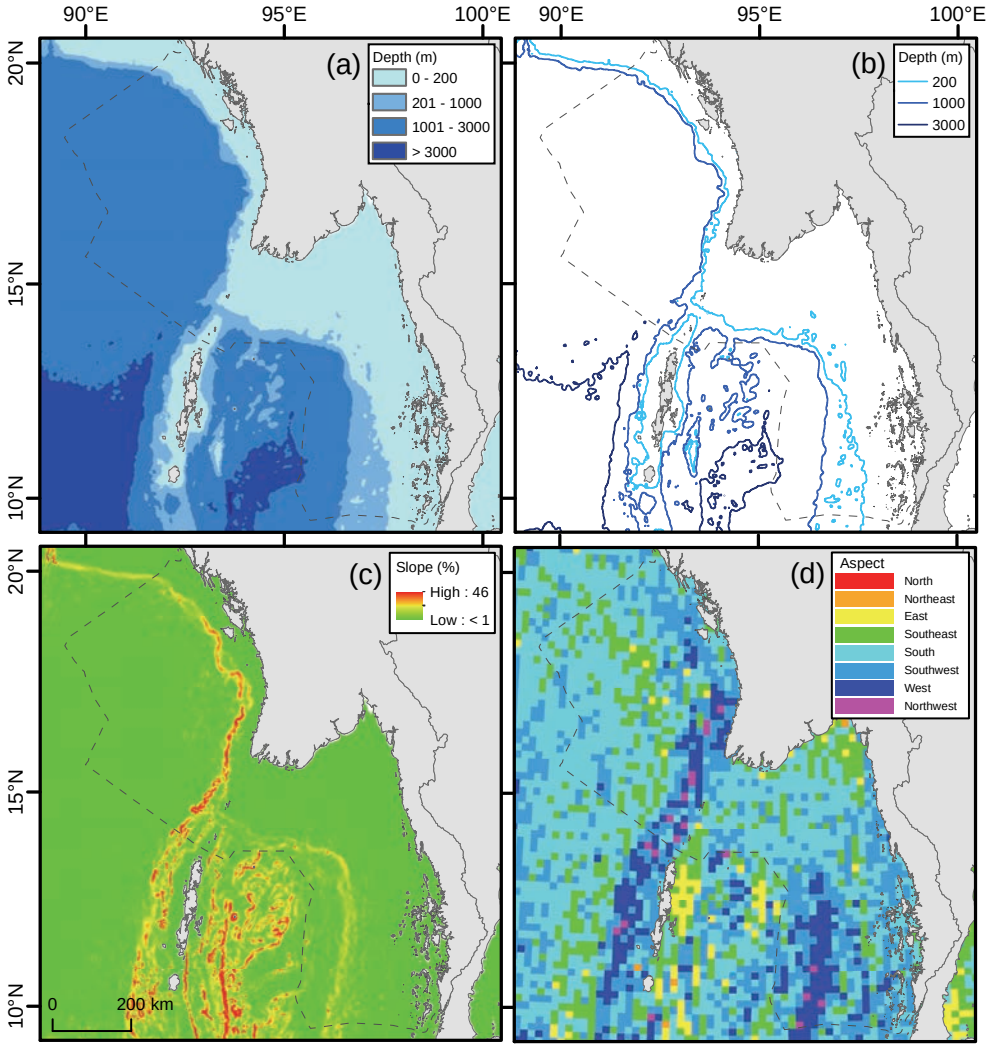

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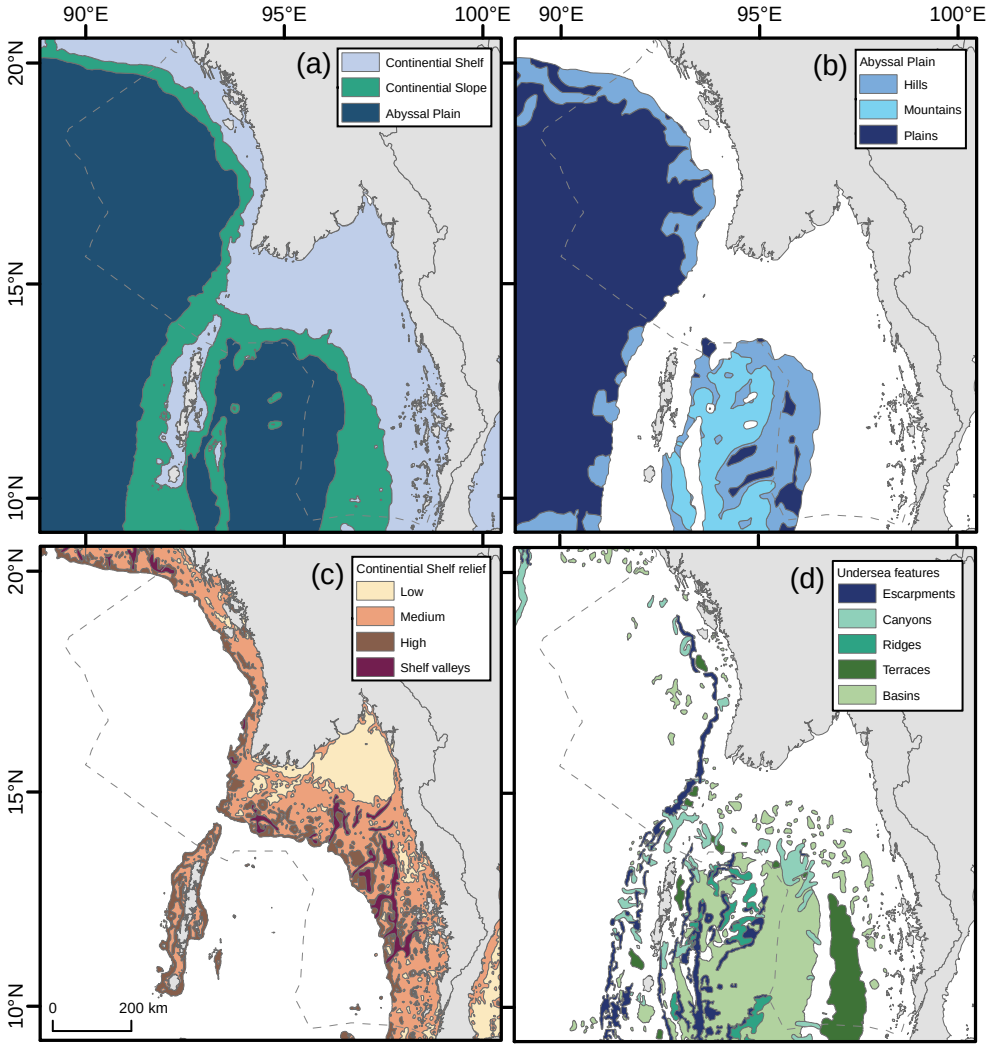

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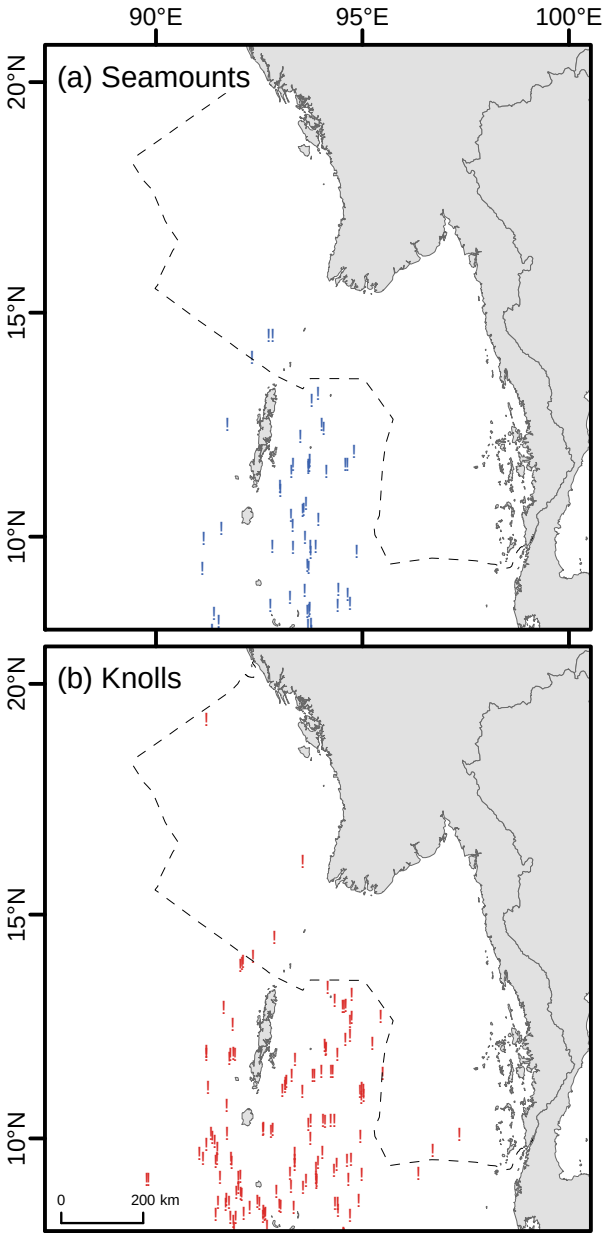

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4. OCEANOGRAPHY

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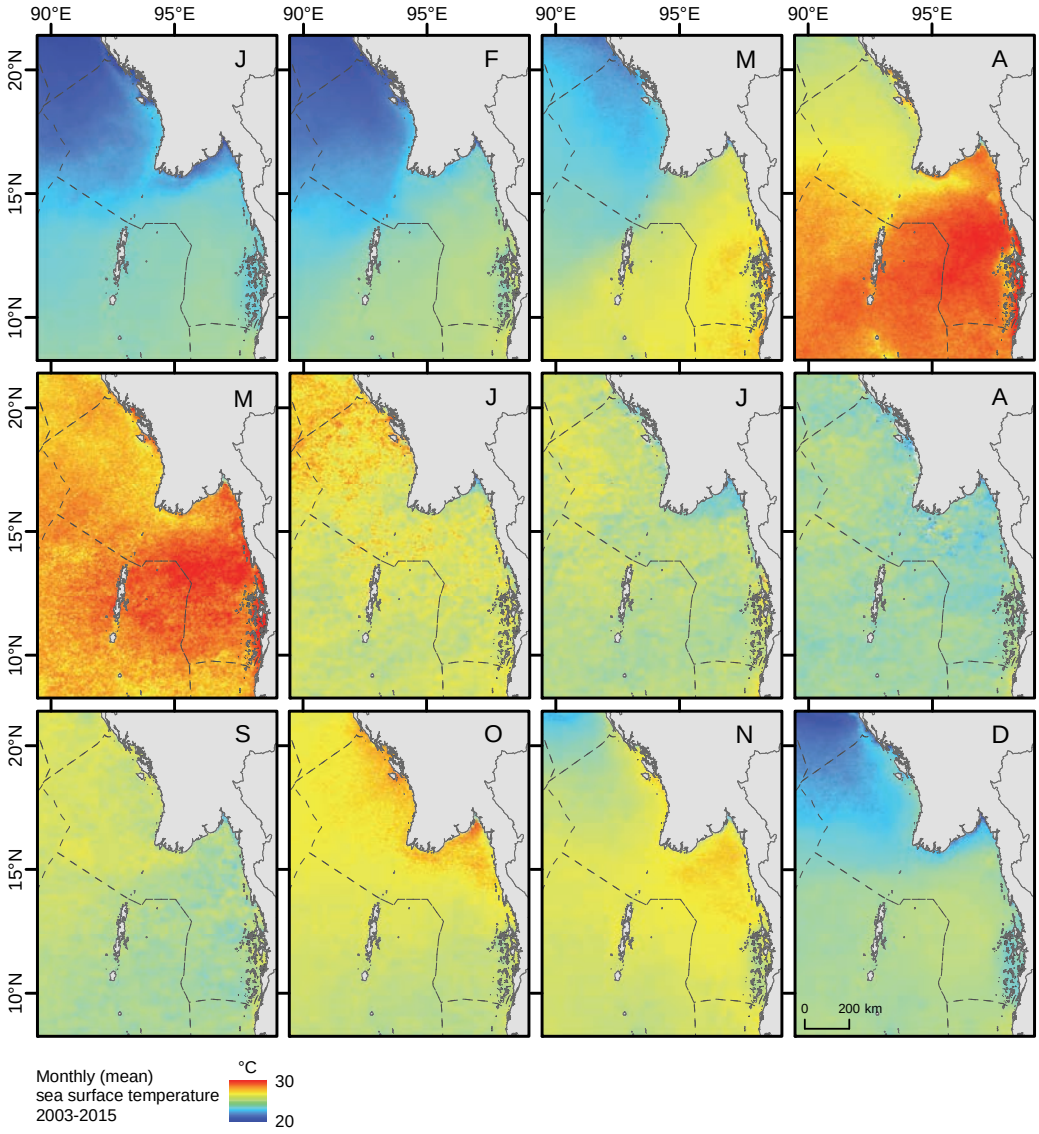
This section details the oceanographic characteristics within Myanmar's maritime limits, from mean monthly sea surface temperature, temperature fronts, chlorophyll-a, net primary productivity, salinity and surface currents, which can be used to derive ecologically important areas for fisheries management and biodiversity conservation. Map parts of each figure are drawn to the same spatial scale unless otherwise stated. Maps are drawn to Geographic Coordinate System: WGS84 unless otherwise stated.



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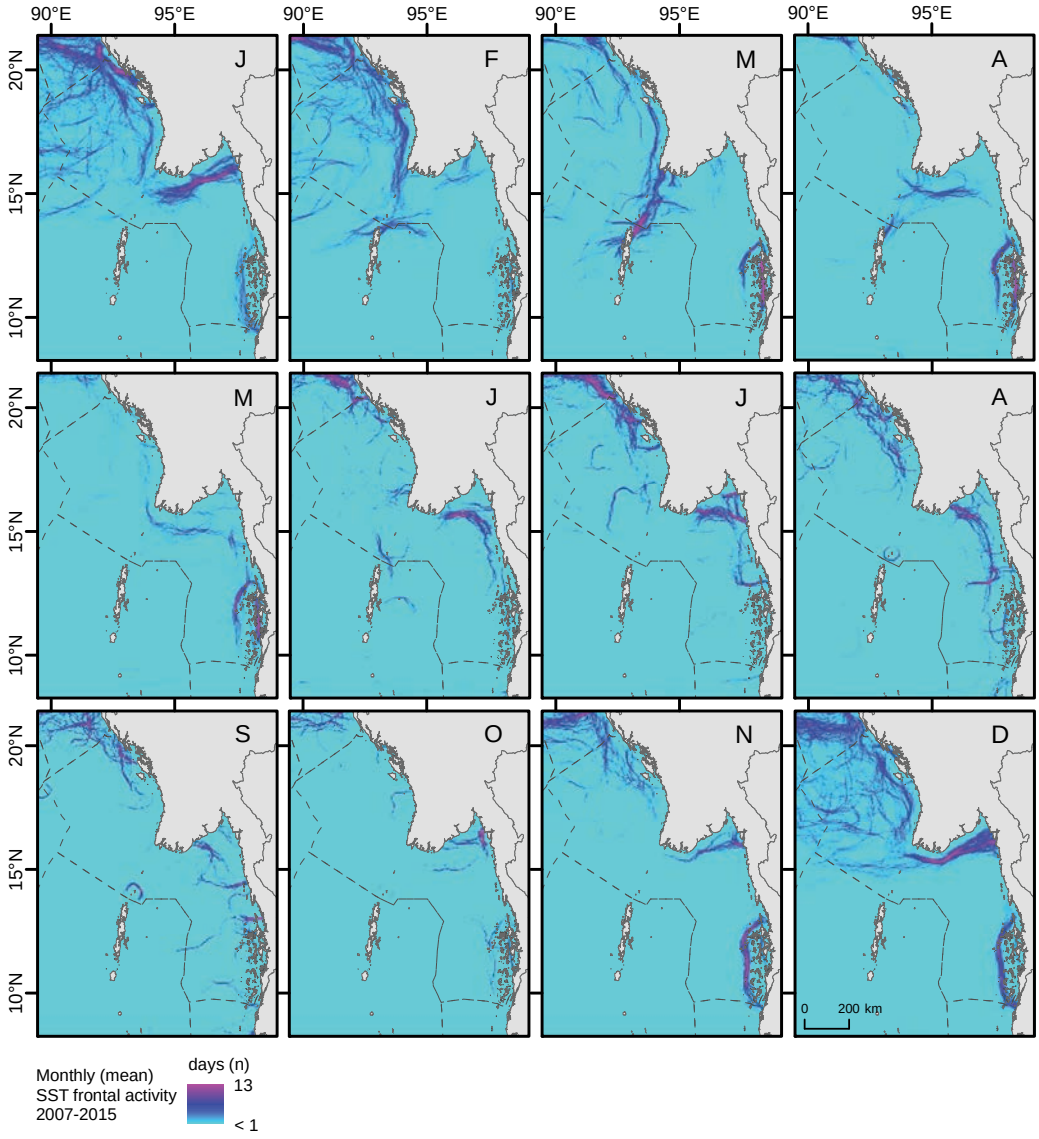

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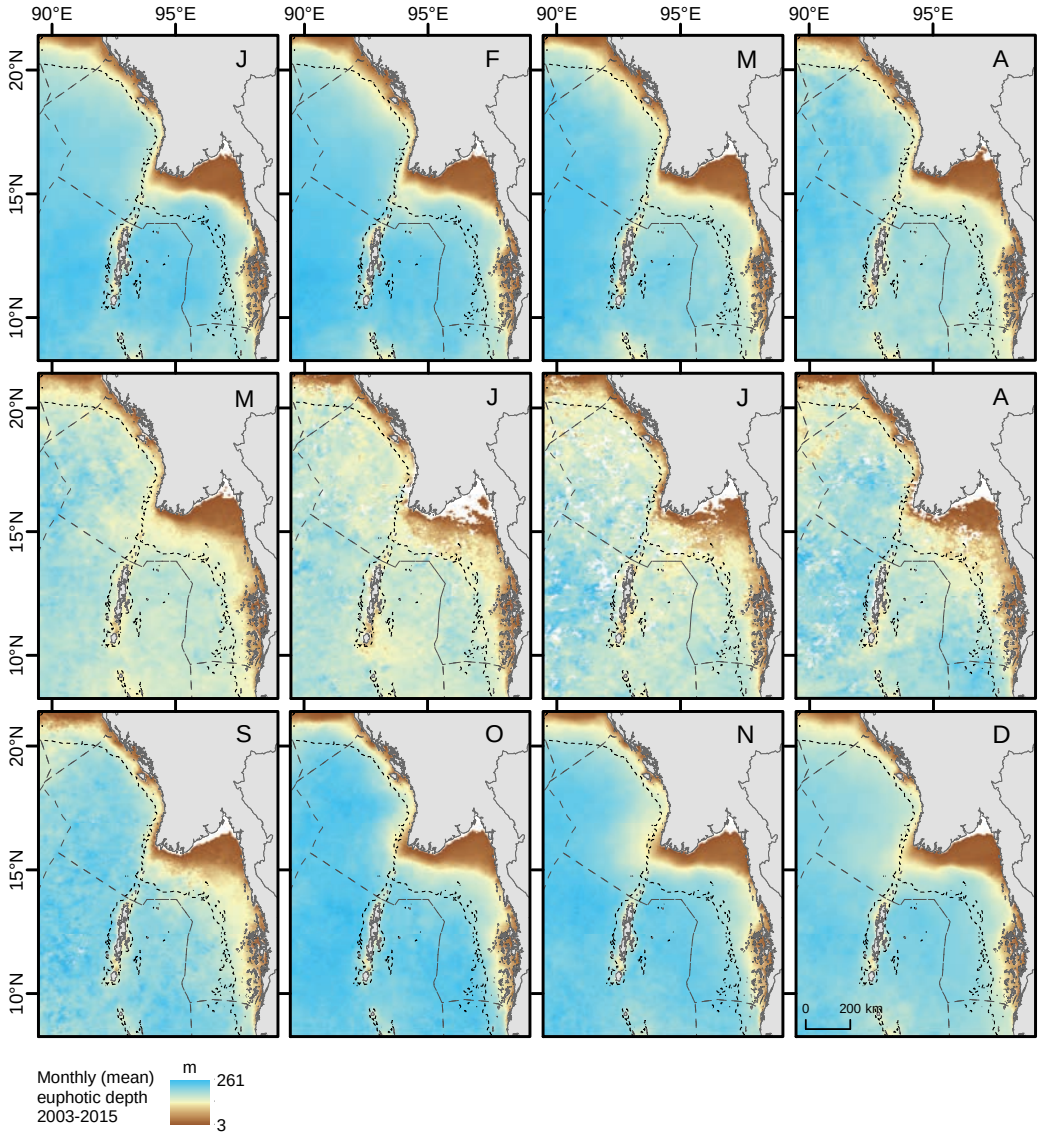

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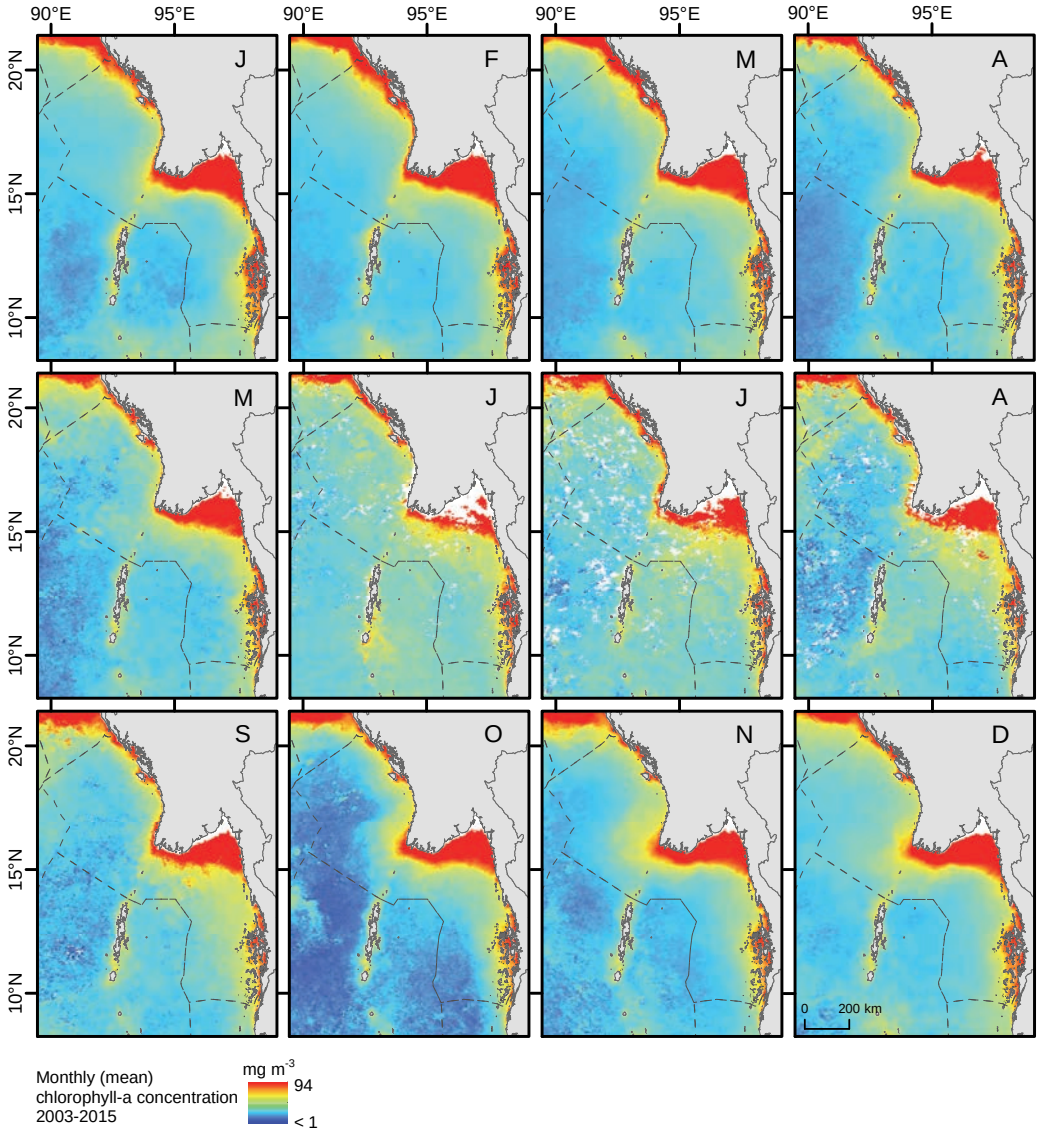

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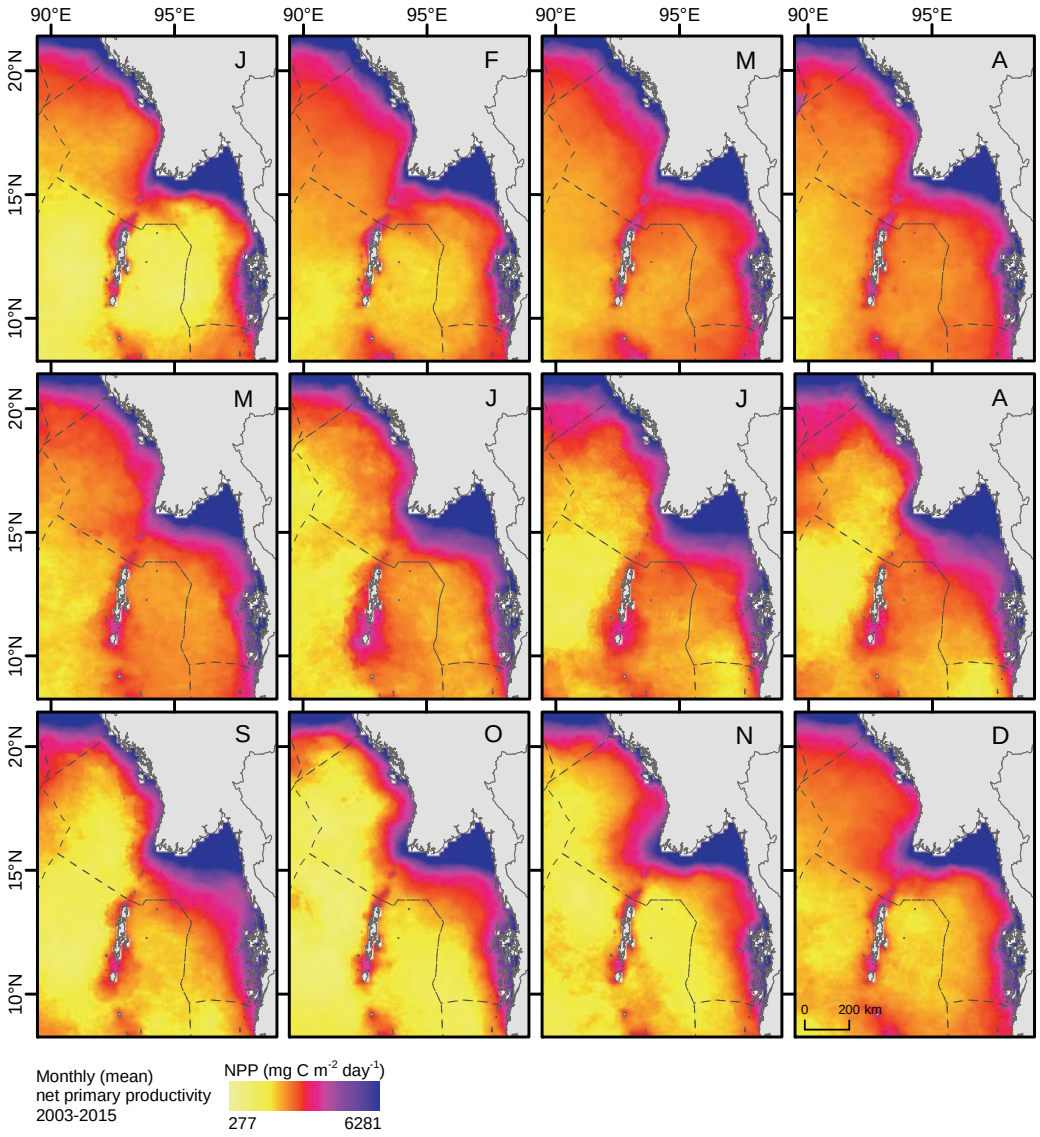

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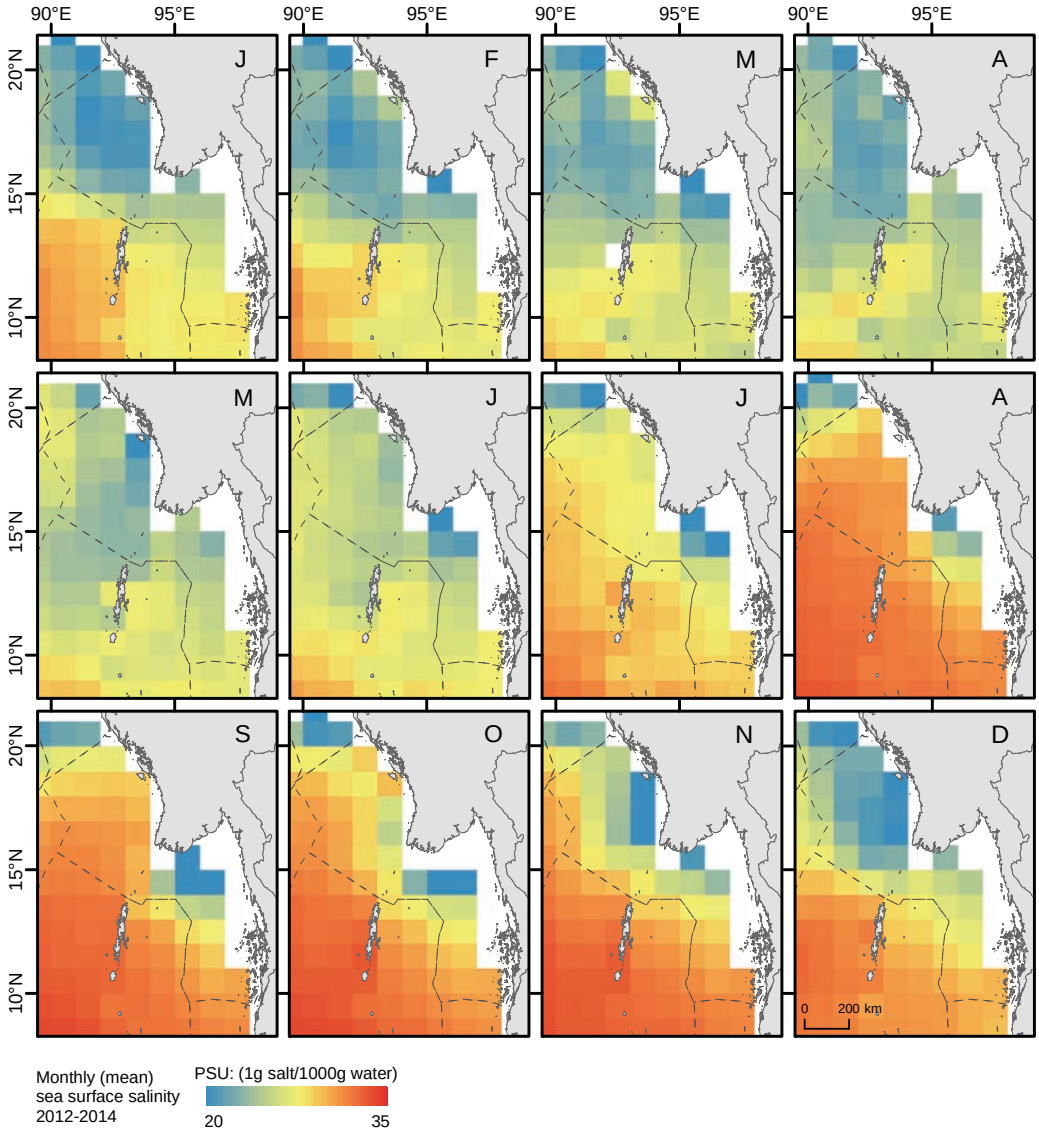

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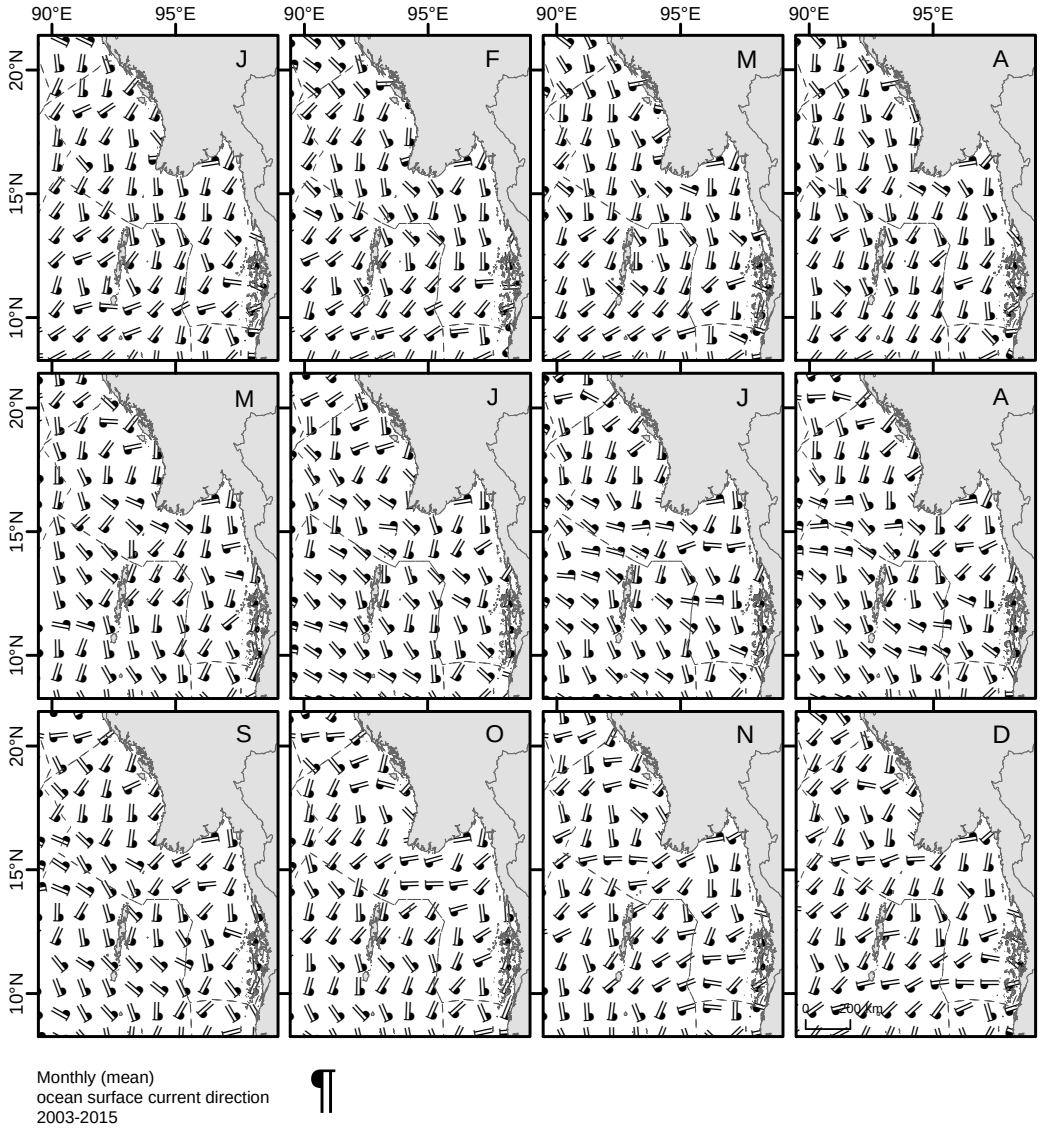

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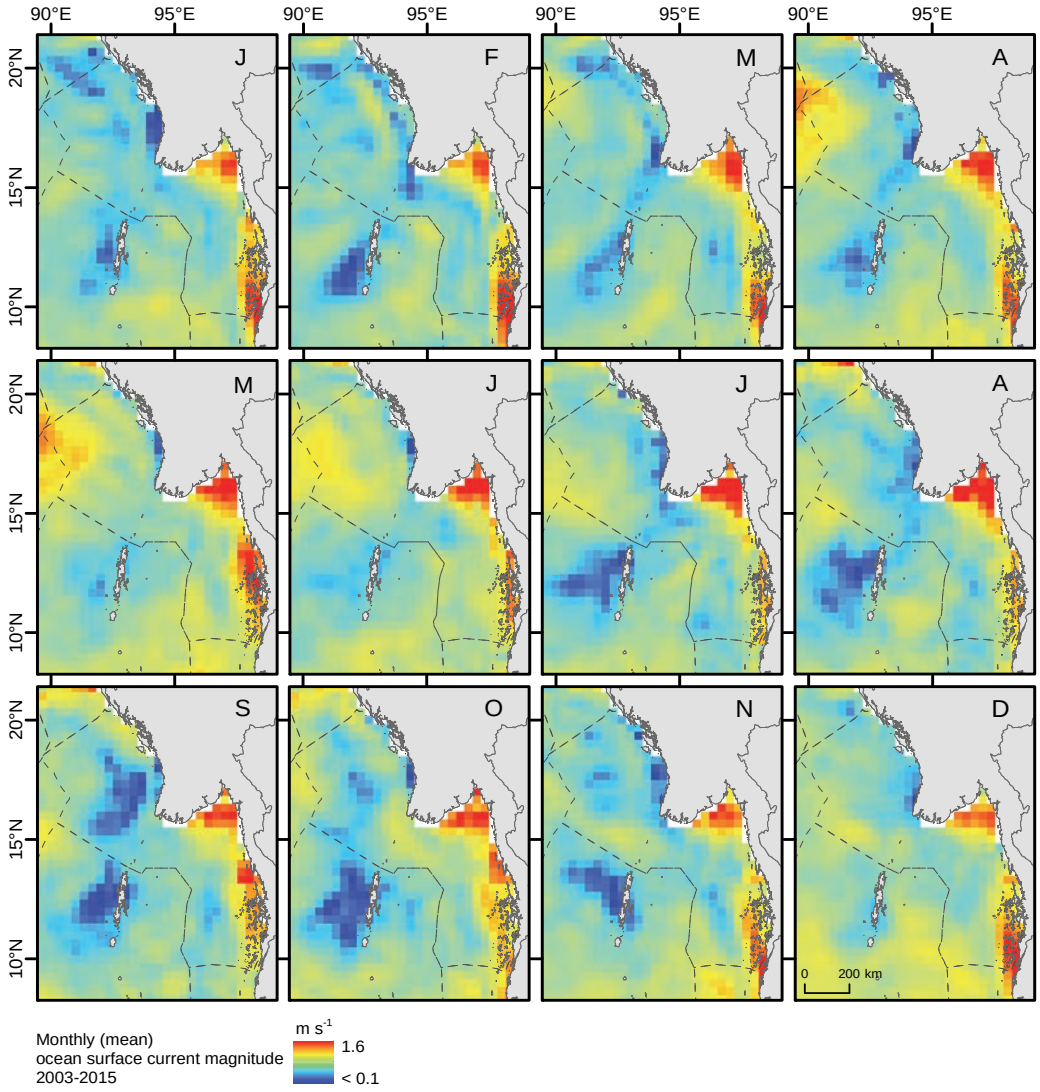

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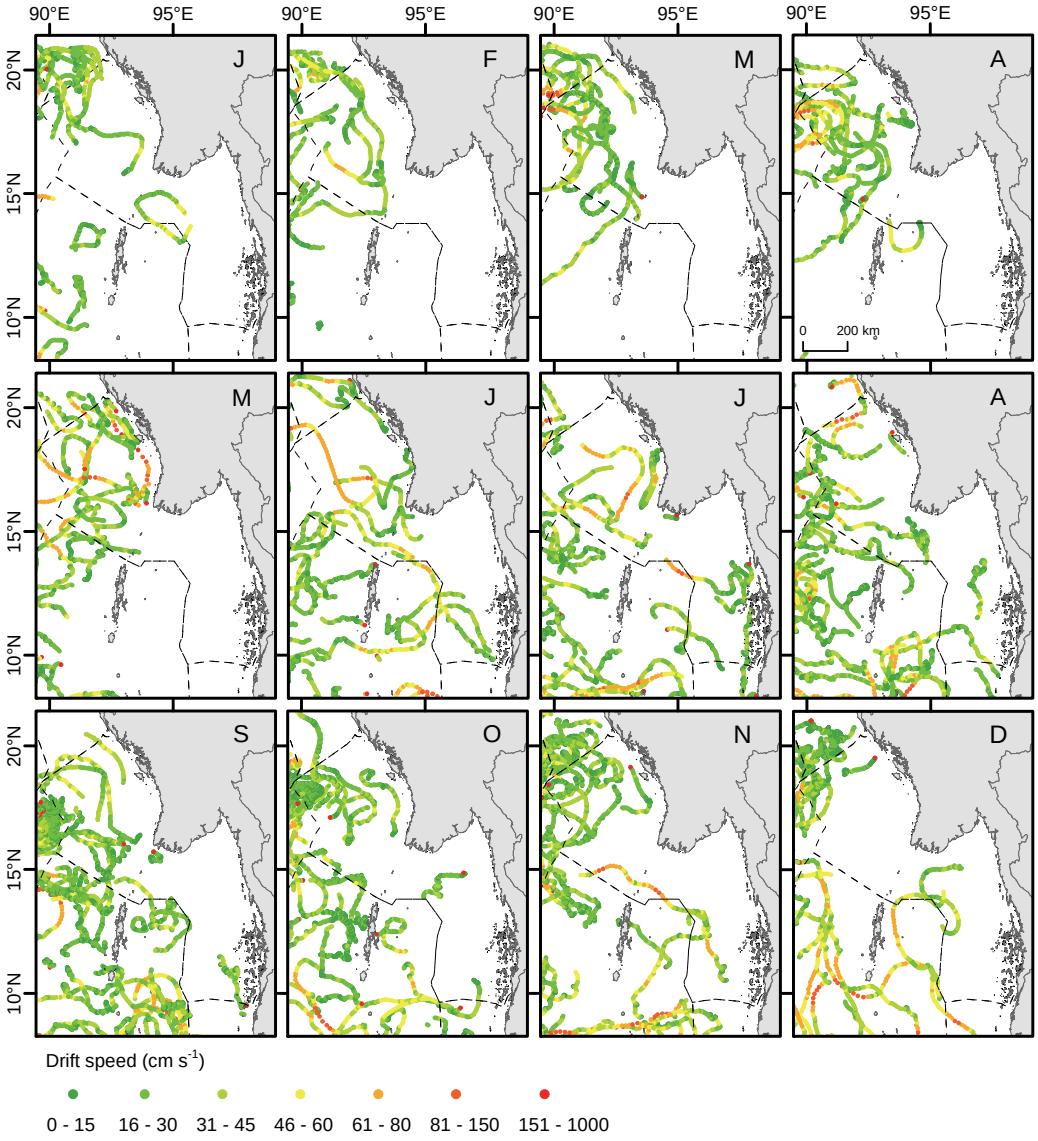

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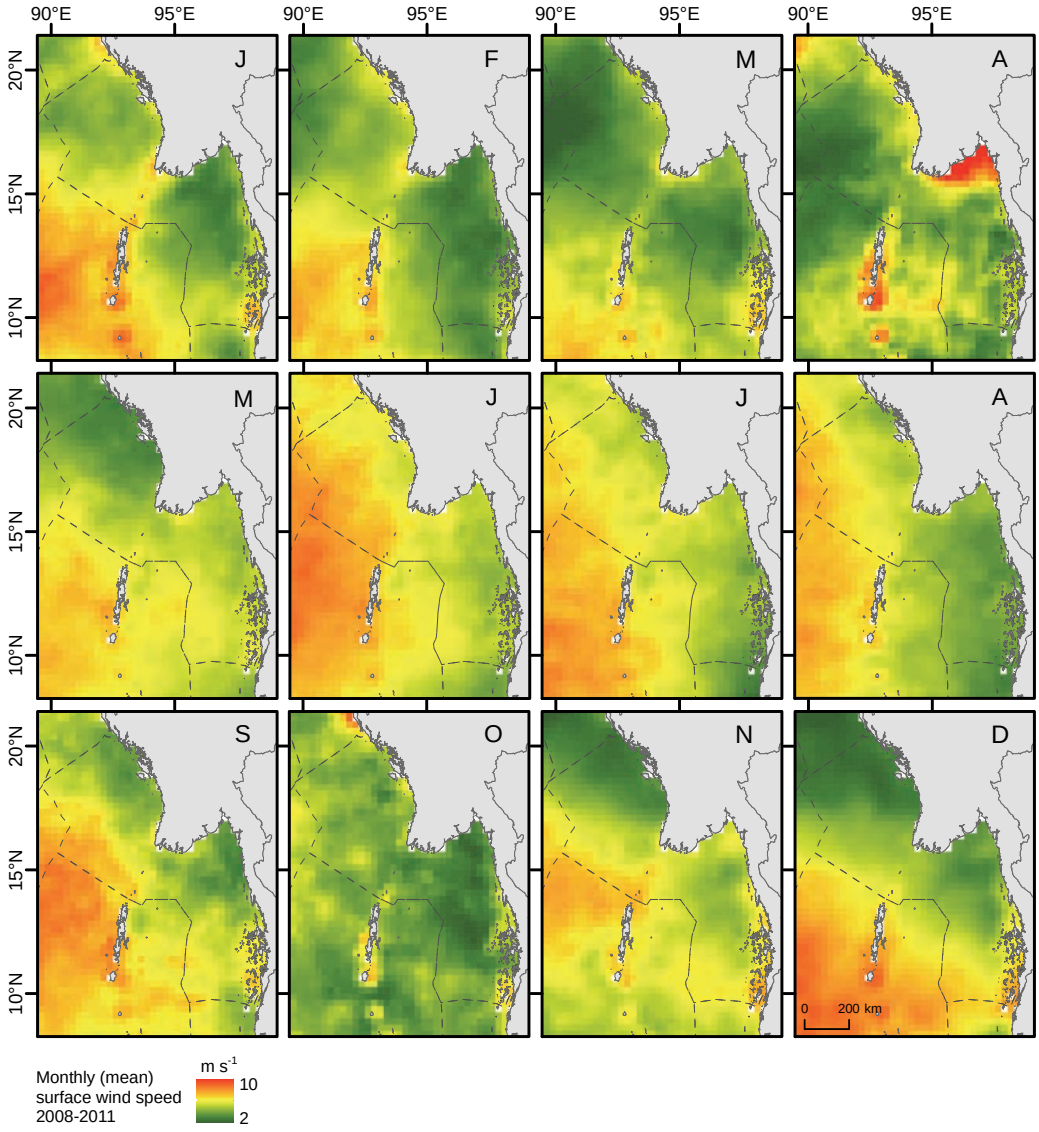

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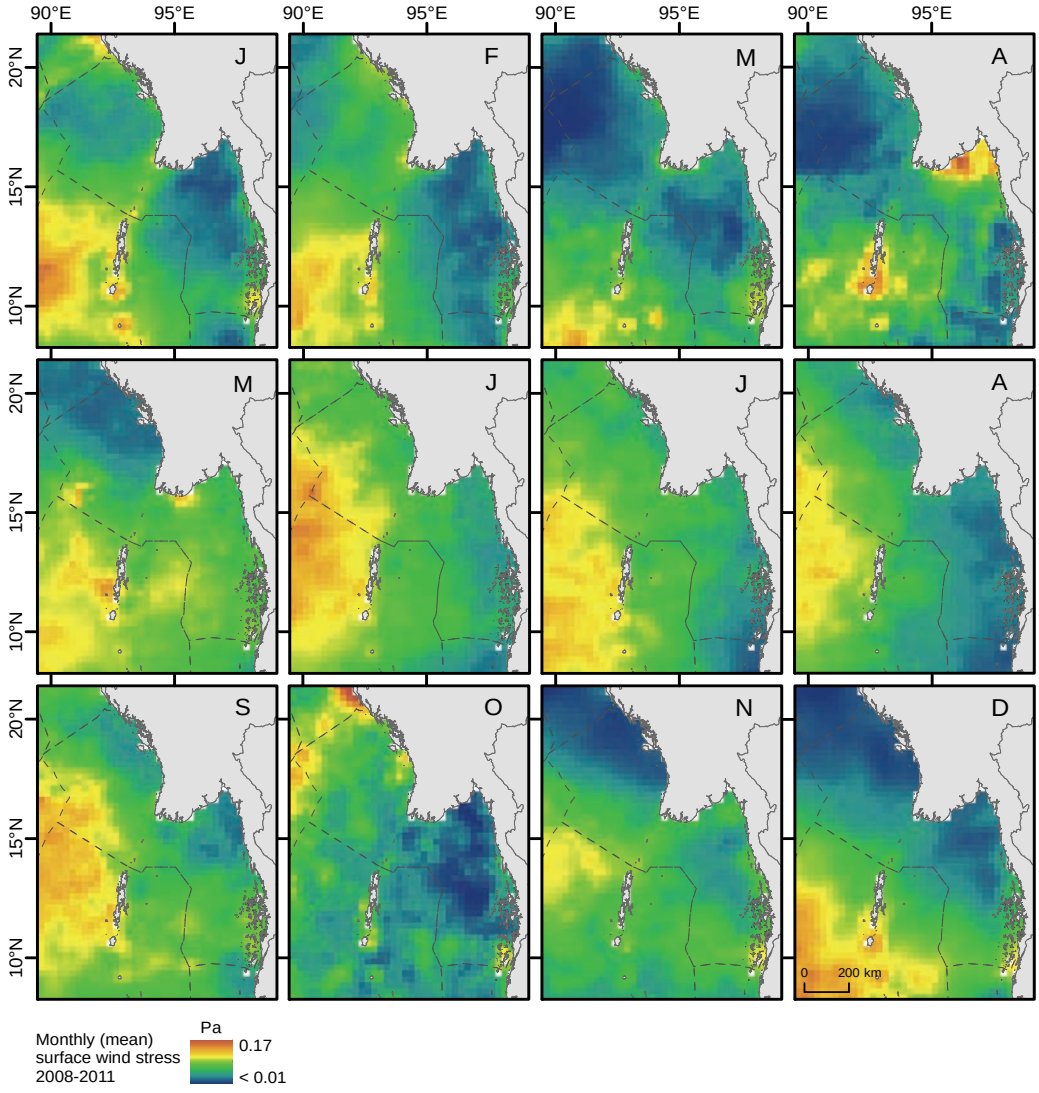

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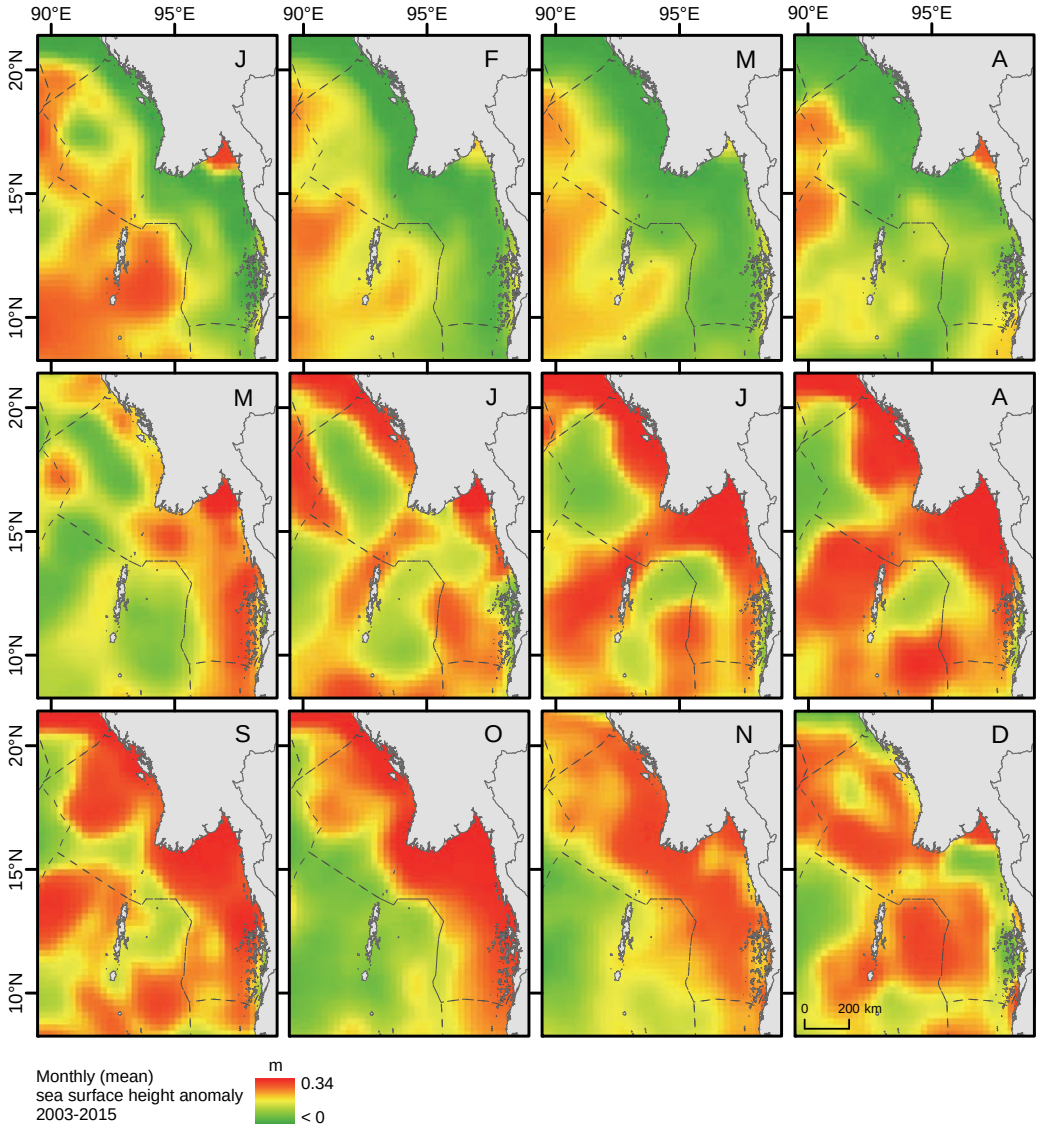

Figure 4.12. Sea surface height anomalies. Mean monthly (13 year average: 2003-2015) satellite-derived sea surface height anomalies (m). Months are ordered from January (J: upper left) to December (D: lower right). Sea surface height anomaly values are displayed using a continuous green/yellow/red colour ramp ranging from minimum (green) to maximum (red) sea surface height. Sea surface height is the height of the ocean's surface relative to a known reference surface. In all parts EEZ (broken line). Cell size 0.25 x 0.25 degree – approx. 27.8 x 27.8 km.

5. MARINE AND COASTAL HABITATS

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This section details the distribution of important areas of marine biodiversity and habitats, including mangroves, coral reefs and seagrass within Myanmar's maritime limits. These can help direct and inform fisheries management and biodiversity conservation. Map parts of each figure are drawn to the same spatial scale unless otherwise stated. Maps are drawn to Projected Coordinate System: Asia North Albers Equal Area Conic (ANAEC) unless otherwise stated.

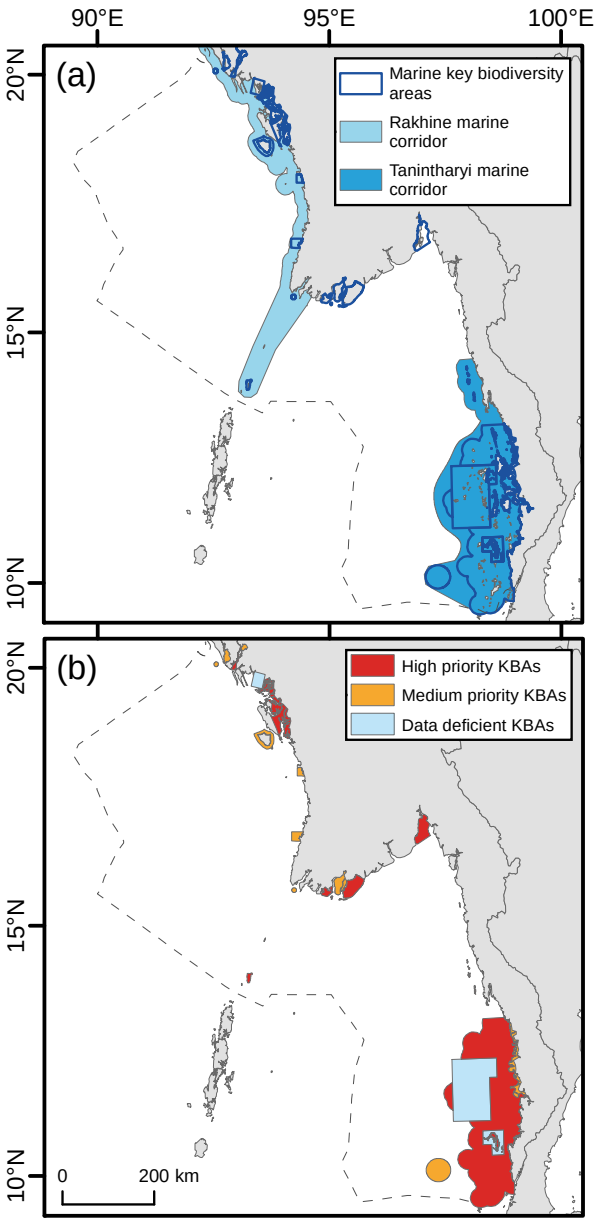


Figure 5.1. Marine key biodiversity areas and corridors. (a) Marine Key Biodiversity Areas (KBAs, empty dark blue polygon) and corridors (filled blue polygons). Corridors are the Rakhine marine biodiversity corridor (pale blue filled polygon) and Tanintharyi marine biodiversity corridor (mid blue filled polygon). (b) Marine KBAs classified according to high priority level (red polygon), medium priority level (orange polygon) and data deficient priority level (blue polygon). In all parts EEZ (broken line). In January 2012, over 80 of Myanmar's environmental experts used international criteria to identify and prioritize 132 marine and terrestrial KBAs. These sites are defined as areas holding significant populations of species of high conservation concern. Marine KBAs are grouped together within two marine biodiversity corridors. These corridors allow for conservation planning that considers connectivity and resource impacts beyond the borders of nationally designated protected areas (WCS, 2013).

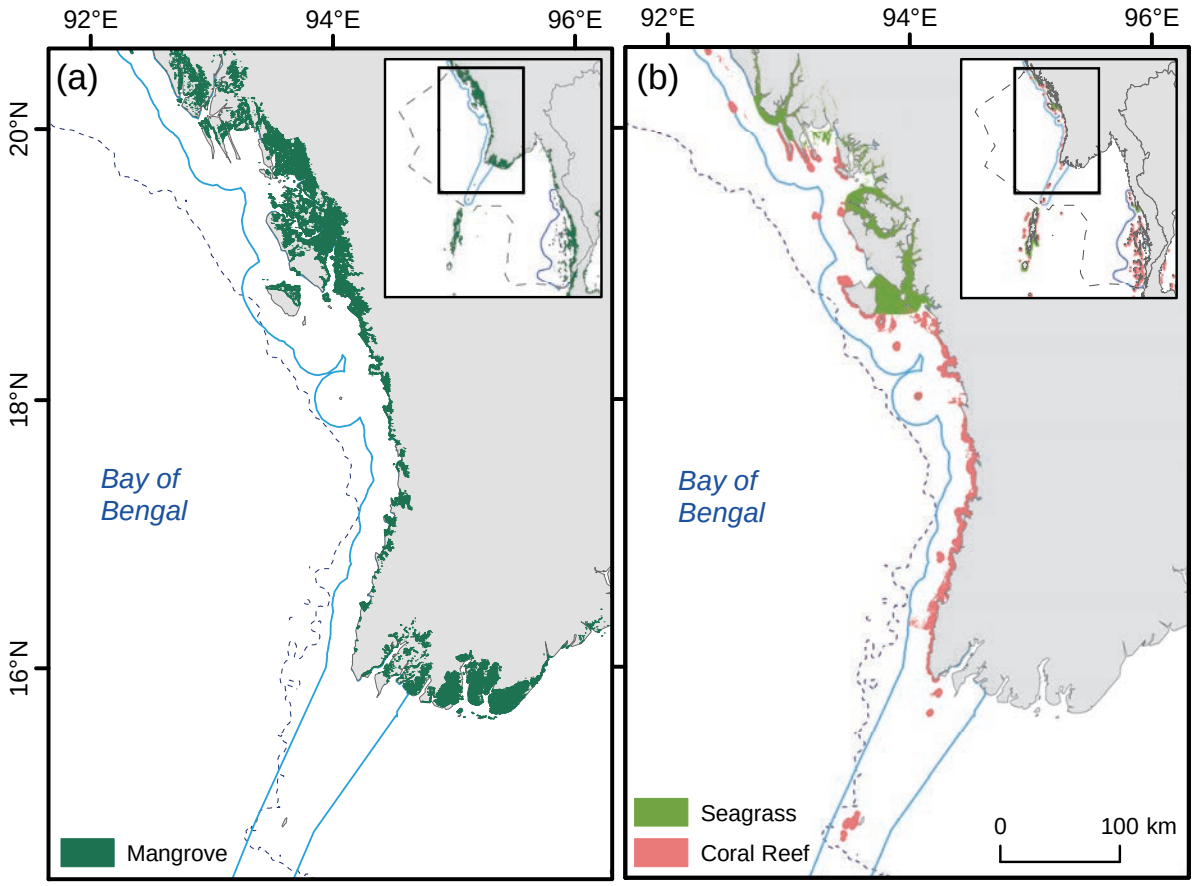


Figure 5.2. Marine and coastal habitats within the Rakhine marine biodiversity corridor. (a) Distribution of mangroves (dark green polygon), (b) coral reefs (pink polygon) and seagrass (pale green polygon), within the Rakhine marine biodiversity corridor (empty blue polygon). Parts (a) and (b) continental shelf (200 m depth, dashed line). Inset maps show complete Myanmar marine habitat distribution, EEZ (broken line).

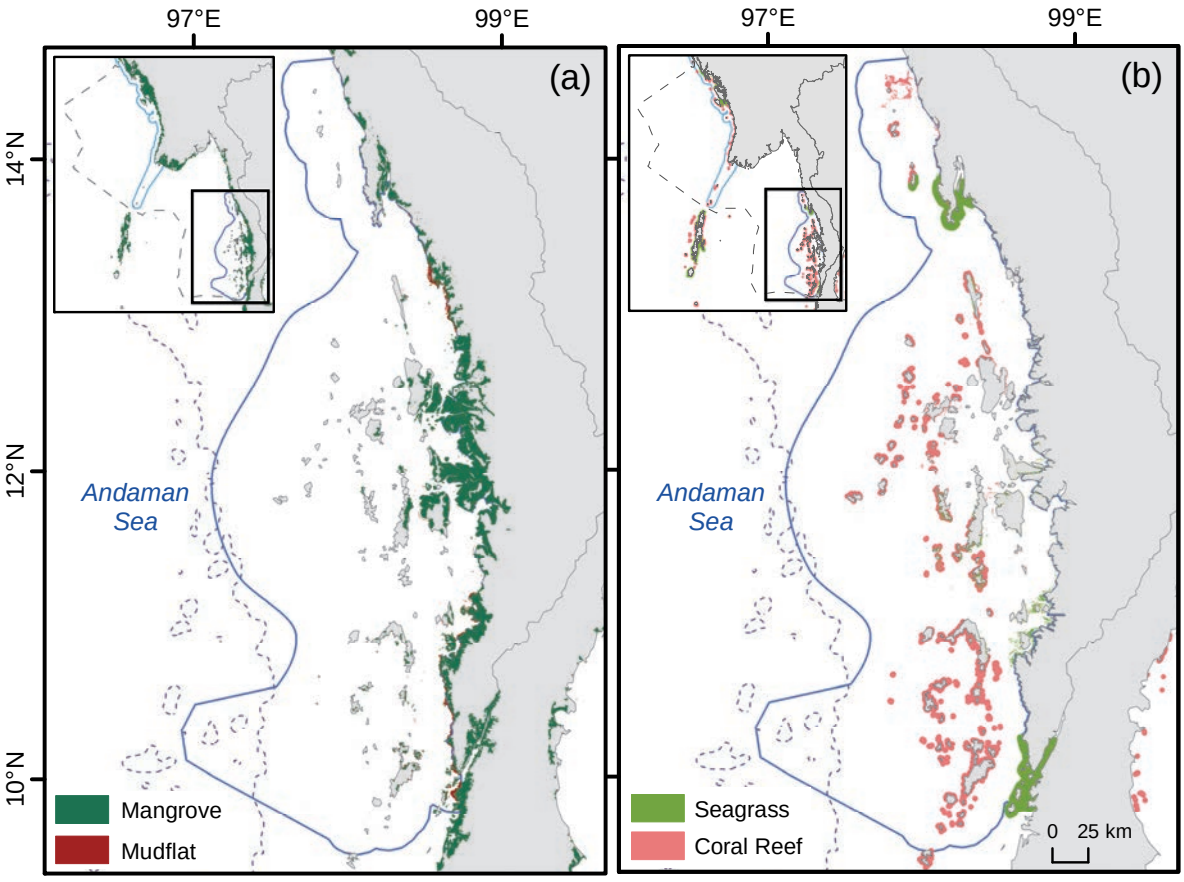
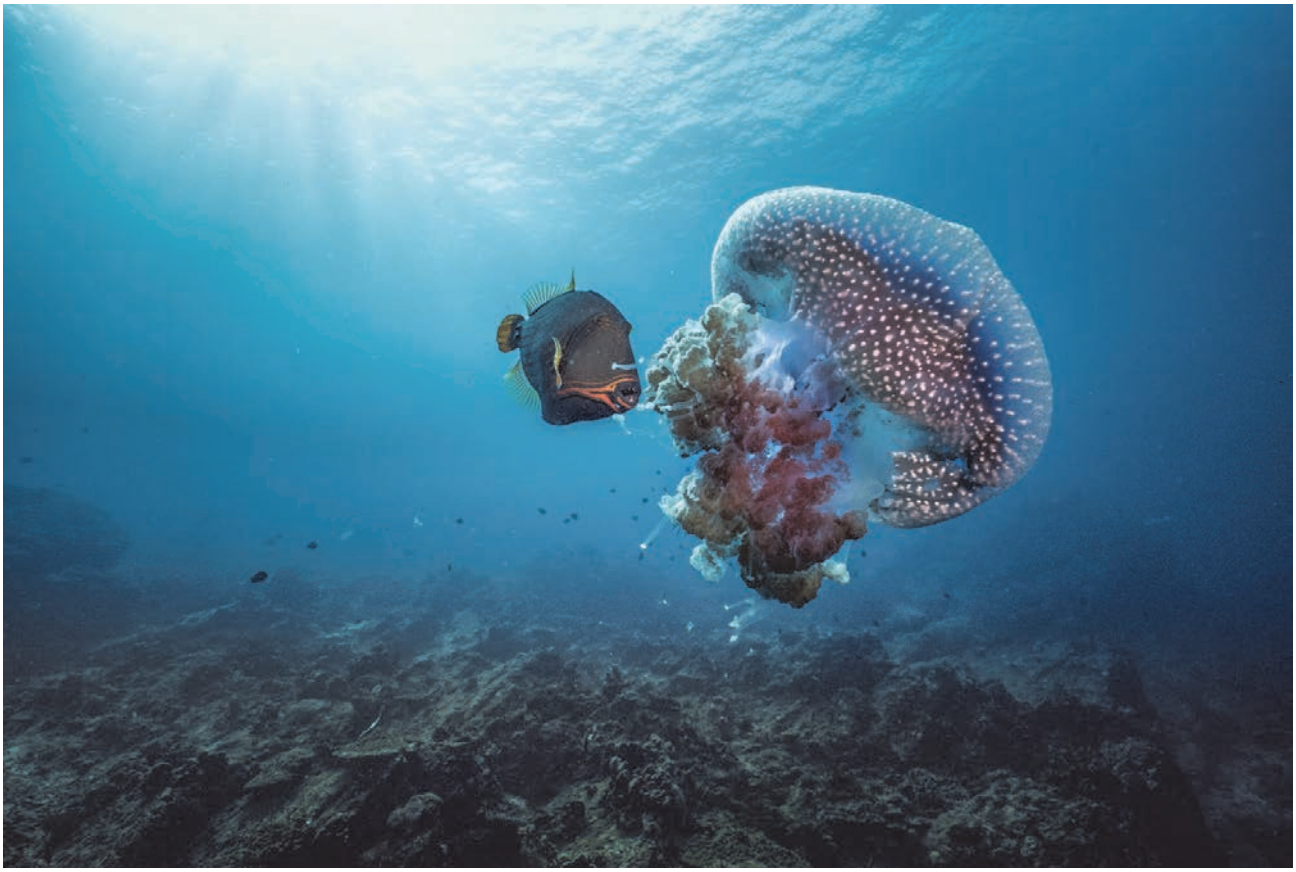


Figure 5.3. Marine and coastal habitats within the Tanintharyi marine biodiversity corridor. (a) Distribution of mangroves (dark green polygon), mudflats (brown polygon), (b) coral reefs (pink polygon) and seagrass (pale green polygon), within the Tanintharyi marine biodiversity corridor (empty blue polygon). Parts (a) and (b) continental shelf (200 m depth, dashed line). Inset maps show complete Myanmar marine habitat distribution, EEZ (broken line).

6. BIODIVERSITY



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This section details Myanmar's regional species biodiversity including a selection of marine turtles, sharks, prawns and cephalopods found within Myanmar's maritime limits, which can be used to inform fisheries management and biodiversity conservation. These were the data sources available at the time of writing. Map parts of each figure are drawn to the same spatial scale unless otherwise stated. Maps are drawn to Projected Coordinate System: Asia North Albers Equal Area Conic (ANAEC) unless otherwise stated.

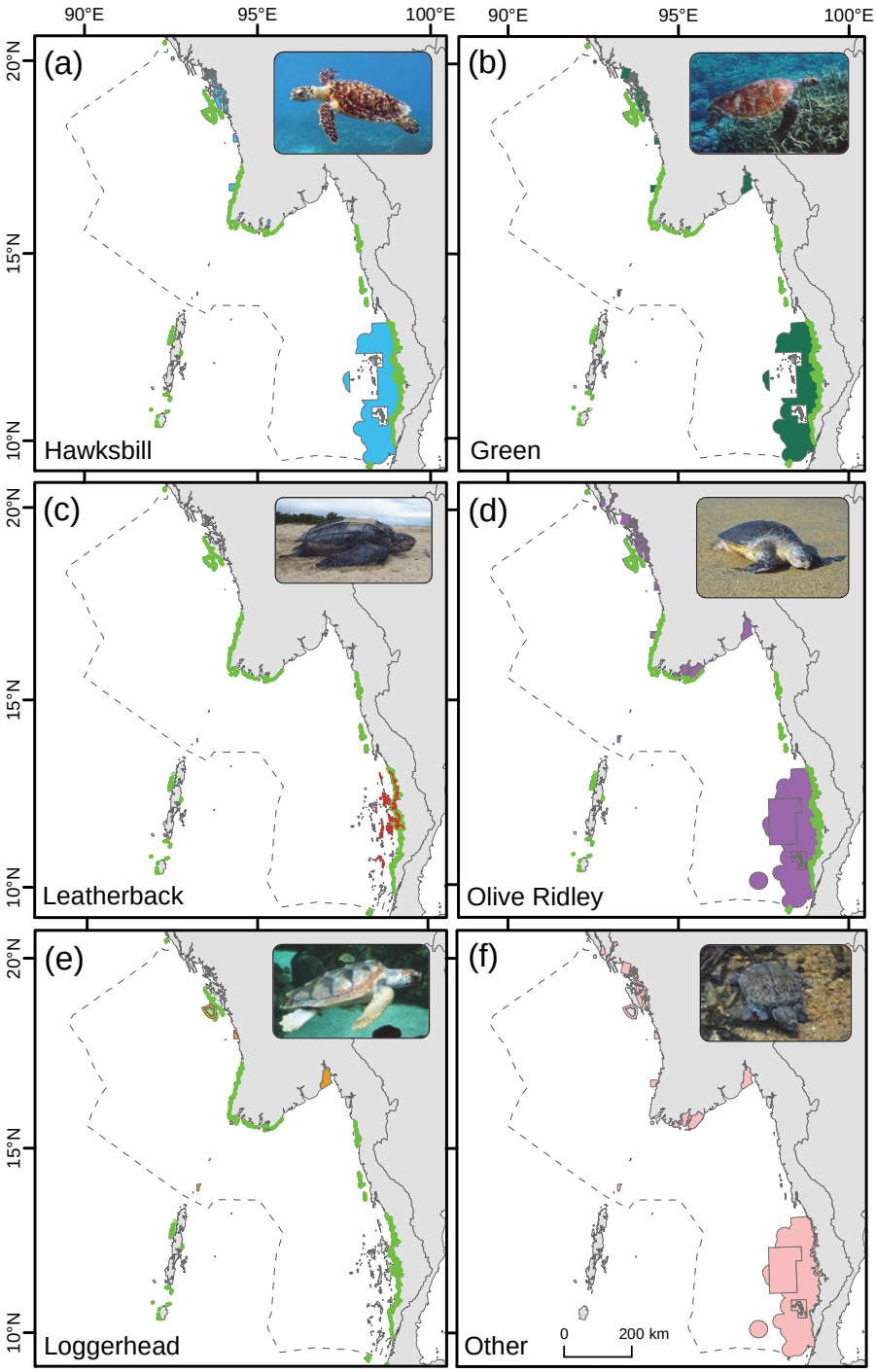

Figure 6.1. Key biodiversity areas for marine and freshwater turtle species. Key biodiversity areas supporting: (a) hawksbill turtle (*Eretmochelys imbricata*, blue polygon), (b) green turtle (*Chelonia mydas*, dark green polygon), (c) leatherback turtle (*Dermochelys coriacea*, red polygon), (d) olive ridley turtle (*Lepidochelys olivacea*, purple polygon), (e) loggerhead turtle (*Caretta caretta*, orange polygon), and (f) other freshwater turtle species (pink polygon): Asiatic softshell turtle (*Amyda cartilaginea*, pictured) and Burmese eyed turtle (*Morenia ocellata*). Parts (a-e) marine turtle nesting sites (green line) based on known locations for five species: hawksbill, green, leatherback, olive ridley and loggerhead. In all parts EEZ (broken line).

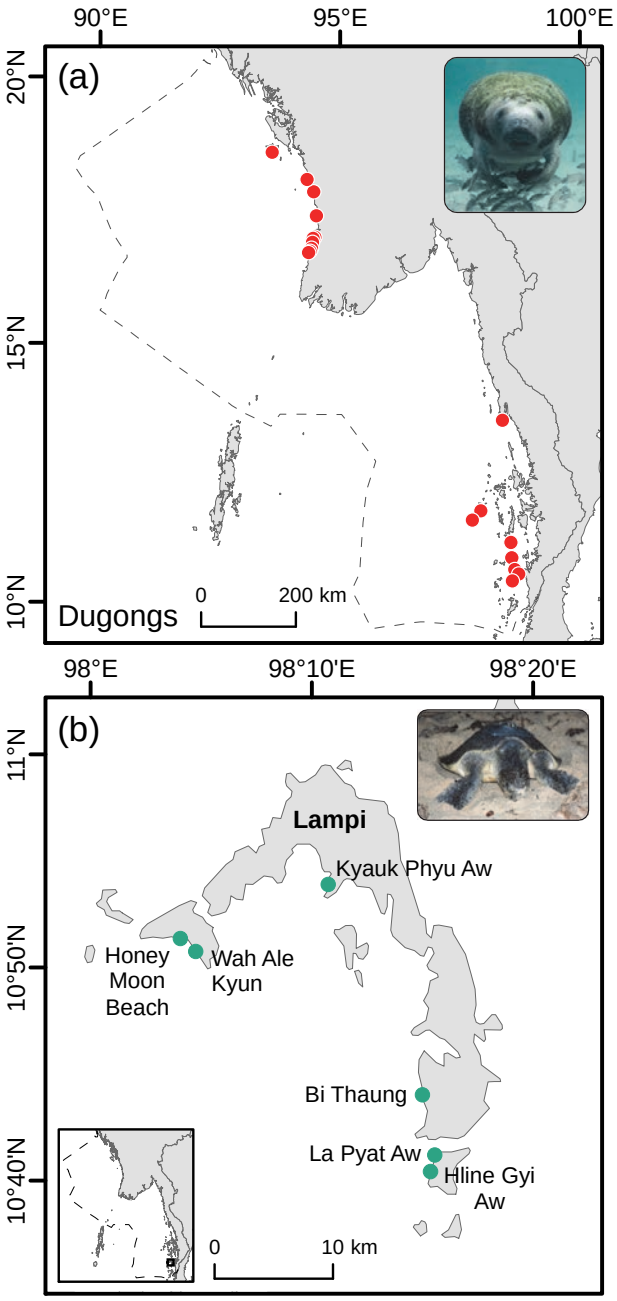

Figure 6.2. Dugong sightings and Lampi island marine turtle nesting sites. (a) Localities where dugongs (*Dugon dugon*, red circle) have been recorded along Myanmar's coastline by studies conducted between 2008-2010. EEZ (broken line). (b) Lampi Island, located in the Tanintharyi coastal region (see Fig. 2.2b for coastal region delineations) showing locations of marine turtle nesting sites (green circle, named). Parts (a) and (b) are drawn to different spatial scales.

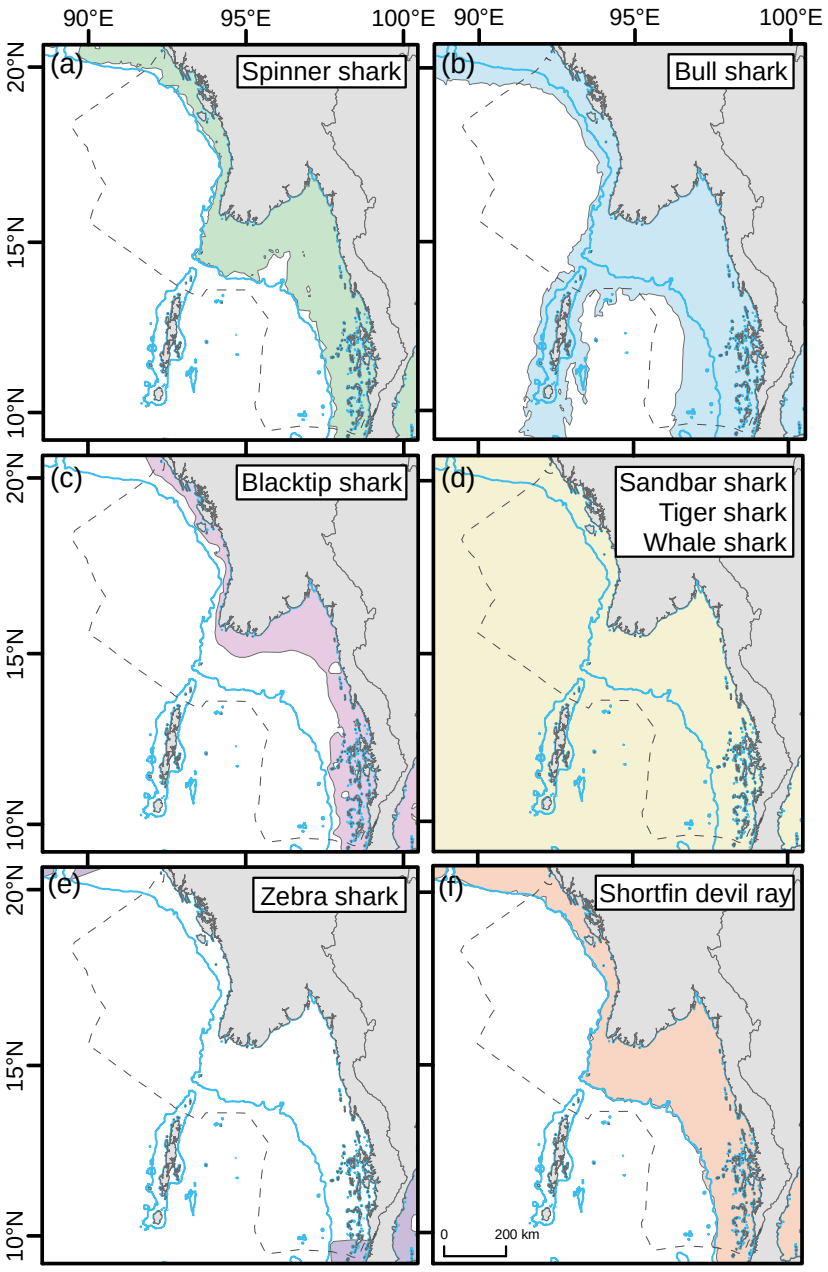

Figure. 6.3. Shark and ray species distributions. Estimated distribution of (a) spinner shark (*Carcharhinus brevipinna*, green polygon), (b) bull shark (*Carcharhinus leucas*, blue polygon), (c) blacktip shark (*Carcharhinus limbatus*, pink polygon), (d) sandbar shark (*Carcharhinus plumbeus*), tiger shark (*Galeocerdo cuvier*), whale shark (*Rhincodon typus*, yellow polygon) grouped because spp. show same distribution, (e) zebra shark (*Stegostoma fasciatum*, purple polygon), (f) shortfin devil ray (*Mobula kuhlii*, orange polygon). Species distributions estimated based on their respective depth ranges. In all parts continental shelf (200 m depth, blue line) and EEZ (broken line).

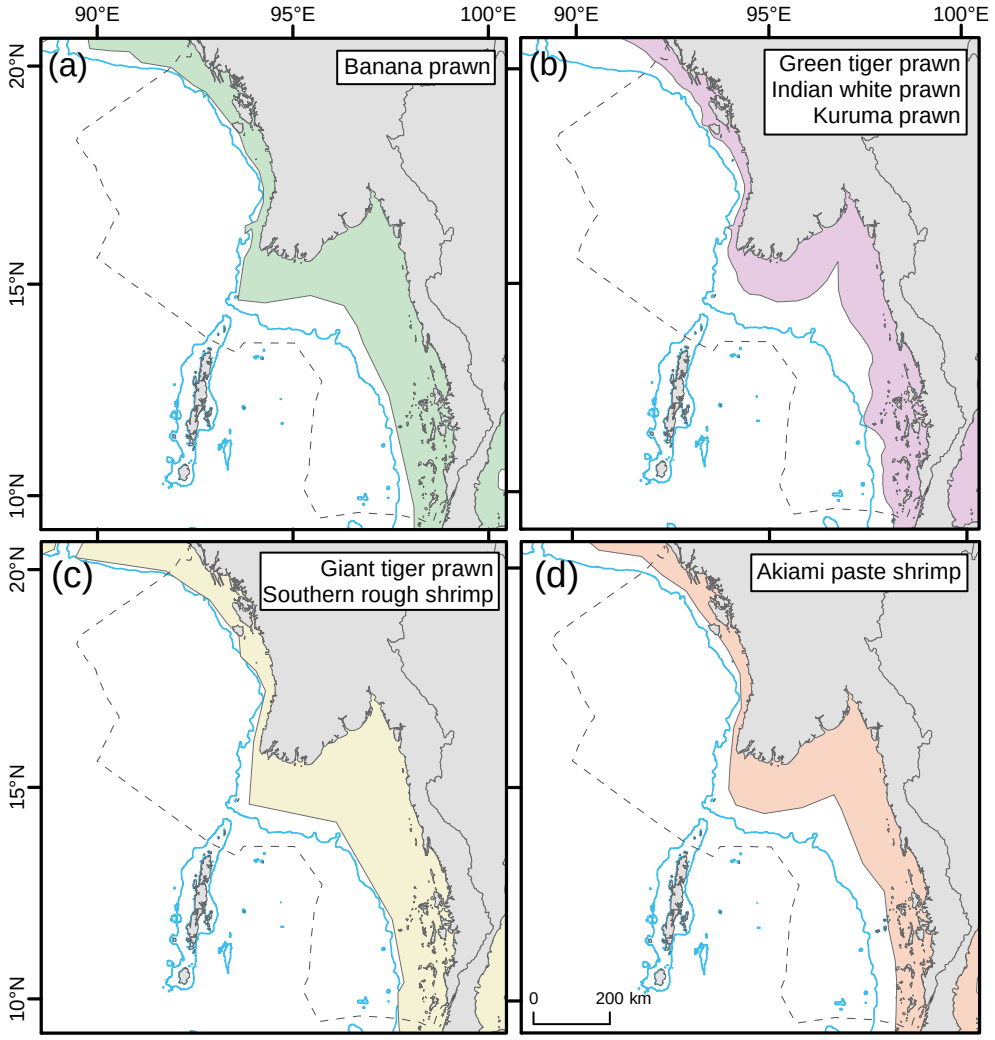

Figure. 6.4. Prawn and shrimp species distributions. Estimated distribution of (a) banana prawn (*Penaeus merguiensis*, green polygon), (b) green tiger prawn (*Penaeus semisulcatus*), Indian white prawn (*Penaeus indicus*), kuruma prawn (*Penaeus japonicas*, pink polygon) grouped because spp. show same distribution, (c) giant tiger prawn (*Penaeus monodon*), southern rough shrimp (*Trachypenaeus curvirostris*, yellow polygon) grouped because spp. show same distribution, (d) akiami paste shrimp (*Acetes japonicas*; orange polygon). Species distributions estimated based on their respective depth ranges. In all parts continental shelf (200 m depth, blue line) and EEZ (broken line).

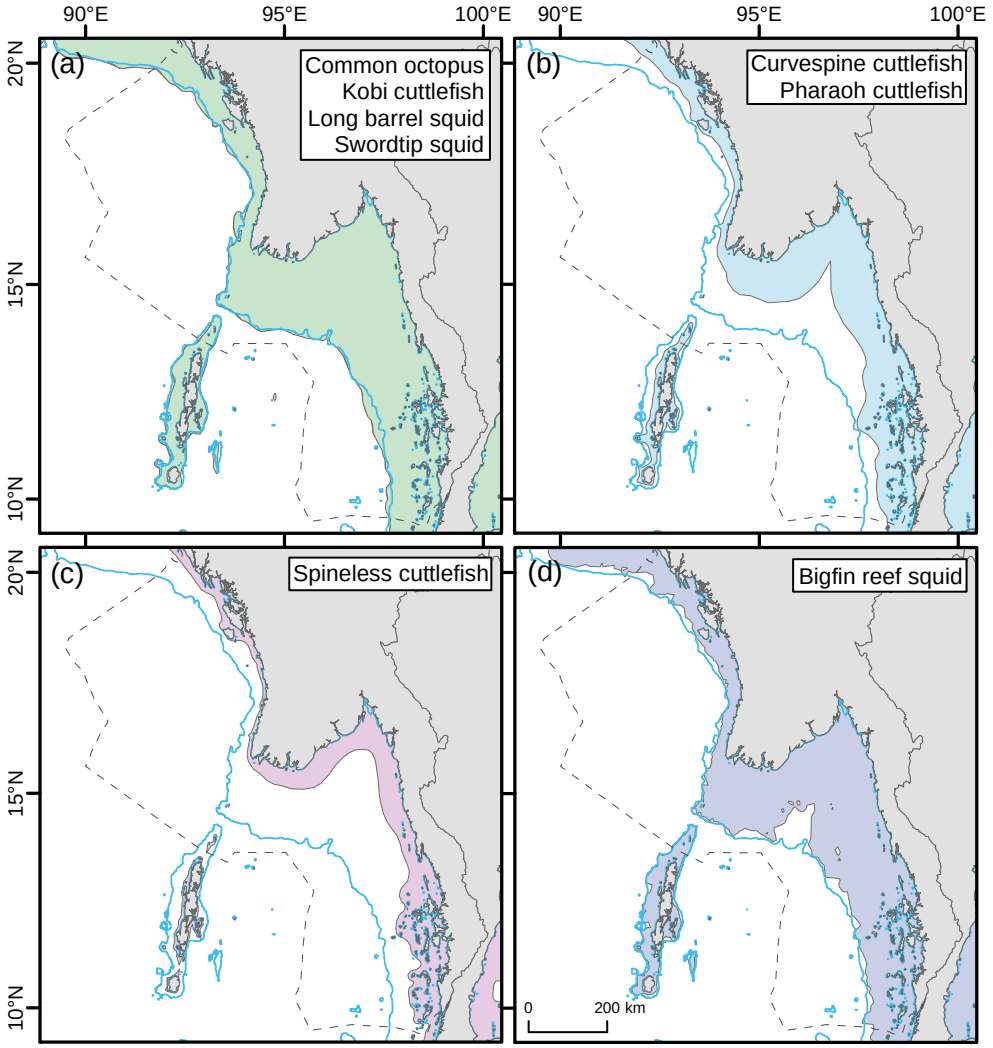

Figure. 6.5. Cephalopod species distributions. Estimated distribution of (a) common octopus (*Octopus vulgaris*), kobi cuttlefish (*Sepia kobiensis*), long barrel squid (*Uroteuthis singhalensis*), swordtip squid (*Loligo edulis*, green polygon) grouped because spp. show same distribution, (b) curvespine cuttlefish (*Sepia recurvirostra*), pharaoh cuttlefish (*Sepia pharaonis*, blue polygon) grouped because spp. show same distribution, (c) spineless cuttlefish (*Sepiella inermis*, pink polygon), (d) bigfin reef squid (*Sepioteuthis lessoniana*, purple polygon). Species distributions estimated based on their respective depth ranges. In all parts continental shelf (200 m depth, blue line) and EEZ (broken line).

7. FISHERIES SURVEYS

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This section details marine ecosystem surveys conducted within Myanmar's maritime limits by the Institute of Marine Research, Norway in 1979, 2013 and 2015. Here we present tow data for 2013 and 2015. Acoustic data are available for all survey years, however, they require substantial analytical effort to ensure robust and accurate comparison. To our knowledge, this is the first time these data have been presented spatially to highlight patterns in species biomass and biodiversity, which can be used to improve fisheries management and biodiversity conservation. Map parts of each figure are drawn to the same spatial scale unless otherwise stated. Maps are drawn to Projected Coordinate System: Asia North Albers Equal Area Conic (ANAEC) unless otherwise stated.

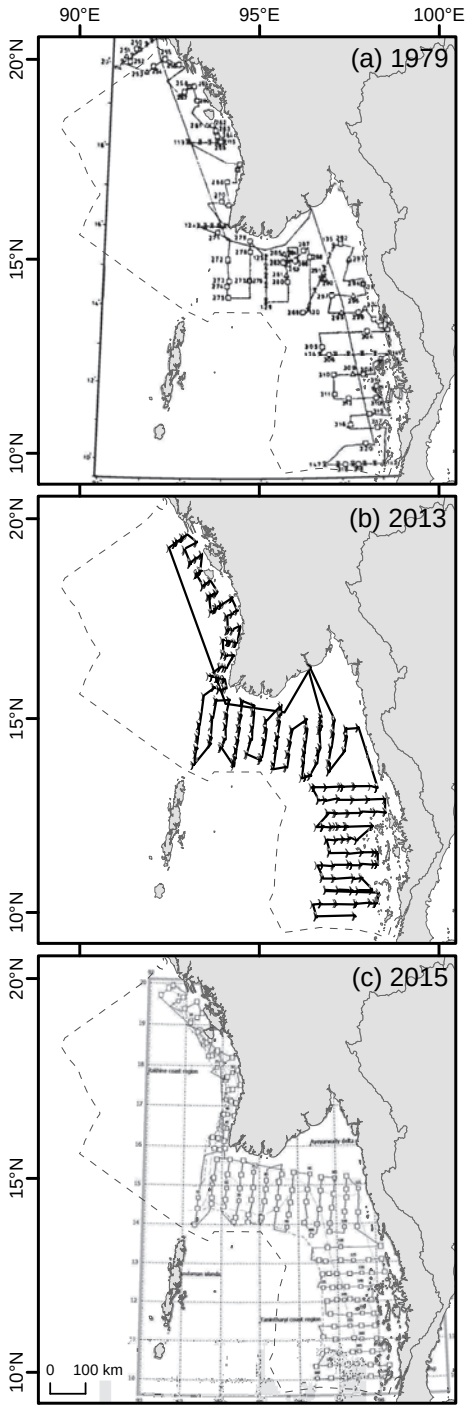

Figure 7.1. Myanmar marine ecosystem surveys: vessel course tracks (1979, 2013, 2015). The course followed by survey vessels (black line) during the (a) 1979, (b) 2013 and (c) 2015 Nansen marine ecosystem surveys conducted by the Institute of Marine Research, Norway. In all parts, sampling stations (white square) and EEZ (broken line).

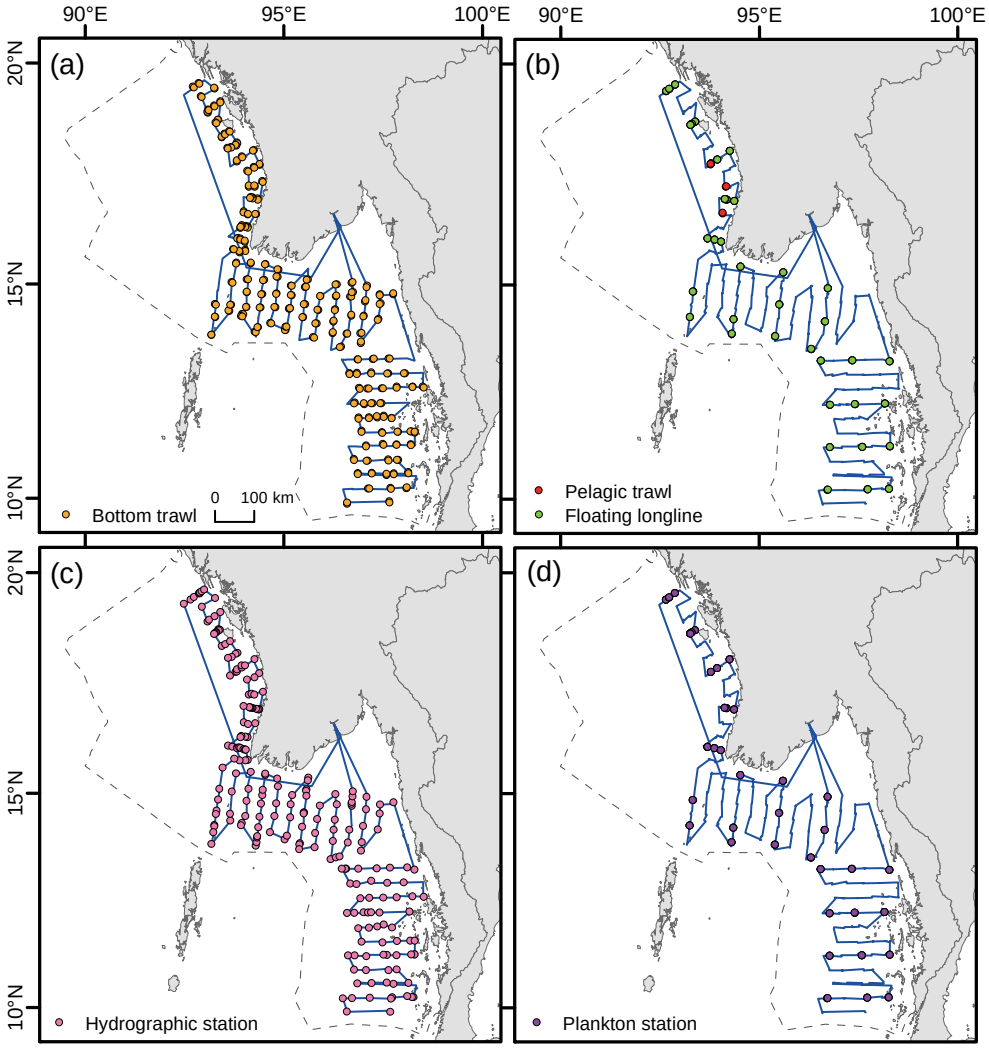

Figure 7.2. Myanmar marine ecosystem surveys: sampling stations (2013). Survey vessel course tracks (blue line) followed during the 2013 Nansen marine ecosystem survey, conducted by the Institute of Marine Research, Norway, between 13/11/2013 and 17/12/2013. The locations at which (a) bottom trawl (orange circle), (b) pelagic trawl (red circle) and floating longline (green circle) gear types were deployed, and the locations of (c) hydrographic stations (pink circle) and (d) plankton stations (purple circle). In all parts EEZ (broken line).

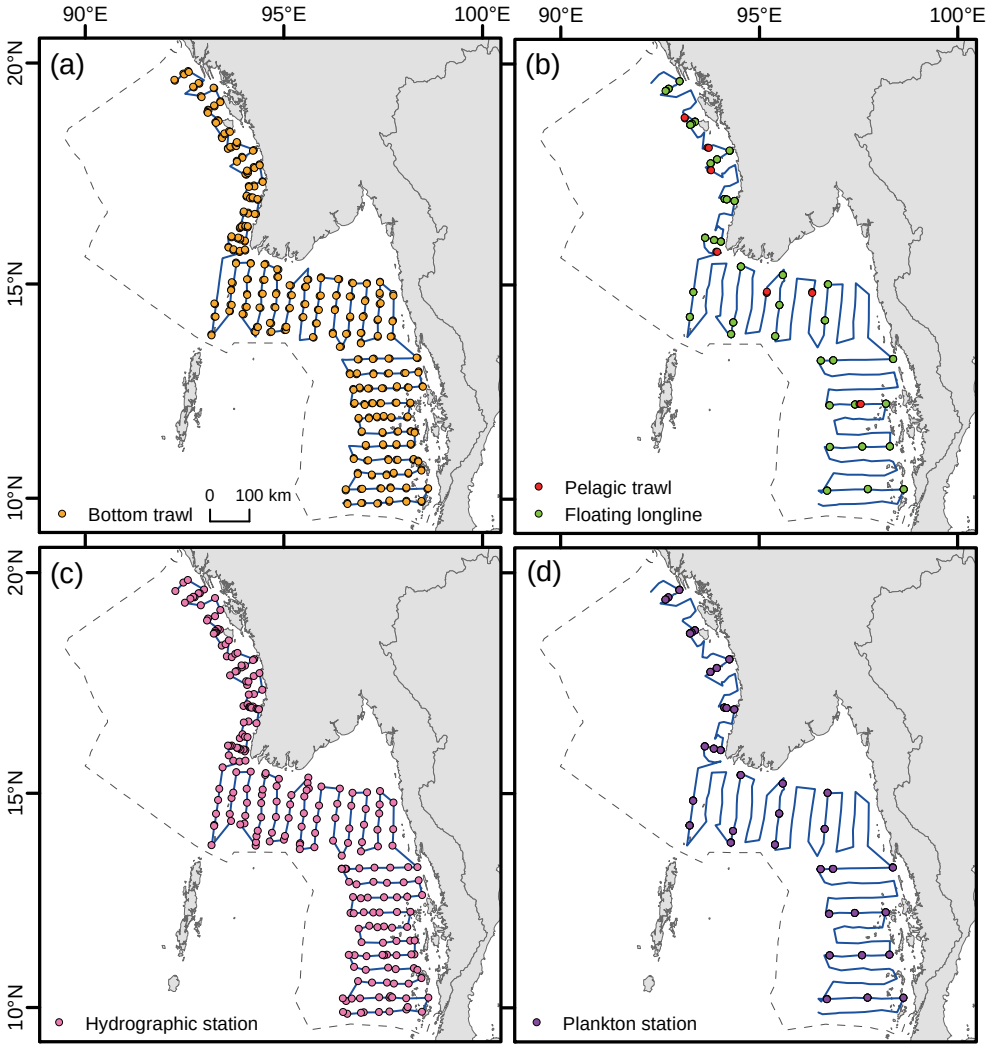

Figure 7.3. Myanmar marine ecosystem surveys: sampling stations (2015). Survey vessel course tracks (blue line) followed during the 2015 Nansen marine ecosystem survey, conducted by the Institute of Marine Research, Norway, between 28/04/2015 and 02/06/2015. The locations at which (a) bottom trawl (orange circle), (b) pelagic trawl (red circle) and floating longline (green circle) gear types were deployed, and the locations of (c) hydrographic stations (pink circle) and (d) plankton stations (purple circle). In all parts EEZ (broken line).

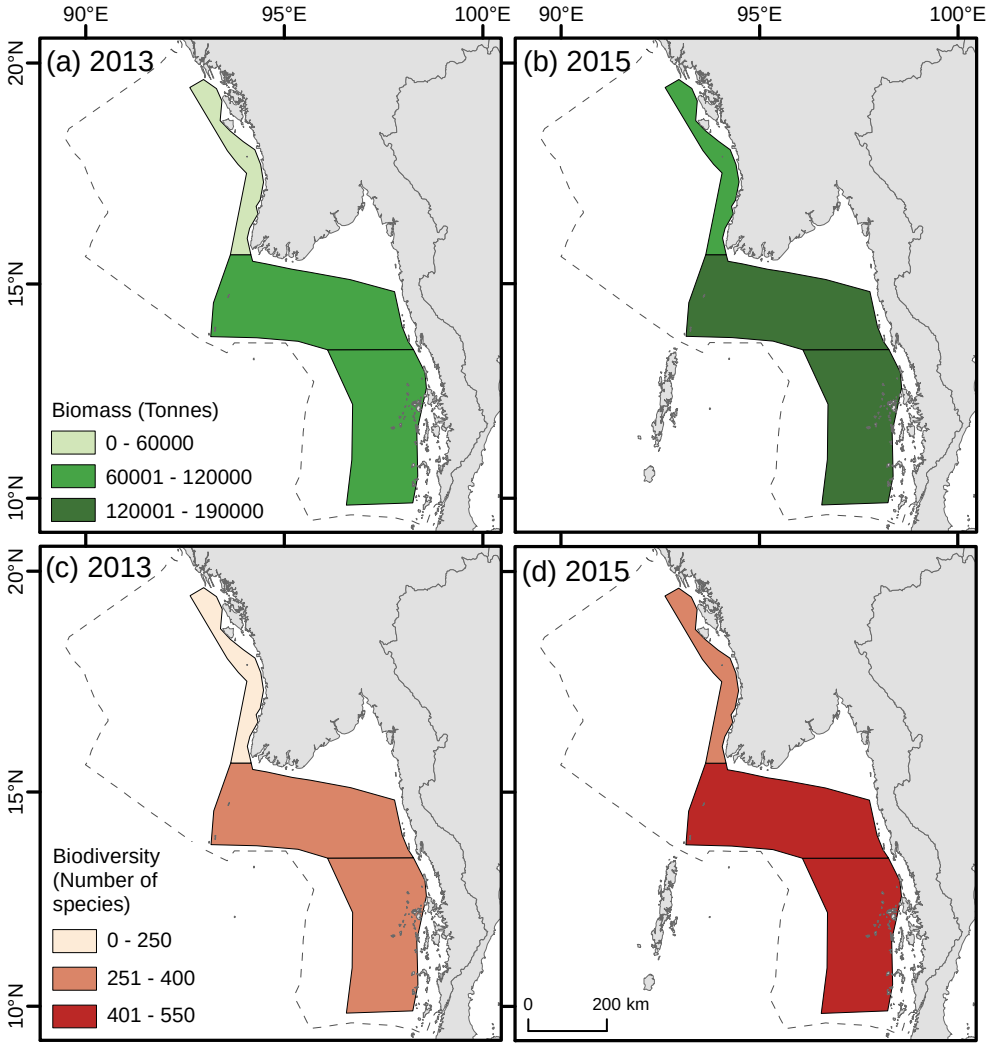

Figure 7.4. Myanmar marine ecosystem surveys: total species biomass and biodiversity estimates (2013, 2015). Species biomass estimates (tonnes; parts a, b) and biodiversity estimates (number of different species entities caught by bottom trawl in each depth stratum; parts c, d) totalled across four depth ranges (20-50 m, 50-100 m, 100-200 m, 200-500 m) for the three coastal regions (northern Rakhine region, central Ayeyarwady Delta region and southern Tanintharyi region - see Fig. 2.2b for coastal region delineations) during the (a, c) 2013 and (b, d) 2015 Nansen marine ecosystem surveys, conducted by the Institute of Marine Research, Norway. Biomass is displayed as a classified pale green to dark green colour ramp and biodiversity as a classified pale red to dark red colour ramp. In all parts EEZ (broken line).

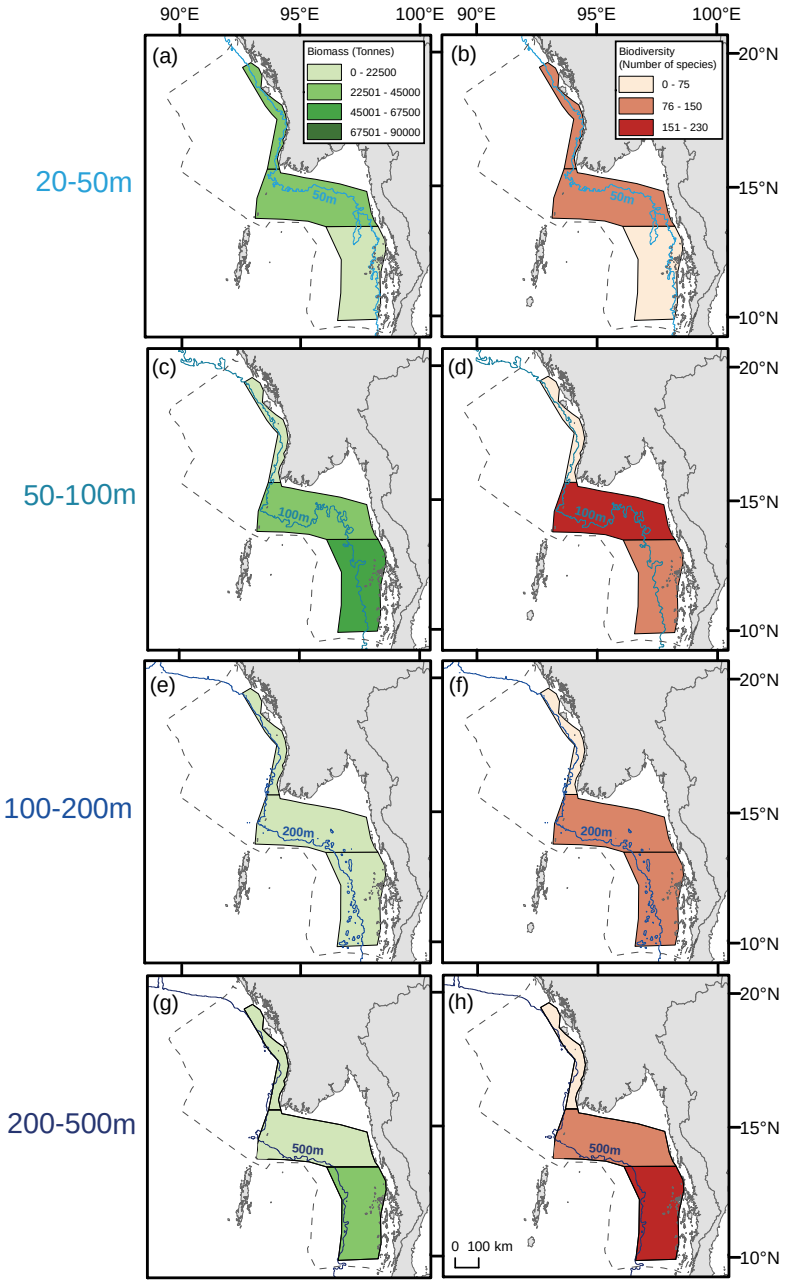

Figure 7.5. Myanmar marine ecosystem surveys: species biomass and biodiversity estimates (2013). Species biomass estimates (tonnes; parts a, c, e, g) and biodiversity estimates (number of different species entities caught by bottom trawl in each depth stratum; parts b, d, f, h) across four depth ranges (20-50 m, 50-100 m, 100-200 m, 200-500 m) for the three coastal regions (northern Rakhine region, central Ayeyarwady Delta region and southern Tanintharyi region - see Fig. 2.2b for coastal region delineations) during the 2013 Nansen marine ecosystem survey, conducted by the Institute of Marine Research, Norway. Biomass is displayed as a classified pale green to dark green colour ramp and biodiversity as a classified pale red to dark red colour ramp. In all parts depth contours (labelled blue lines) and EEZ (broken line).

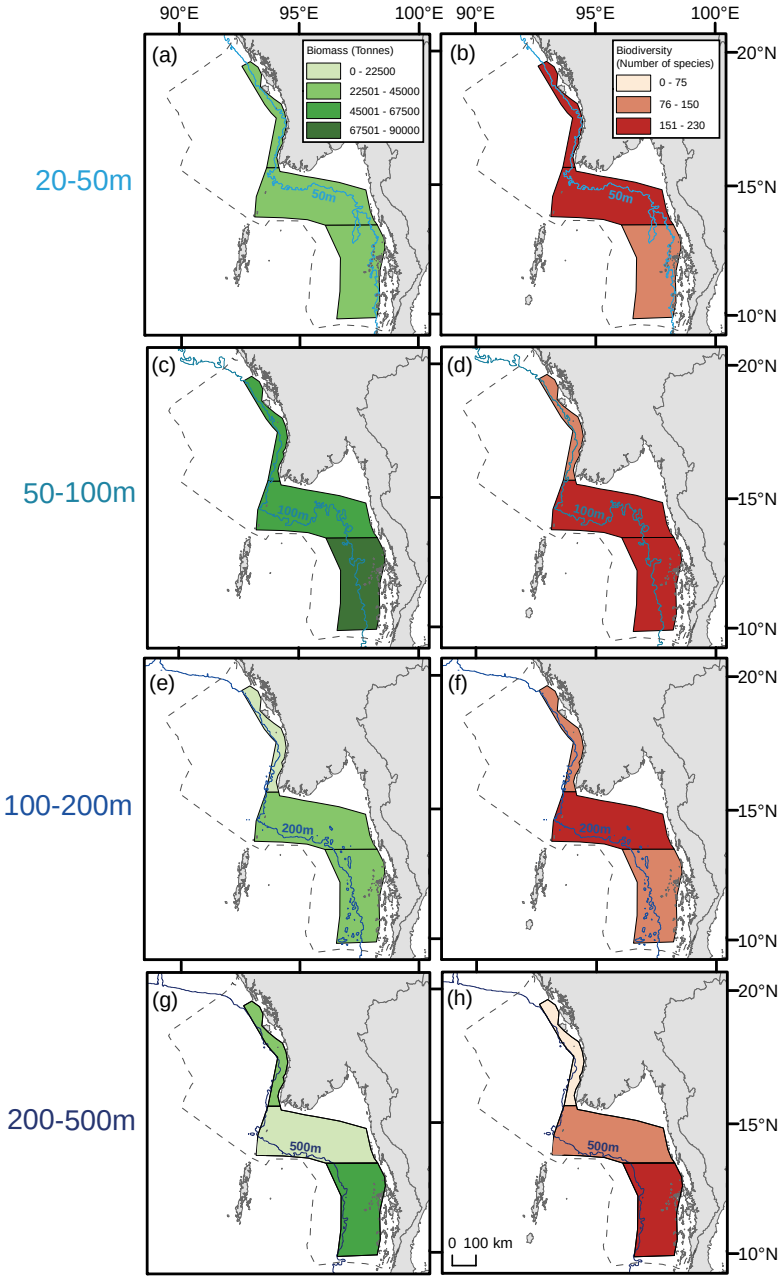

Figure 7.6. Myanmar marine ecosystem surveys: species biomass and biodiversity estimates (2015). Species biomass estimates (tonnes; parts a, c, e, g) and biodiversity estimates (number of different species entities caught by bottom trawl in each depth stratum; parts b, d, f, h) across four depth ranges (20-50 m, 50-100 m, 100-200 m, 200-500 m) for the three coastal regions (northern Rakhine region, central Ayeyarwady Delta region and southern Tanintharyi region - see Fig. 2.2b for coastal region delineations) during the 2015 Nansen marine ecosystem survey, conducted by the Institute of Marine Research, Norway. Biomass is displayed as a classified pale green to dark green colour ramp and biodiversity as a classified pale red to dark red colour ramp. In all parts depth contours (labelled blue lines) and EEZ (broken line).

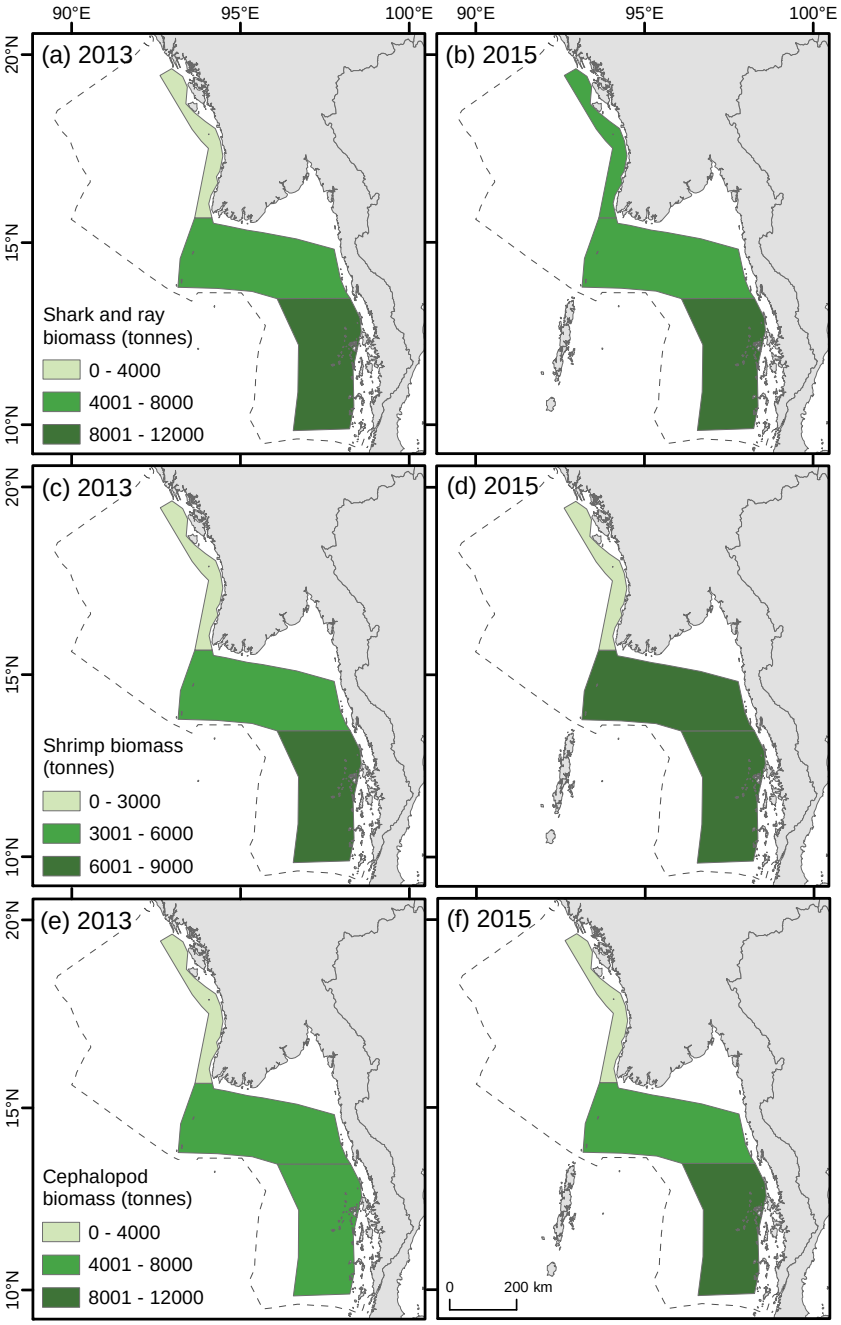

Figure 7.7. Myanmar marine ecosystem surveys: shark, ray, shrimp and cephalopod biomass (2013, 2015). Species biomass estimates (tonnes) of (a, b) sharks and rays, (c, d) shrimp, and (e, f) cephalopods totalled across four depth ranges (20-50 m, 50-100 m, 100-200 m, 200-500 m) for the three coastal regions (northern Rakhine region, central Ayeyarwady Delta region and southern Tanintharyi region - see Fig. 2.2b for coastal region delineations) during the (a, c, e) 2013 and (b, d, f) 2015 Nansen marine ecosystem surveys, conducted by the Institute of Marine Research, Norway. Biomass is displayed as a classified pale green to dark green colour ramp. In all parts EEZ (broken line).

8. FISHERIES SECTOR

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This section details the fisheries sector currently operating in Myanmar's exclusive economic zone, from small-scale artisanal inshore fisheries to industrial offshore fisheries. Fisheries productivity, activity and aquaculture ponds are also presented, which can be used to improve fisheries enforcement, management and biodiversity conservation. Map parts of each figure are drawn to the same spatial scale unless otherwise stated. Maps are drawn to Projected Coordinate System: Asia North Albers Equal Area Conic (ANAEC) unless otherwise stated.

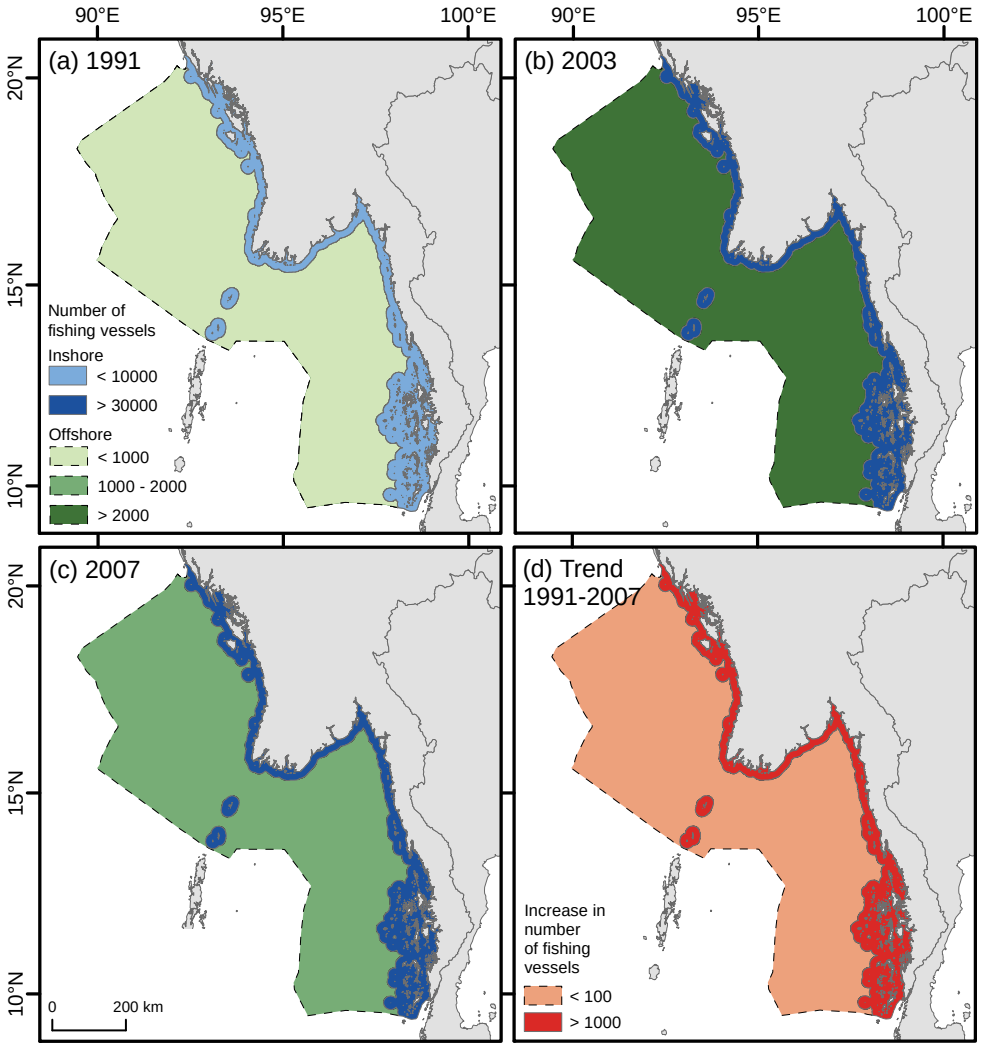

Figure 8.1. Number of registered fishing vessels. Number of registered fishing vessels of inshore fisheries displayed as a classified pale blue to dark blue colour ramp, and offshore fisheries displayed as a classified pale green to dark green colour ramp in (a) 1991, (b) 2003, (c) 2007. (d) Trend increase in the number of registered fishing vessels in inshore and offshore fisheries between 1991 and 2007, displayed as a classified pale red to dark red colour ramp. In all parts EEZ (broken line).

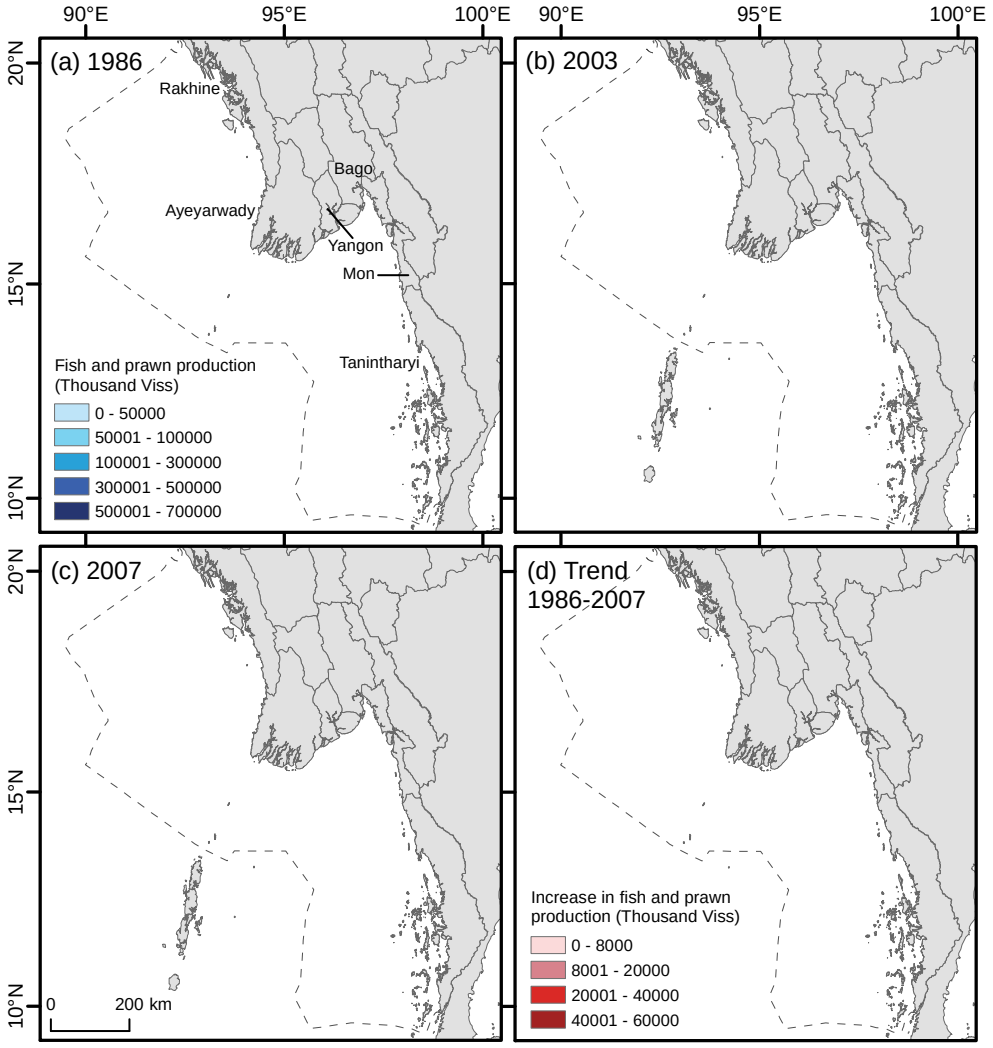

Figure 8.2. Production of fish and prawns by coastal states and divisions. Production of fish and prawns (Thousand Viss (Myanmar weight metric: 1 viss = 3.6 lbs / 1.63 kg)) by coastal states and divisions, displayed as a classified pale blue to dark blue colour ramp in (a) 1986, (b) 2003, (c) 2007. (d) Trend increase in the production of fish and prawns (Thousand Viss) by coastal states and divisions between 1986 and 2007, displayed as a classified pale red to dark red colour ramp. In all parts EEZ (broken line).

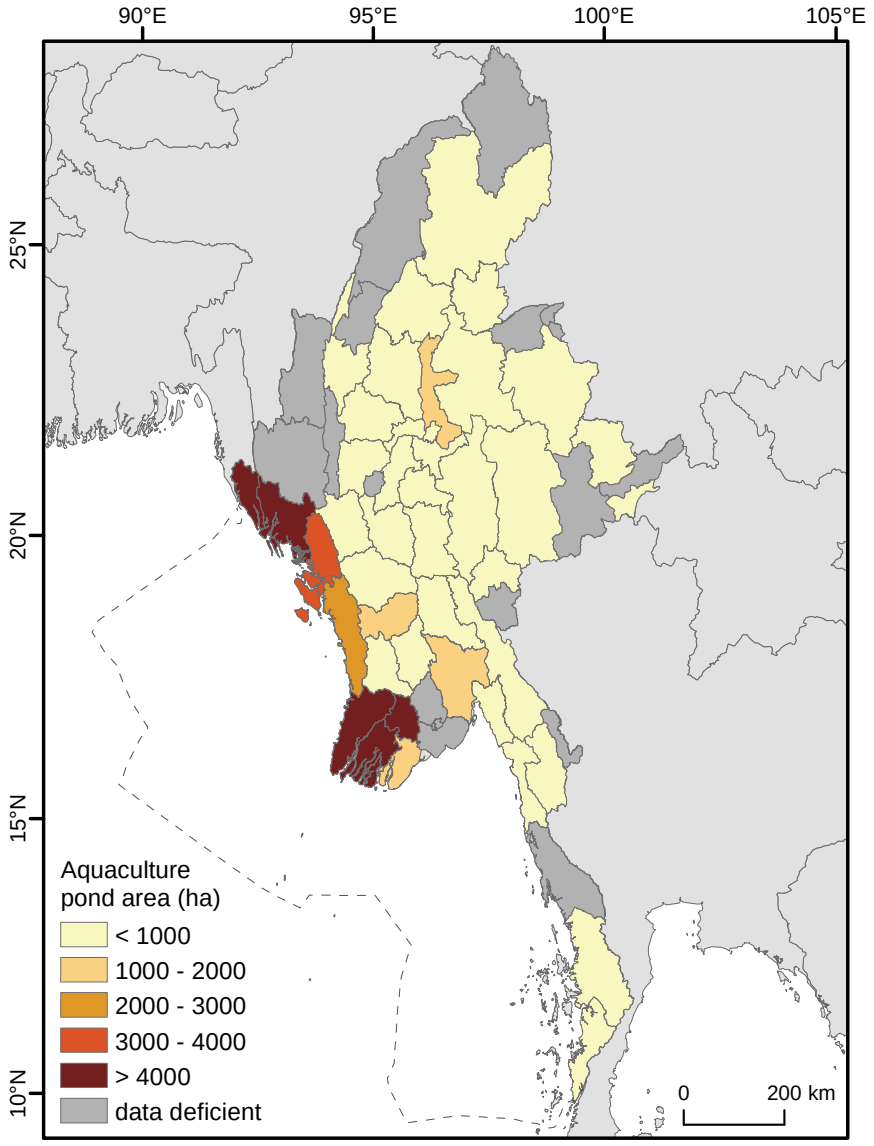

Figure. 8.3. Aquaculture ponds. Total aquaculture pond area (ha) including fish ponds and prawn ponds by state and division, displayed as a classified pale yellow to dark red colour ramp, data deficient states/divisions (grey). EEZ (broken line).

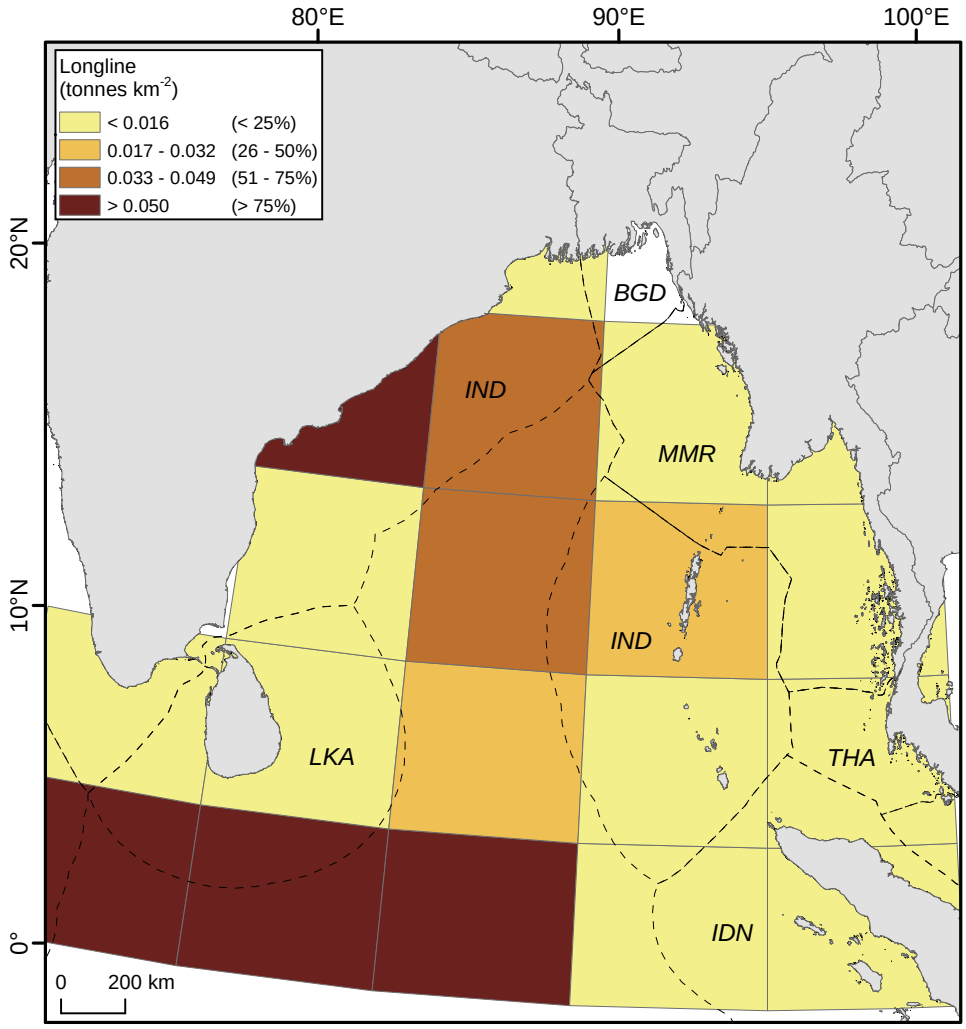

Figure 8.4. Cumulative longline fisheries catch data (1993-2012). Cumulative longline tuna and billfish catch data expressed as tonnes km^{-2} per Food and Agriculture Organisation of the United Nations (FAO) major fishing cell (5 x 5 degree resolution). As some of these FAO cells contained landmasses data were corrected for each cell's coincident sea area. Catch data are drawn as filled polygons using a yellow/dark brown classification. In all parts EEZs (broken line) and labelled (three-digit ISO country code: italics).

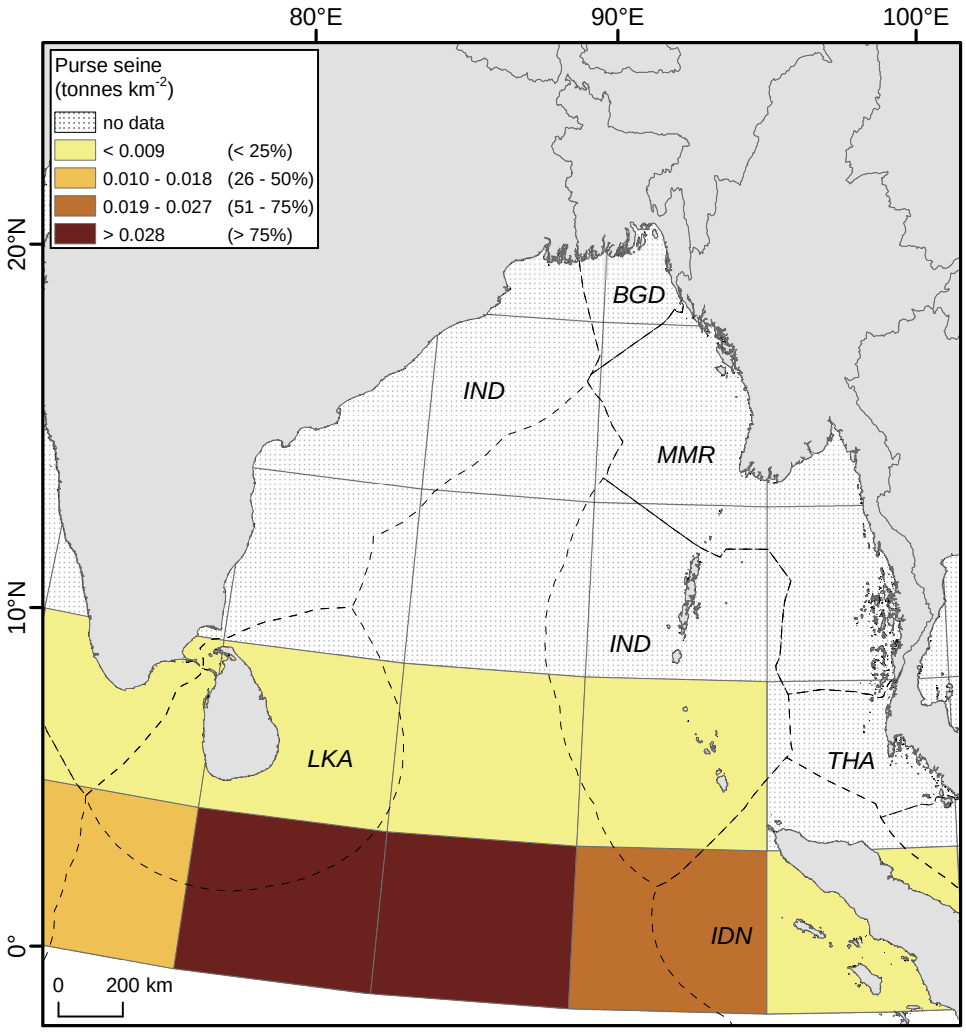

Figure 8.5. Cumulative purse seine fisheries catch data (1993-2012). Cumulative purse seine tuna and billfish catch data expressed as tonnes km^{-2} per Food and Agriculture Organisation of the United Nations (FAO) major fishing cell (5 x 5 degree resolution). As some of these FAO cells contained landmasses data were corrected for each cell's coincident sea area. Catch data are drawn as filled polygons using a yellow/dark brown classification, data deficient cells (grey dot). In all parts EEZs (broken line) and labelled (three-digit ISO country code: italics).

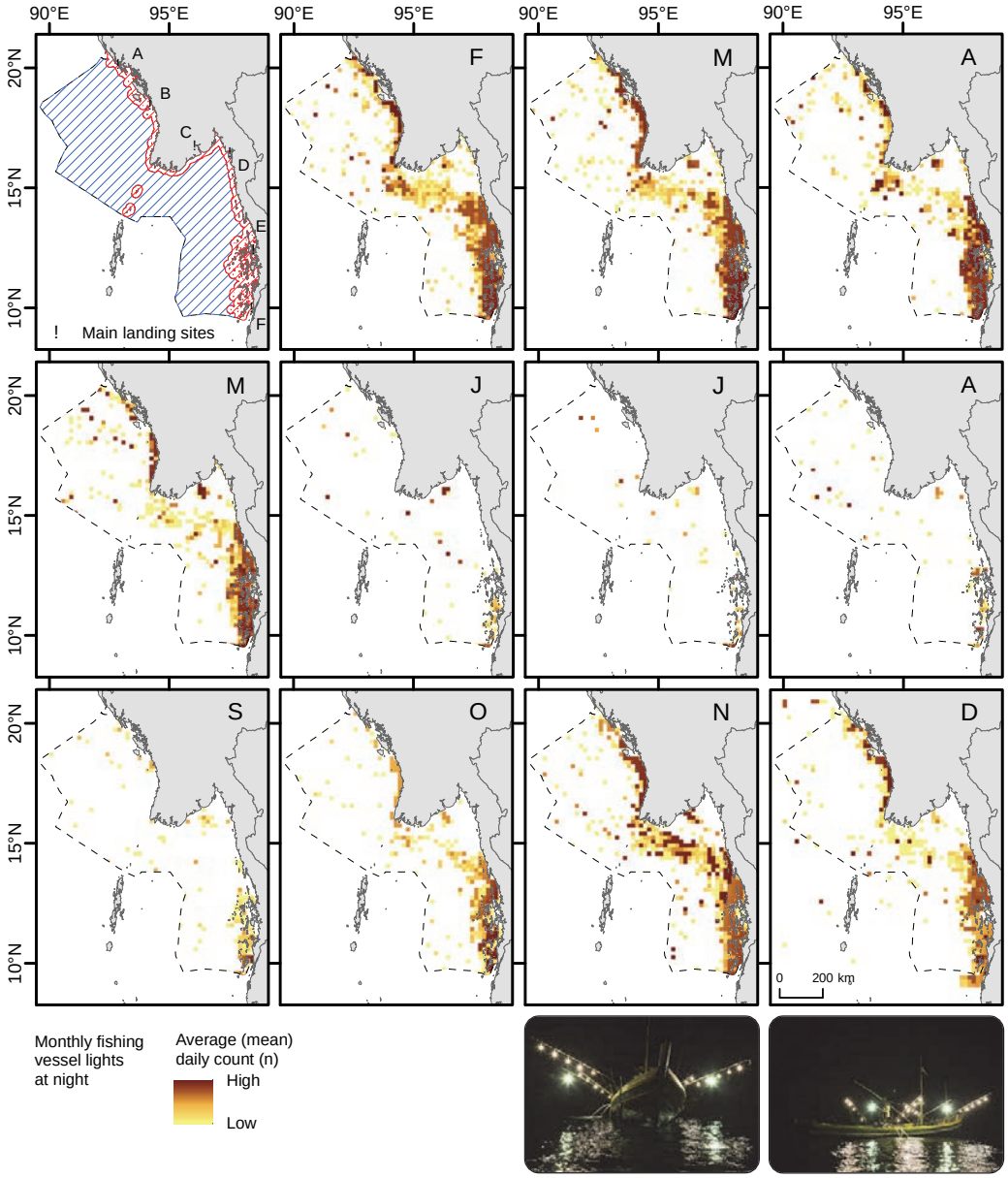

Figure 8.6. Nightly fishing vessel lights. Myanmar designated inshore fisheries zone (red hatched polygon) devolved to state management and offshore fisheries zone (blue hatched polygon) managed by Central Union Government (top left). Fisheries zones have been established through a licensing scheme whereby zones are designated for specific fishing gear, classes of fishing vessels and ownership. The two fishing zones are: zone 1, extending from the shoreline to 5 nautical miles in the north, and to 10 nautical miles in the southern coastal area; and zone 2, from the outer limit of zone 1 to the seaward limit of the EEZ (FAO: http://www.fao.org/fishery/facp/MMR/en#CountrySector-Statistics). Inshore fisheries are designated for artisanal fishers, using small powered or unpowered vessels deploying simple gear types. Offshore fisheries are designated for industrial fisheries (national and international vessels) licensed to fish in Myanmar waters. Main fisheries landing sites: Sitwee (A), Thandwe (B), Yangon (C), Mawlamyine (D), Myeik (E) and Kawthaung (F). Vessel lights at night (pictured) from February (F: upper mid-left) to December (D: lower right), data unavailable for January. Nightly fishing vessel lights summed by 20 x 20 km grid 15/08/2016 to 13/12/2016. In all parts EEZ (broken line).

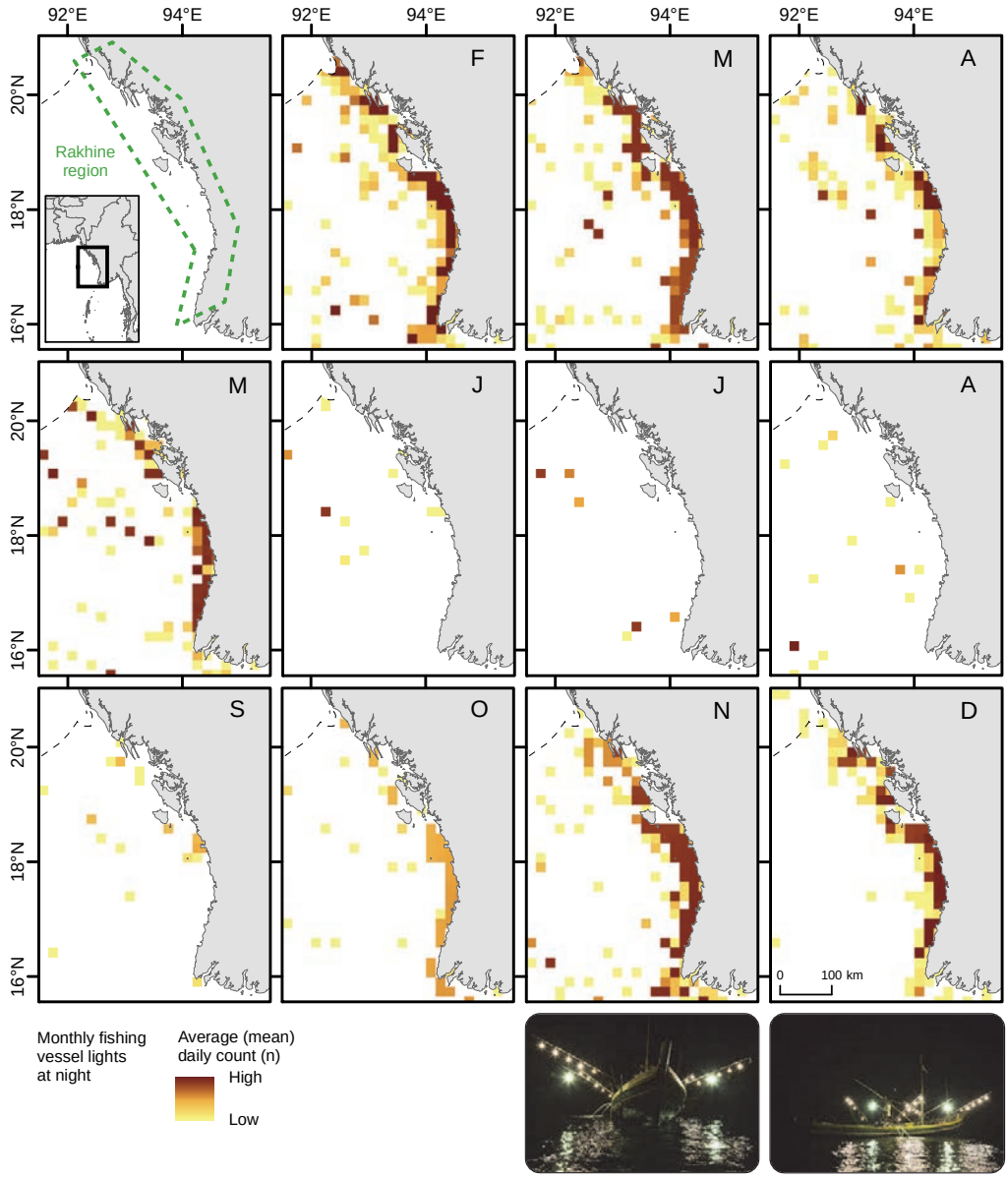

Figure 8.7. Nightly fishing vessel lights in the Rakhine coastal region. Rakhine region and adjacent sea areas (top left). Vessel lights at night (pictured) from February (F: upper mid-left) to December (D: lower right), data unavailable for January. Nightly fishing vessel lights summed by 20 x 20 km grid 15/08/2016 to 18/11/2016.

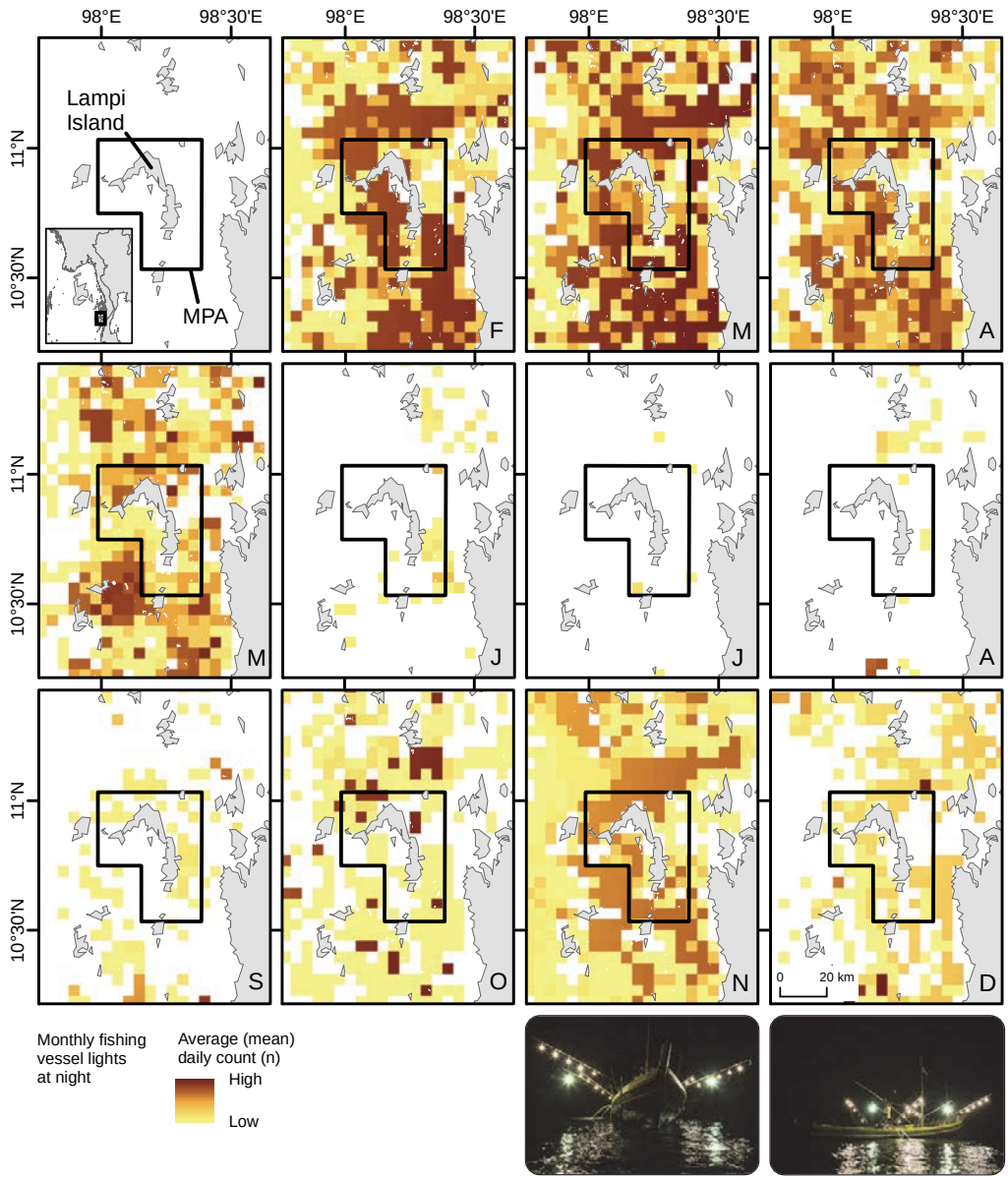

Figure 8.8. Nightly fishing vessel lights surrounding Lampi island. Lampi island and adjacent sea areas (top left). In all parts Lampi Marine National Park, a Marine Protected Area (MPA), is displayed. Vessel lights at night (pictured) from February (F: upper mid-left) to December (D: lower right), data unavailable for January. Nightly fishing vessel lights summed by 4.5 x 4.5 km grid 15/08/2016 to 18/11/2016.

9. BOATS FROM SPACE

© Google Earth

This section details preliminary spatial vessel identification data collected from satellite imagery (Google Earth and Bing) of the Rakhine coastal region, by the University of Exeter. Consistent scanning of satellite imagery allowed boats to be identified, their locations recorded and subsequently mapped. Spatial information on vessel locations can be used to identify landing sites, fishing hotspots, improve fisheries enforcement, management and biodiversity conservation. Map parts of each figure are drawn to the same spatial scale unless otherwise stated. Maps are drawn to Projected Coordinate System: Asia North Albers Equal Area Conic (ANAEC) unless otherwise stated.

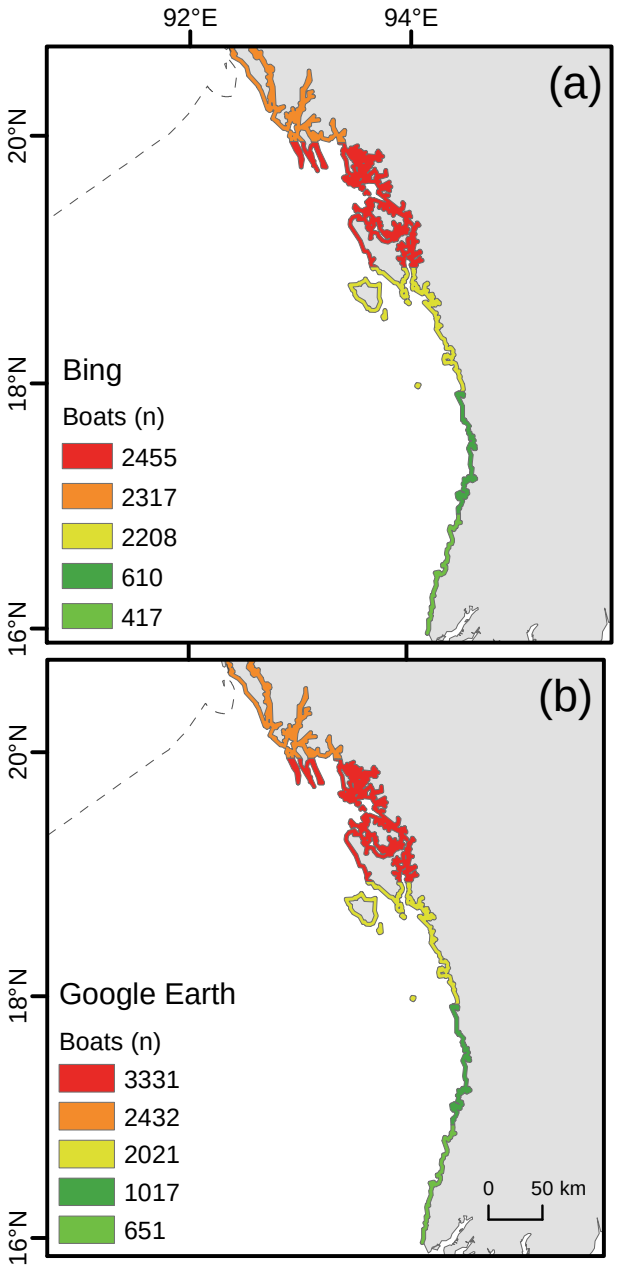

Figure 9.1. Count of fishing vessels detected from optical satellite imagery. Positions of fishing boats detected within the Rakhine coastal region with medium and high confidence from (a) Bing (n=8,450 vessels) and (b) Google Earth (n=10,813 vessels), displayed using a classified green to red colour ramp. Count of boats summarised by 1 degree latitudinal segments. In all parts EEZ (broken line).

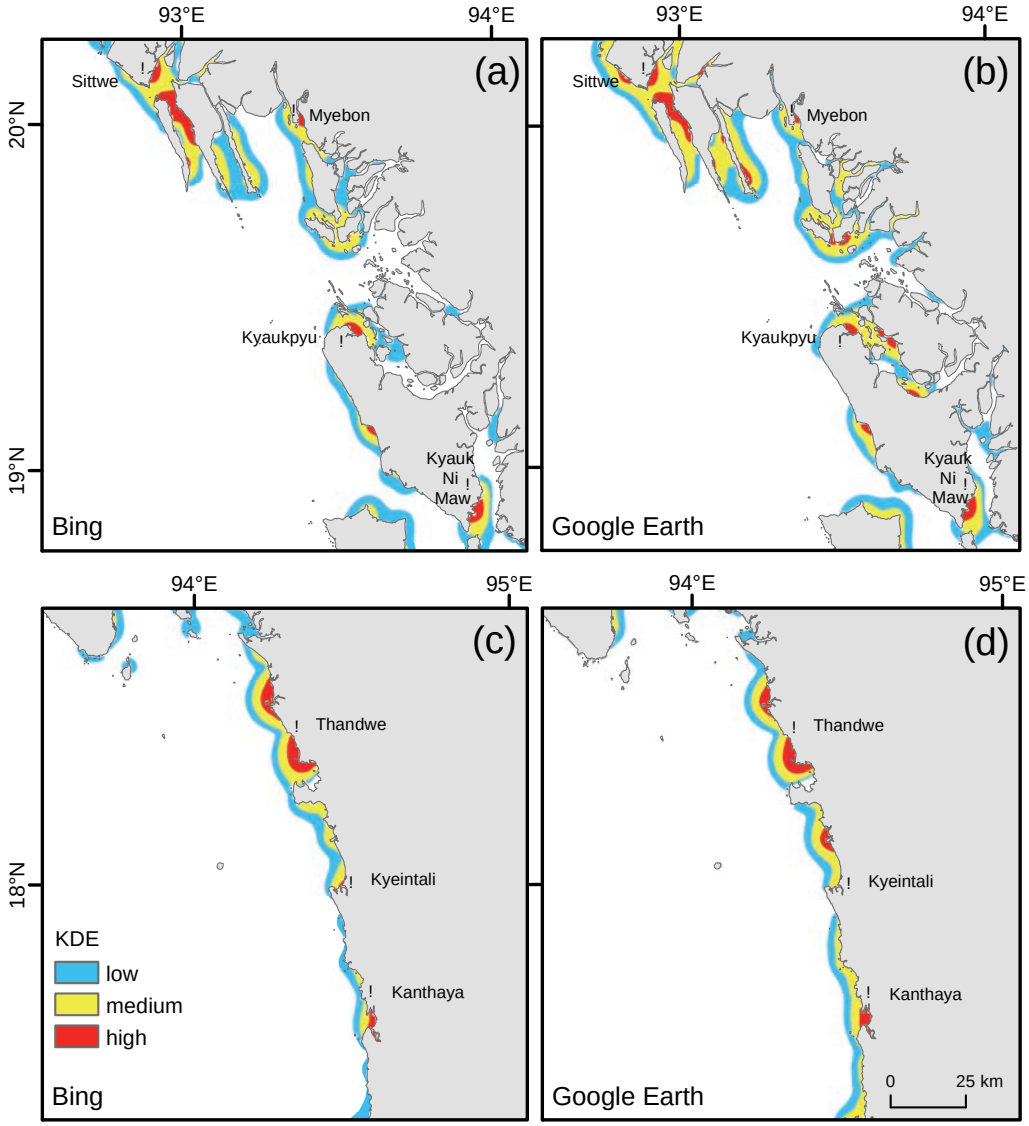

Figure 9.2. Kernel density estimate (KDE) analysis of detected fishing vessels from optical satellite imagery. Point pattern assessment using KDE of locations of fishing boats expressed using a low (blue), medium (yellow) and high (red) categorical scale. Selected areas of interest within the Rakhine coastal region for both (a) and (c) Bing, and (b) and (d) Google Earth. Parts (a-b) and (c-d) are drawn to different spatial scales.

10. FISHERIES TRACKING

© Katherine Holmes (WCS)

This section details spatial tracking data collected from GPS-GSM instrumented vessels located off Kyeintali in the Rakhine coastal region, by the University of Exeter. Spatial information on vessel tracking can be used to improve fisheries enforcement, management and biodiversity conservation. Map parts of each figure are drawn to the same spatial scale unless otherwise stated. Maps are drawn to Projected Coordinate System: Asia North Albers Equal Area Conic (ANAEC) unless otherwise stated.

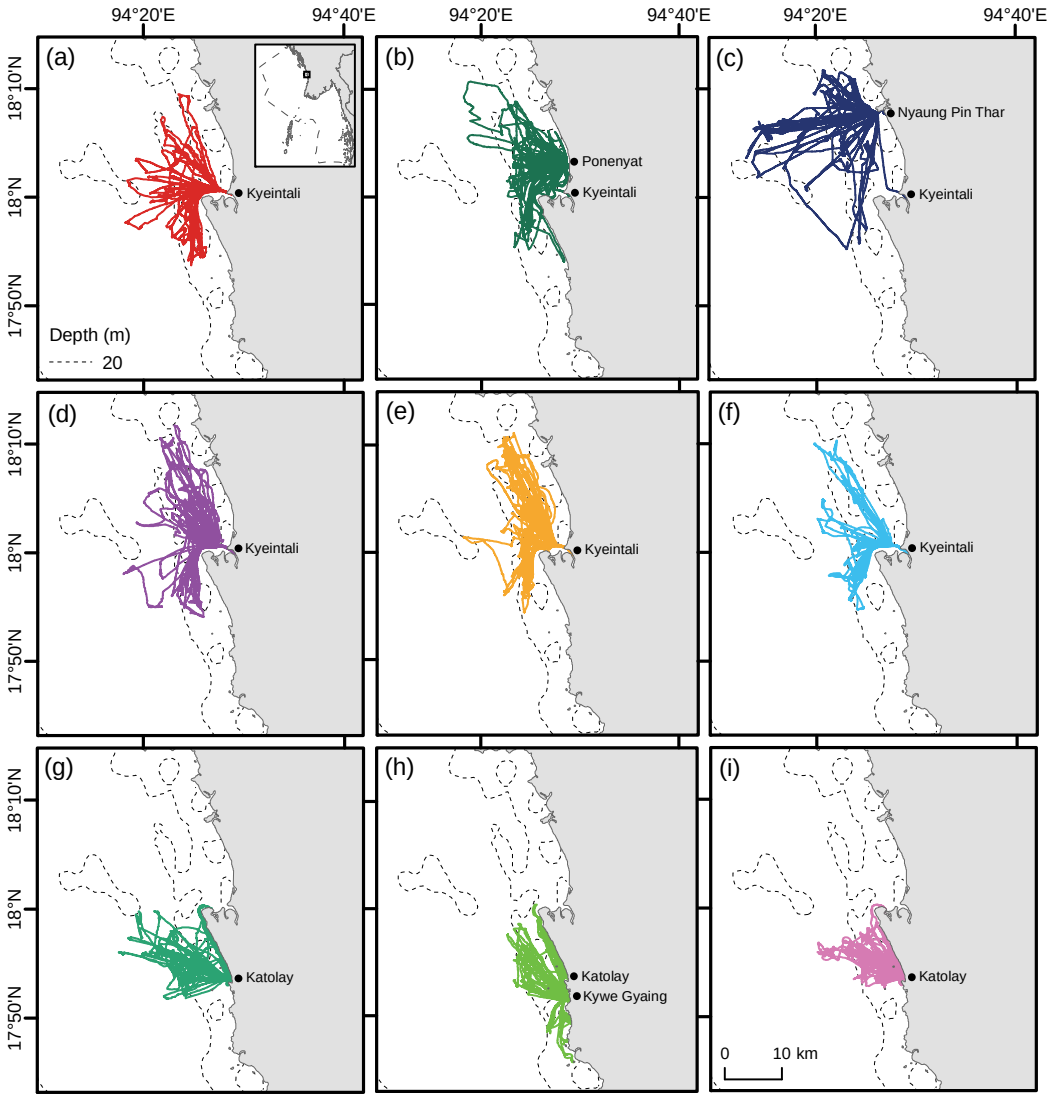

Figure 10.1. Individual vessel tracks. Vessel tracks of GPS-GSM instrumented vessels (a-i) (n=9) located in an area of the Rakhine coastal region between 4/10/2016 and 10/12/2016. Each map part shows the trips made by a single tagged vessel (total n=338), tracks are displayed as individually coloured lines. Ports of departure are displayed (black circles, named). In all parts 20 m depth contour (dashed line). Inset map EEZ (broken line).

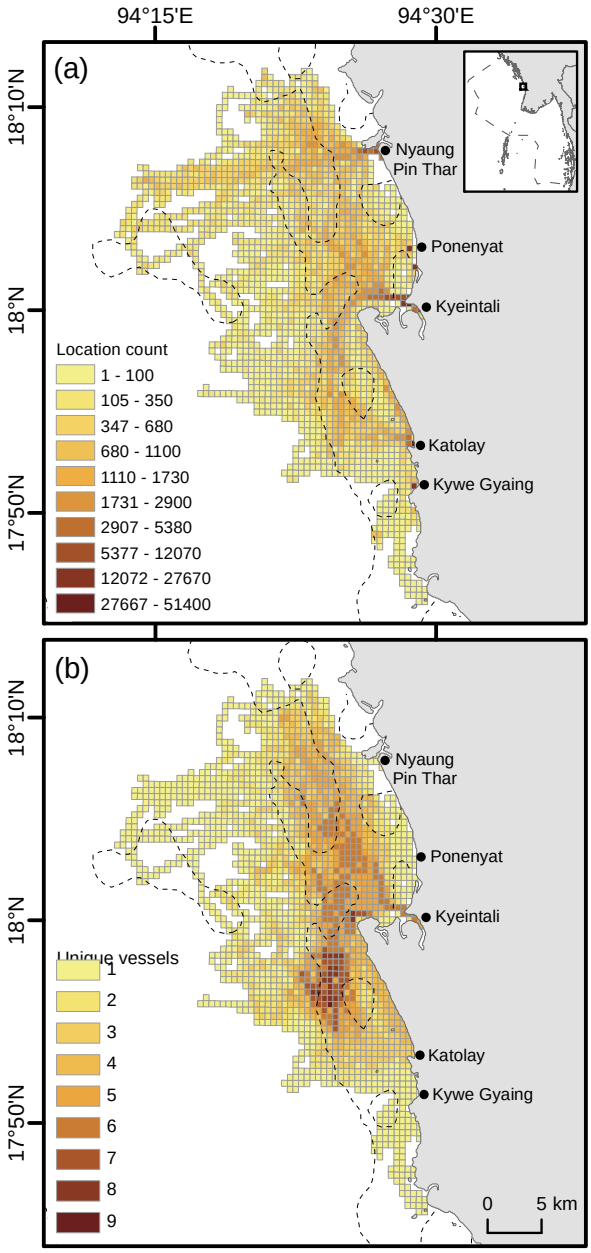

Figure 10.2. At sea vessel distribution. (a) Count of GPS-GSM instrumented vessel locations on a 500 m x 500 m grid from 9 vessels, in an area of the Rakhine coastal region between 4/10/2016 and 10/12/2016. Data are drawn as filled polygons using a pale yellow/dark brown classification ranging from low (pale yellow) to high (dark brown). (b) Count of unique number of vessels using coastal waters (on a 500 m x 500 m grid). Data are drawn as filled polygons using a pale yellow/dark brown classification ranging from a single vessel (1; pale yellow) to all vessels (9; dark brown). In all parts 20 m depth contour (dashed line). Inset map EEZ (broken line).

11. THREATS

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This section details the local threats facing the marine environment within Myanmar's maritime limits, including overfishing, coastal development, watershed and marine-based pollution. Map parts of each figure are drawn to the same spatial scale unless otherwise stated. Maps are drawn to Projected Coordinate System: Asia North Albers Equal Area Conic (ANAEC) unless otherwise stated.

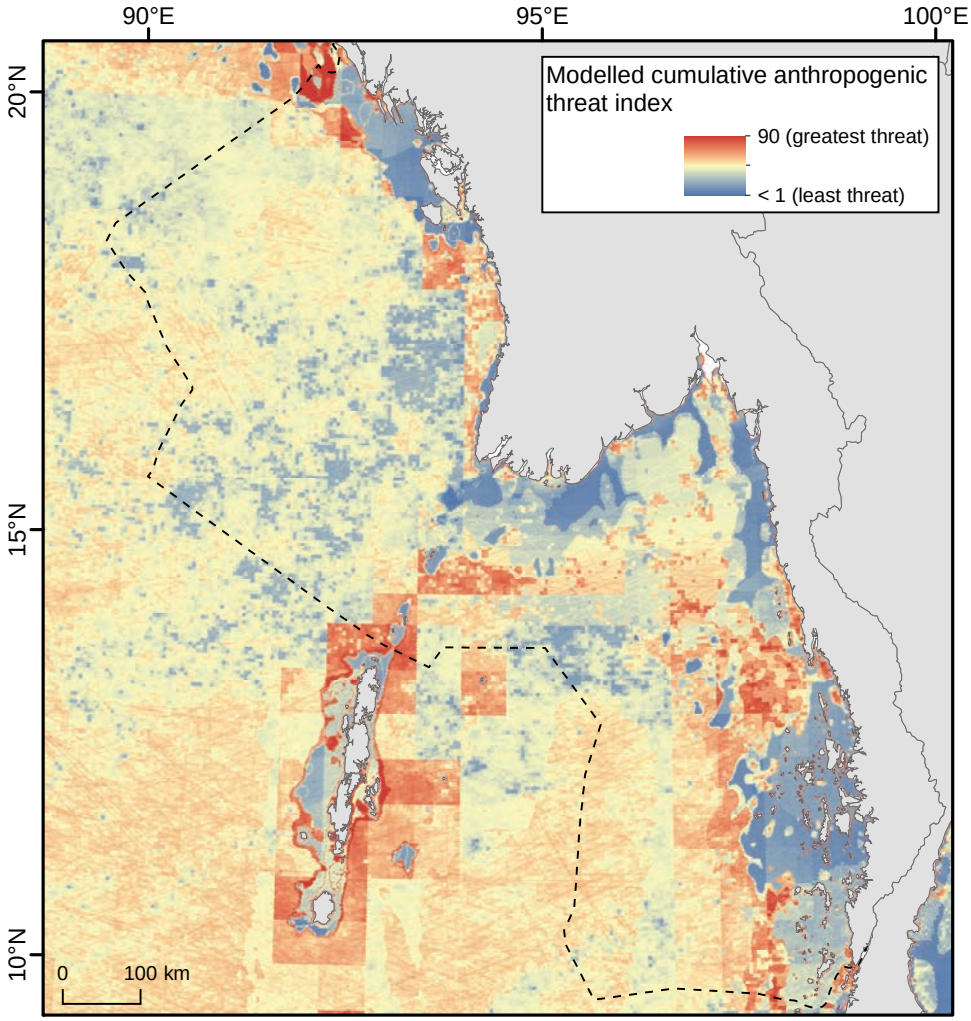

Figure 11.1. Cumulative human impact. Modelled cumulative anthropogenic threat index (Halpern, 2008) described by a continuous blue/yellow/red colour ramp. Spatial model incorporates 17 global data sets of anthropogenic drivers of ecological change within the marine ecosystem (e.g. nutrient run off, pollutants (organic and inorganic), fisheries, invasive species, shipping, ocean acidification and sea surface temperature) to highlight spatially explicit areas where marine ecosystems may be negatively impacted by human activity. EEZ (broken line).

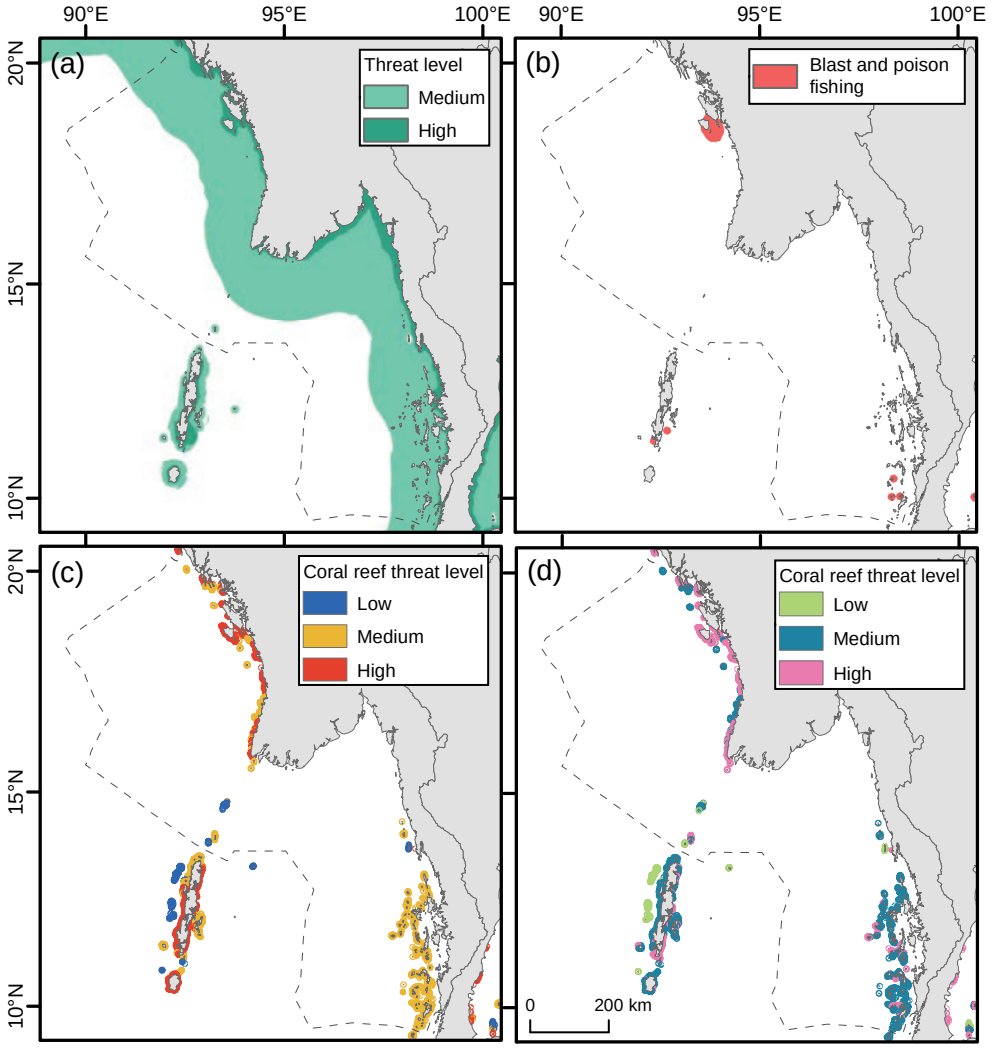

Figure 11.2. Threat from overfishing and destructive fishing practices. (a) Estimated threat of overfishing and destructive fishing to shallow shelf areas along Myanmar's coastline, classified according to areas of medium (light green polygon) and high threat (dark green polygon). (b) Areas of observed blast (dynamite) and/or poison fishing (red polygon). (c) Estimated threat of overfishing and destructive fishing on coral reefs, classified according to areas of low (blue polygon), medium (orange polygon) and high threat (red polygon). (d) Estimated integrated local threat of overfishing/destructive fishing, coastal development, marine based pollution/damage and watershed based pollution on coral reefs, classified according to areas of low (green polygon), medium (blue polygon) and high threat (pink polygon). In all parts EEZ (broken line). Threats from overfishing were evaluated based on coastal population density and extent of fishing areas, with adjustments to account for increased demand due to proximity to large populations and market centres. Areas where destructive fishing occurs (with explosives or poisons) were also included, based on observations from monitoring and mapping by experts.

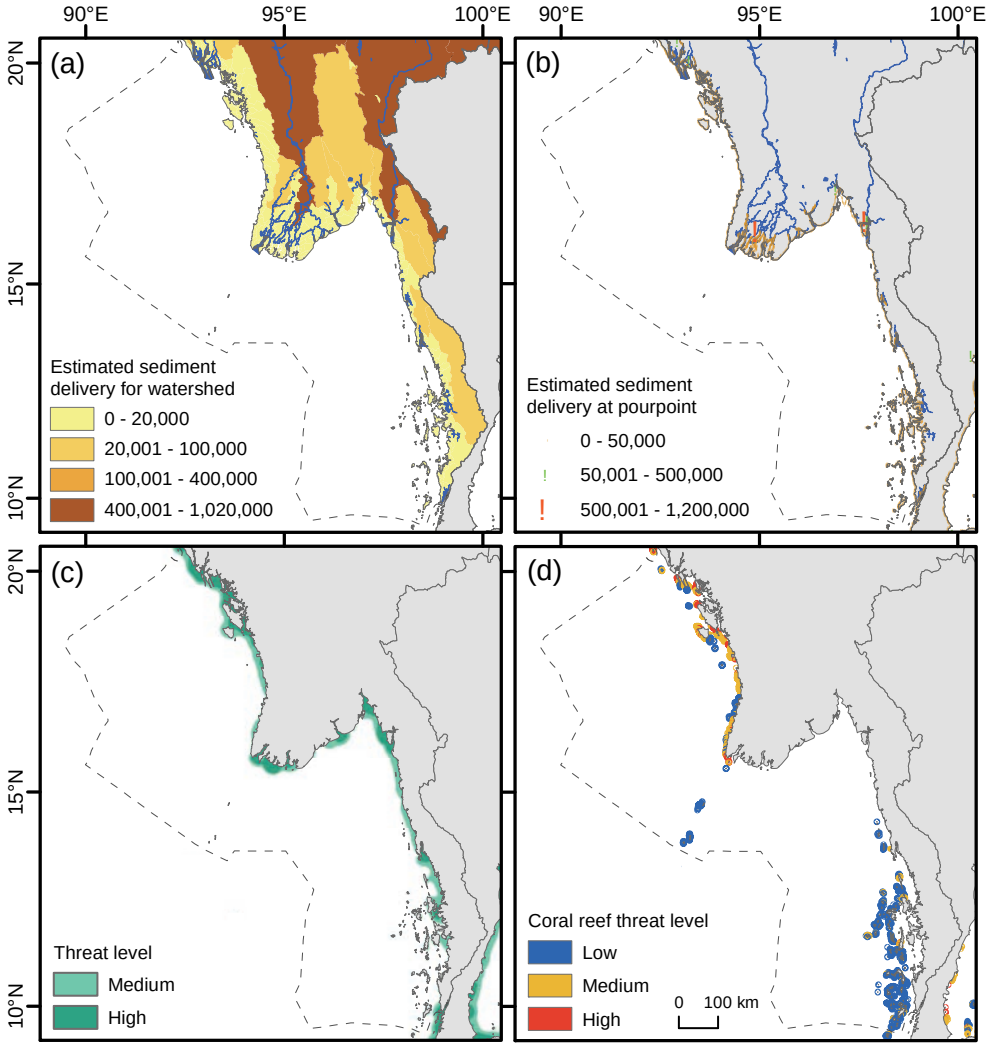

Figure 11.3. Threat from watershed based pollution. (a) Estimated sediment delivery by watershed, measured as an index of relative erosion potential, sediment delivery and additional statistics by watershed, displayed as a classified pale yellow to brown colour ramp. (b) Estimated sediment delivery at pourpoint (i.e. river mouth), measured as an index of relative erosion potential, sediment delivery and additional statistics by pourpoint, displayed as orange, green and red circles as detailed in the legend. Parts (a) and (b) main river systems (blue line). (c) Estimated threat from watershed-based pollution to shallow shelf areas along Myanmar's coastline, classified according to areas of medium (light green polygon) and high threat (dark green polygon). (d) Estimated threat of watershed based pollution on coral reefs, classified according to areas of low (blue polygon), medium (orange polygon) and high threat (red polygon). In all parts EEZ (broken line). Threats from watershed based pollution were modelled for over 300,000 watersheds (catchments) discharging to coastal waters.

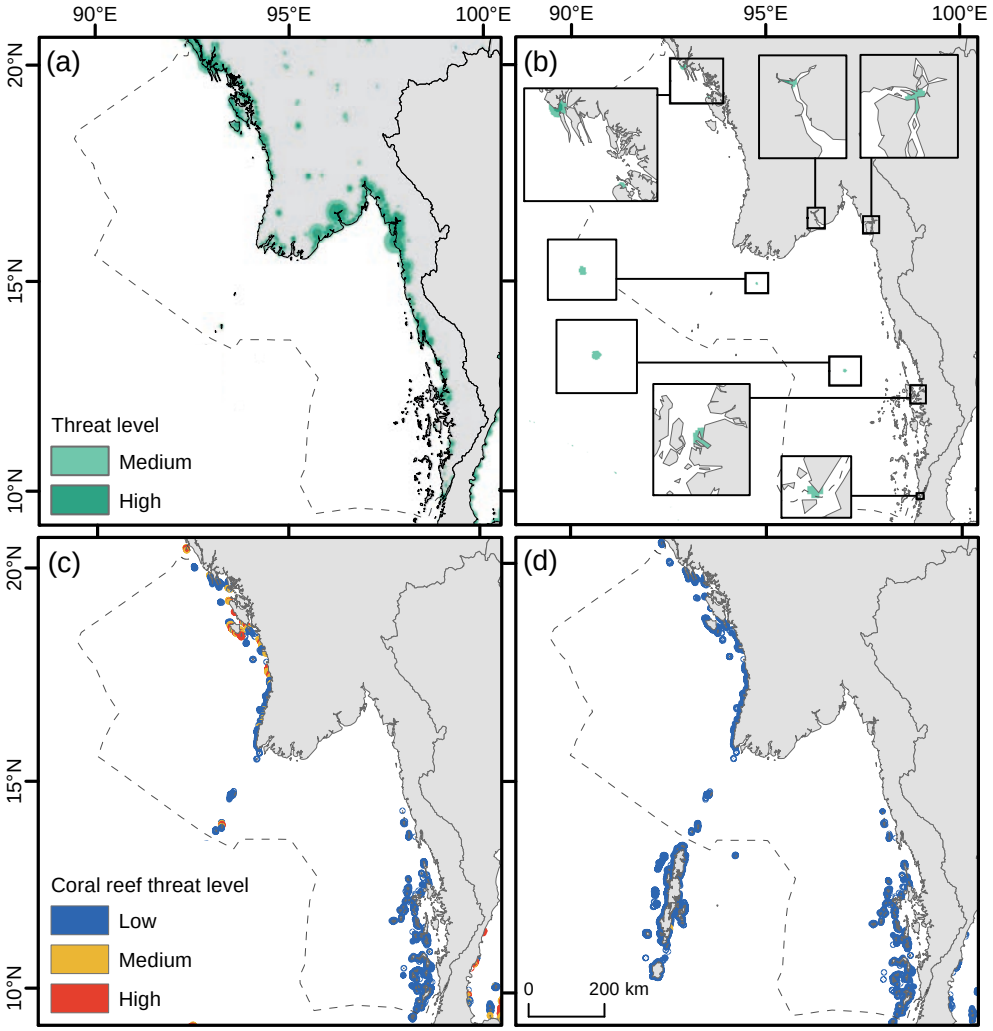

Figure 11.4. Threat from coastal development and marine based pollution and damage. Estimated threat from (a) coastal development (including threat from development to lakes on land) to shallow shelf areas along Myanmar's coastline and (b) marine based pollution and damage, classified according to areas of medium (light green polygon) and high threat (dark green polygon). Estimated threat of (c) coastal development and (d) marine based pollution and damage on coral reefs, classified according to areas of low (blue polygon), medium (orange polygon) and high threat (red polygon). In all parts EEZ (broken line). Threats from marine-based pollution and damage were evaluated based on the size and volume of commercial shipping ports, size and volume of cruise ship ports, intensity of shipping traffic, and the location of oil infrastructure.

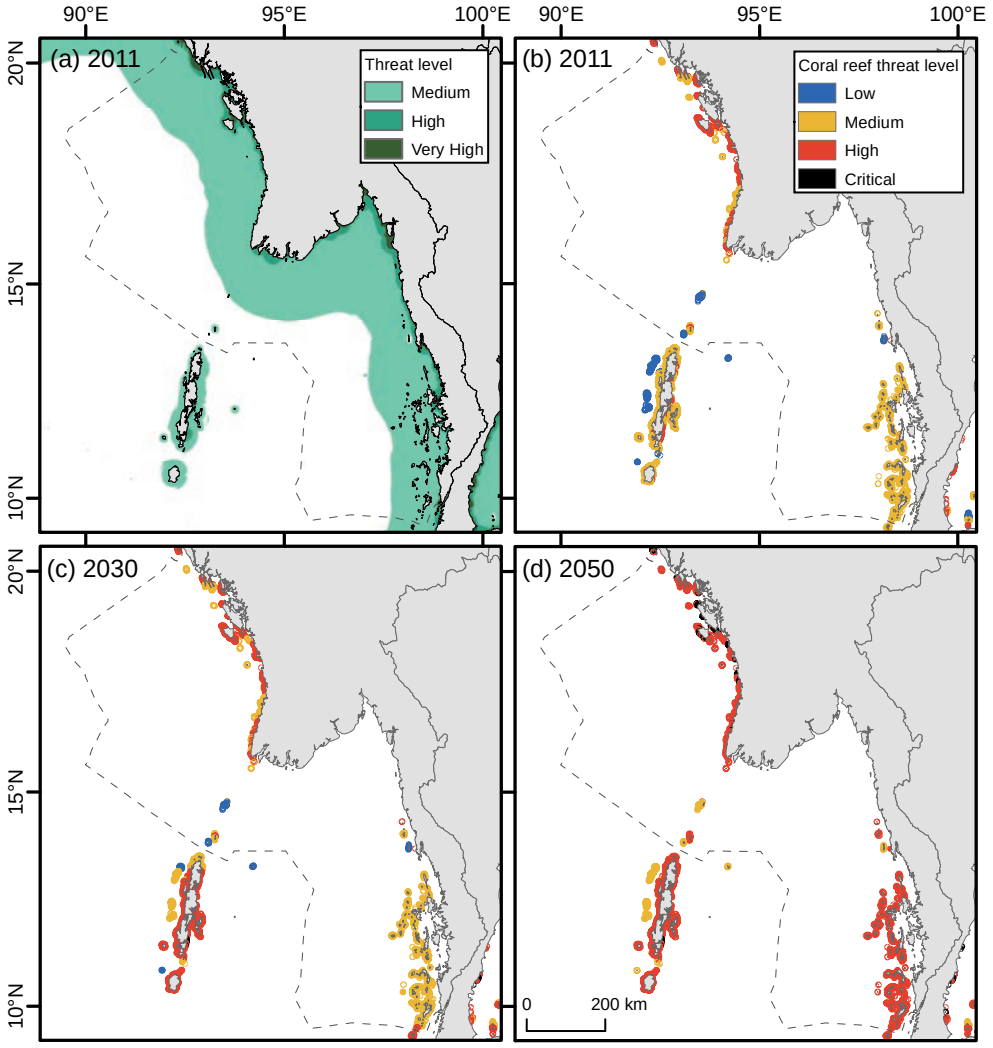

Figure 11.5. Integrated local threat (2011, 2030, 2050). (a) Estimated integrated local threat from coastal development, marine based pollution/damage, watershed based pollution and overfishing/destructive fishing to shallow shelf areas along Myanmar's coastline in 2011, classified according to areas of medium (light green polygon) and high threat (dark green polygon). Estimated integrated local threat from all local threats relevant to (a) in addition to the threat from thermal stress and acidification on coral reefs for (b) 2011, and projected to (c) 2030, (d) 2050, classified according to areas of low (blue polygon), medium (orange polygon), high (red polygon) and critical threat (black polygon). In all parts EEZ (broken line). A single broad measure of integrated threat was evaluated based on the four individual threats combined into a single integrated local threat index, reflecting their cumulative impact on shallow shelf areas and reef ecosystems. This index was adjusted to combine past (2011) and modelled future (2030, 2050) estimates of thermal stress and ocean acidification to predict threat to reefs in 2030 and 2050.

12. BIBLIOGRAPHY

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This section details the data sources and references for important databases, reports and scientific literature consulted during the creation of the Myanmar Marine Biodiversity Atlas, which can be used to help inform marine spatial planning efforts in support of marine protected area design, fisheries management and petrochemical exploration activities.

Atlas section:

2. GEOPOLITICAL CONTEXT

Figure 2.1. Location and maritime zones
Data sources: land polygons - https://www.ngdc.noaa.gov/mgg/shorelines/gshhs.html, EEZ polygons - http://www.marineregions.org/, maritime boundaries derived from: http://www.marineregions.org/

Figure 2.2. Seas, bays, islands and coastal regions
Data sources: seas, bays, islands - derived from Google Earth, coastal regions - derived from http://www.fao.org/fishery/facp/MMR/en

Figure 2.3. Ecological classifications
Data source: http://www.marineregions.org/downloads.php

Figure 2.4. Internal states, divisions and population density
Data sources: internal states/divisions and capitals - Wildlife Conservation Society (WCS), population density - http://sedac.ciesin.columbia.edu/data/collection/gpw-v4/sets/browse, hydrology - WCS.

Figure 2.5. Infrastructure
Data sources: shipping ports, airports, shipping lanes - World Resources Institute Reefs at Risk Revisited 2011 (http://www.wri.org/publication/reefs-risk-revisited), major railways and roads - WCS.

Figure 2.6. Protected areas
Data sources: terrestrial protected areas - World Database on Protected Areas (WDPA, https://www.protectedplanet.net/search?q=myanmar), Ramsar site - https://rsis.ramsar.org/, marine protected areas compiled from sources including the WDPA, WCS, ReefBase (http://www.reefbase.org/main.aspx) and BOBLME (http://www.boblme.org/).

Figure 2.7. Hydrocarbons: licence blocks, operational wells and pipelines
Data sources: licence blocks - WCS Myanmar, and digitised from resources at http://www.myanmar-responsiblebusiness.org/pdf/SWIA/Oil-Gas/00-Myanmar-Oil-and-Gas-Sector-Wide-Assessment.pdf and http://myanmarembassy.sg/downloads/declarations/Bids%20of%20Petroleum%20Operations%20deep%20shore.pdf. Pipelines digitised from http://www.china.org.cn/business/2014-07/09/content_32890066.htm and www.ogj.com/articles/2015/08/tap-oil-signs-psc-for-block-offshore-myanmar.html. Operational wells identified from satellite imagery downloaded from http://ngdc.noaa.gov/eog/viirs/

3. PHYSICAL ENVIRONMENT

Figure 3.1. Land elevation and aspect
Data source: land elevation - NASA Socioeconomic Data and Applications Centre (SEDAC: http://srtm.csi.cgiar.org/), land aspect - derived from land elevation data.

Figure 3.2. Precipitation
Data sources: precipitation map - World Resources Institute Reefs at Risk Revisited 2011 (http://www.wri.org/publication/reefs-risk-revisited), precipitation graph - http://www.climatemps.com/

Figure 3.3. Bathymetry
Data source: seabed depth - General Bathymetric Chart of the Oceans (GEBCO) from the British Oceanographic Data Centre (BODC: www.gebco.net), seabed slope and aspect - derived from seabed depth data.

Figure 3.4. Geomorphological seabed features
Data source: http://www.bluehabitats.org/

Figure 3.5. Seamounts and knolls
Data source: http://data.unep-wcmc.org/datasets/41

4. OCEANOGRAPHY

Figure 4.1. Sea Surface Temperature (SST)
Data derived from night-time skin SST observations using Aqua mission Moderate Resolution Imaging Spectroradiometer (MODIS) data at a 0.041 degree (approx. 4 x 4 km) spatial resolution. Data source: ftp://podaac-ftp.jpl.nasa.gov/allData/modis/L3/aqua/4um/v2014.0/4km/monthly

Figure 4.2. Oceanic SST persistence frontal activity
Daily Level 4 SST Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA) data were sourced (http://podaac.jpl.nasa.gov/dataset/UKMO-L4HRfnd-GLOB-OSTIA) and frontal activity was detected using the Cayula and Cornillon Single Image Edge Detection (SIED) algorithm (Cayula and Cornillon, 1992) for each day between 2007-2012. A minimum frontal edge detection threshold of 0.5°C (SST) was used (Roberts et al., 2010). Daily frontal activity was aggregated by month (cumulative total), and then averaged (mean) into long-term monthly products.

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

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 (10): 1197–1207.

Figure 4.3. Euphotic depth
Data derived from Aqua mission Moderate Resolution Imaging Spectroradiometer (MODIS) data at a 0.041 degree (approx. 4 x 4 km) spatial resolution. Data source: http://oceancolor.gsfc.nasa.gov/cgi/l3

Figure 4.4. Chlorophyll-a
Data derived from Aqua mission Moderate Resolution Imaging Spectroradiometer (MODIS) data at a 0.041 degree (approx. 4 x 4 km) spatial resolution. Data source: ftp://podaac-ftp.jpl.nasa.gov/allData/modis/L3/aqua/chlA/v2014.0/4km/monthly

Figure 4.5. Net Primary Productivity (NPP)
Data derived from mathematical models using chlorophyll-a and sea surface temperature data at a 0.083 degree (approx. 9 x 9 km) spatial resolution. Data source: http://www.science.oregonstate.edu/ocean.productivity/standard.product.php

Figure 4.6. Sea surface salinity
Data derived from Aquarius/SAC-D mission radiometer and scatterometer sensors at a 1 degree (approx. 111 x 111 km) spatial resolution. Data source: ftp://podaac-ftp.jpl.nasa.gov/allData/aquarius/L3/mapped/CAPv4

Figure 4.7. Ocean current direction
Data derived from National Oceanic and Atmospheric Administration (NOAA) Ocean Surface Current Analyses Real-time (OSCAR) data at a 0.33 degree (approx. 37 x 37 km) spatial resolution. Data source: ftp://podaac-ftp.jpl.nasa.gov/allData/oscar/preview/L4/oscar_third_deg

Figure 4.8. Ocean current magnitude
Data derived from National Oceanic and Atmospheric Administration (NOAA) Ocean Surface Current Analyses Real-time (OSCAR) data at a 0.33 degree (approx. 37 x 37 km) spatial resolution. Data source: ftp://podaac-ftp.jpl.nasa.gov/allData/oscar/preview/L4/oscar_third_deg

Figure 4.9. Ocean drifter movement and speed
Data source: http://www.aoml.noaa.gov/envids/gld/FtpInterpolatedInstructions.php

Figure 4.10. Surface wind speed
Data derived from METOP-A mission scatterometer sensors at a 0.25 degree (approx. 28 x 28 km) spatial resolution. Data source: ftp://cmems.isac.cnr.it/Core/WIND_GLO_WIND_L4_REP_OBSERVATIONS_012_003

Figure 4.11. Sea surface wind stress
Data derived from METOP-A mission scatterometer sensors at a 0.25 degree (approx. 28 x 28 km) spatial resolution. Data source: ftp://cmems.isac.cnr.it/Core/WIND_GLO_WIND_L4_REP_OBSERVATIONS_012_003

Figure 4.12. Sea surface height anomalies
Data derived from Jason mission altimeter sensors at a 0.25 degree (approx. 28 x 28 km) spatial resolution. Data source: ftp://ftp.aviso.altimetry.fr/global/delayed-time/grids/climatology/monthly_mean

5. MARINE AND COASTAL HABITATS

Figure 5.1. Marine key biodiversity areas and corridors
Data source: https://myanmar.wcs.org/Research/Publications.aspx and
Wildlife Conservation Society (2013). 'Myanmar Biodiversity Conservation Investment Vision Report'. 68 pp.

Figure 5.2. Marine and coastal habitats within the Rakhine marine biodiversity corridor
Data sources: key biodiversity corridors - https://myanmar.wcs.org/Research/Publications.aspx, mangrove - http://data.unep-wcmc.org/datasets/4, coral reef - http://data.unep-wcmc.org/datasets/1, seagrass - http://data.unep-wcmc.org/datasets/7

Figure 5.3. Marine and coastal habitats within the Tanintharyi marine biodiversity corridor
Data sources: key biodiversity corridors - https://myanmar.wcs.org/Research/Publications.aspx, mudflats - WCS, mangrove - http://data.unep-wcmc.org/datasets/4, coral reef - http://data.unep-wcmc.org/datasets/1, seagrass - http://data.unep-wcmc.org/datasets/7

6. BIODIVERSITY

Figure 6.1. Key biodiversity areas for marine and freshwater turtle species
Data sources: key biodiversity areas - https://myanmar.wcs.org/Research/Publications.aspx, turtle nesting sites - http://data.unep-wcmc.org/datasets/22

Figure 6.2. Dugong sightings and Lampi island marine turtle nesting sites
Data sources: Dugong sightings - adapted from:

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Figure. 6.3. Shark and ray species distributions
Data source: http://www.fao.org/geonetwork/srv/en/main.home

Figure. 6.4. Prawn and shrimp species distributions
Data source: http://www.fao.org/geonetwork/srv/en/main.home

Figure. 6.5. Cephalopod species distributions
Data source: http://www.fao.org/geonetwork/srv/en/main.home

7. FISHERIES SURVEYS

Figure 7.1. Myanmar marine ecosystem surveys: vessel course tracks (1979, 2013, 2015)
Data sources:

Nansen, F. 1979. 'Myanmar Ecosystem Survey Cruise Report'. Institute of Marine Research, Bergen, Norway. 37 pp;

Nansen, F. 2013. 'Myanmar Ecosystem Survey Cruise Report'. Institute of Marine Research, Bergen, Norway. 100 pp;

Nansen, F. 2015. 'Myanmar Ecosystem Survey Cruise Report'. Institute of Marine Research, Bergen, Norway. 104 pp.

Figure 7.2. Myanmar marine ecosystem surveys: sampling stations (2013)
Data source: http://webprod1.nodc.no:8080/nansis/index.html#

Figure 7.3. Myanmar marine ecosystem surveys: sampling stations (2015)
Data source: Institute of Marine Research, Norway.

Figure 7.4. Myanmar marine ecosystem surveys: total species biomass and biodiversity estimates (2013, 2015)
Data sources:

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Nansen, F. 2015. 'Myanmar Ecosystem Survey Cruise Report'. Institute of Marine Research, Bergen, Norway. 104 pp.

Figure 7.5. Myanmar marine ecosystem surveys: species biomass and biodiversity estimates (2013)
Data source:

Nansen, F. 2013. 'Myanmar Ecosystem Survey Cruise Report'. Institute of Marine Research, Bergen, Norway. 100 pp.

Figure 7.6. Myanmar marine ecosystem surveys: species biomass and biodiversity estimates (2015)
Data source:
Nansen, F. 2015. 'Myanmar Ecosystem Survey Cruise Report'. Institute of Marine Research, Bergen, Norway. 104 pp.

Figure 7.7. Myanmar marine ecosystem surveys: shark, ray, shrimp and cephalopod biomass (2013, 2015)
Data sources:
Nansen, F. 2013. 'Myanmar Ecosystem Survey Cruise Report'. Institute of Marine Research, Bergen, Norway. 100 pp;
Nansen, F. 2015. 'Myanmar Ecosystem Survey Cruise Report'. Institute of Marine Research, Bergen, Norway. 104 pp.

8. FISHERIES SECTOR

Figure 8.1. Number of registered fishing vessels
Data source: http://www.myanmar.cm/myanmardata2007/5.htm

Figure 8.2. Production of fish and prawns by coastal states and divisions
Data source: http://www.myanmar.cm/myanmardata2007/5.htm

Figure. 8.3. Aquaculture ponds
Data source: http://www.fao.org/geonetwork/srv/en/main.home

Figure 8.4. Cumulative longline fisheries catch data (1993-2012)
Data source: http://www.fao.org/figis/geoserver/tunaatlas

Figure 8.5. Cumulative purse seine fisheries catch data (1993-2012)
Data source: http://www.fao.org/figis/geoserver/tunaatlas

Figure 8.6. Nightly fishing vessel lights
Data sources: https://ngdc.noaa.gov/eog/viirs/download_total_boat.html (version 2.1 and 2.2). Fisheries zones - http://www.fao.org/fishery/facp/MMR/en#CountrySector-Statistics, fisheries landing sites - http://www.fao.org/fishery/facp/MMR/en#CountrySector-Statistics, vessel lights at night - http://ngdc.noaa.gov/eog/viirs/download_total_boat.html

Figure 8.7. Nightly fishing vessel lights in the Rakhine coastal region
Data sources: https://ngdc.noaa.gov/eog/viirs/download_total_boat.html (version 2.1 and 2.2). Fisheries zones - http://www.fao.org/fishery/facp/MMR/en#CountrySector-Statistics, fisheries landing sites - http://www.fao.org/fishery/facp/MMR/en#CountrySector-Statistics, vessel lights at night - http://ngdc.noaa.gov/eog/viirs/download_total_boat.html

Figure 8.8. Nightly fishing vessel lights surrounding Lampi island
Data sources: https://ngdc.noaa.gov/eog/viirs/download_total_boat.html (version 2.1 and 2.2). Fisheries zones - http://www.fao.org/fishery/facp/MMR/en#CountrySector-Statistics, fisheries landing sites - http://www.fao.org/fishery/facp/MMR/en#CountrySector-Statistics, Lampi Marine National Park boundaries - WCS, vessel lights at night - http://ngdc.noaa.gov/eog/viirs/download_total_boat.html

9. BOATS FROM SPACE

Figure 9.1. Count of fishing vessels detected from optical satellite imagery
Data source: Vessel locations manually digitised from Google Earth and Bing mapping accessible through the OpenLayers module in QGIS 12.8.1.

Figure 9.2. Kernel density estimate (KDE) analysis of detected fishing vessels from optical satellite imagery
Data source: Vessel locations manually digitised from Google Earth and Bing mapping accessible through the OpenLayers module in QGIS 12.8.1.

10. FISHERIES TRACKING

Figure 10.1. Individual vessel tracks
Data source: Pelagic data systems. Equipment funded by WCS Myanmar.

Figure 10.2. At sea vessel distribution
Data source: Pelagic data systems. Equipment funded by WCS Myanmar.

11. THREATS

Figure 11.1. Cumulative human impact
Data source: https://www.nceas.ucsb.edu/globalmarine and
Halpern, B. S., S. Walbridge, K. A. Selkoe, C. V. Kappel, F. Micheli, C. D'Agrosa, J. F. Bruno, K. S. Casey, C. Ebert, H. E. Fox, and R. Fujita. 2008. 'A global map of human impact on marine ecosystems'. *Science* 319(5865): 948-952.

Figure 11.2. Threat from overfishing and destructive fishing practices
Data source: World Resources Institute Reefs at Risk Revisited 2011 (http://www.wri.org/publication/reefs-risk-revisited).

Figure 11.3. Threat from watershed based pollution
Data source: World Resources Institute Reefs at Risk Revisited 2011 (http://www.wri.org/publication/reefs-risk-revisited), hydrology - WCS.

Fig 11.4. Threat from coastal development and marine based pollution and damage
Data source: World Resources Institute Reefs at Risk Revisited 2011 (http://www.wri.org/publication/reefs-risk-revisited).

Fig 11.5. Integrated local threat (2011, 2030, 2050)
Data source: World Resources Institute Reefs at Risk Revisited 2011 (http://www.wri.org/publication/reefs-risk-revisited).

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