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NORTH-WEST INDIAN OCEAN AND ADJACENT GULF AREAS REGIONAL WORKSHOP TO FACILITATE THE DESCRIPTION OF ECOLOGICALLY OR BIOLOGICALLY SIGNIFICANT MARINE AREAS
Dubai, United Arab Emirates, 20-25 April 2015

DATA TO INFORM THE NORTH-WEST INDIAN OCEAN AND ADJACENT GULF AREAS REGIONAL WORKSHOP TO FACILITATE THE DESCRIPTION OF ECOLOGICALLY OR BIOLOGICALLY SIGNIFICANT MARINE AREAS

Note by the Executive Secretary

1. The Executive Secretary is circulating herewith a background document on data to inform the North-West Indian Ocean and Adjacent Gulf Areas Regional Workshop to Facilitate the Description of Ecologically or Biologically Significant Marine Areas. The document was prepared by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), in support of the Secretariat of the Convention on Biological Diversity in its scientific and technical preparation for the above-mentioned workshop.

2. The document is being circulated in the form and language in which it was received by the Secretariat of the Convention on Biological Diversity.

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Data to inform the CBD North West Indian Ocean Regional Workshop to Facilitate the Description of Ecologically or Biologically Significant Marine Areas

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April 20, 2015

Prepared for: Secretariat of the Convention on Biodiversity (SCBD)

Copyright and disclaimer

Important disclaimer

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1 Background

CSIRO, in conjunction with international partners, has identify and mapped a large number of data sets and analyses for consideration by the North West Indian Ocean Regional Workshop to facilitate the description of Ecologically or Biologically Significant Marine Areas (EBSAs). The data sets obtained cover both biological and physical data sets. The data is intended to be used by the expert regional workshop convened by SCBD to aid in identifying EBSAs through application of scientific criteria in annex I of decision IX/20 as well as other relevant compatible and complementary nationally and intergovernmentally agreed scientific criteria. Each data set may be used to meet one or more of the EBSA criteria. Printed maps will also be available for annotation at the workshop. The data collected will be made available for download at the Australian Ocean Data Network Portal http://portal.aodn.org.au/webportal/ can can be found by searching for the key word "EBSA". The layers are available as shape files and geotiffs.

2 Biogeography

2.1 GOODS

A new biogeographic classification of the worlds oceans has been developed which includes pelagic waters subdivided into 30 provinces as well as benthic areas subdivided into three large depth zones consisting of 38 provinces (14 bathyal, 14 abyssal and 10 hadal). In addition, 10 hydrothermal vent provinces have been delineated. This classification has been produced by a multidisciplinary scientific expert group, who started this task at the workshop in Mexico City in January 2007. It represents the first attempt at comprehensively classifying the open ocean and deep seafloor into distinct biogeographic regions. The biogeographic classification classifies specific ocean regions using environmental features and to the extent data are available their species composition. This represents a combined physiognomic and taxonomic approach. Generalised environmental characteristics of the benthic and pelagic environments (structural features of habitat, ecological function and processes as well as physical features such as water characteristics and seabed topography) are used to select relatively homogeneous regions with respect to habitat and associated biological community characteristics. These are refined with direct knowledge or inferred understanding of the patterns of species and communities, driven by processes of dispersal, isolation and evolution; ensuring that biological uniqueness found in distinct basins and water bodies is also captured in the classification. This work is hypothesis-driven and still preliminary, and will thus require further refinement and peer review in the future. However, in its present format it provides a basis for discussions that can assist policy development and implementation in the context of the Convention on Biological Diversity and other fora. Global Open Oceans and Deep Seabed (GOODS) biogeographic classification (http://ioc-unesco.org/index.php?option=com_content&task=view&id=146&Itemid=76)

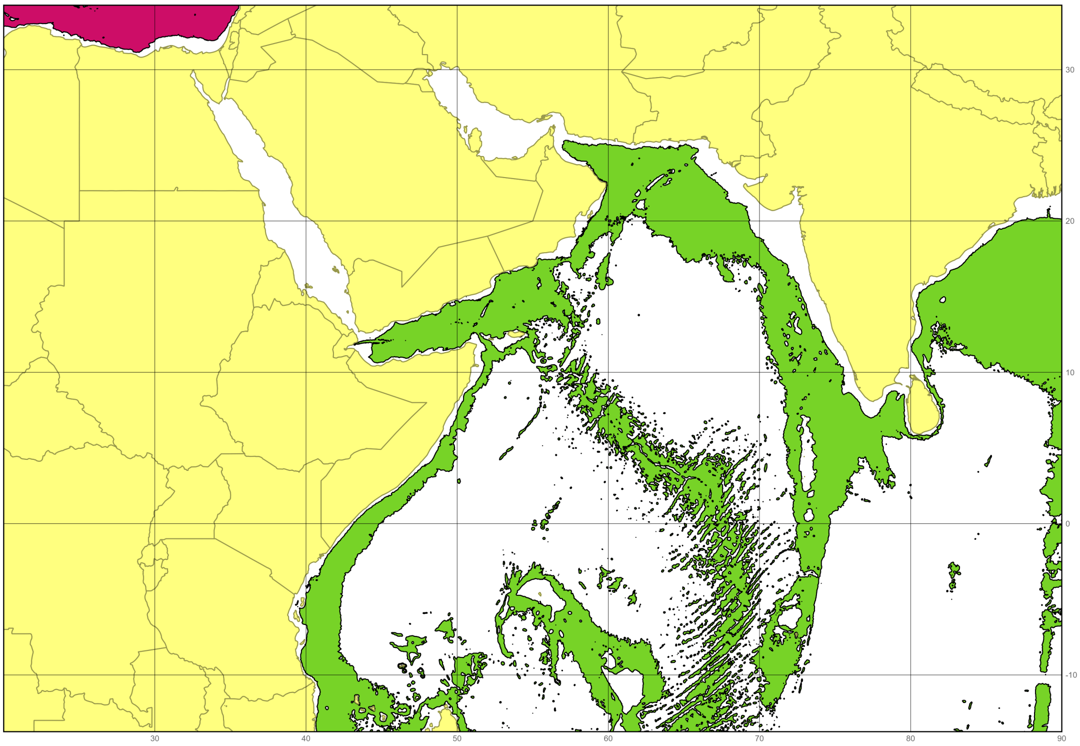


Figure 2.1: GOODS Bathyl Bioregions

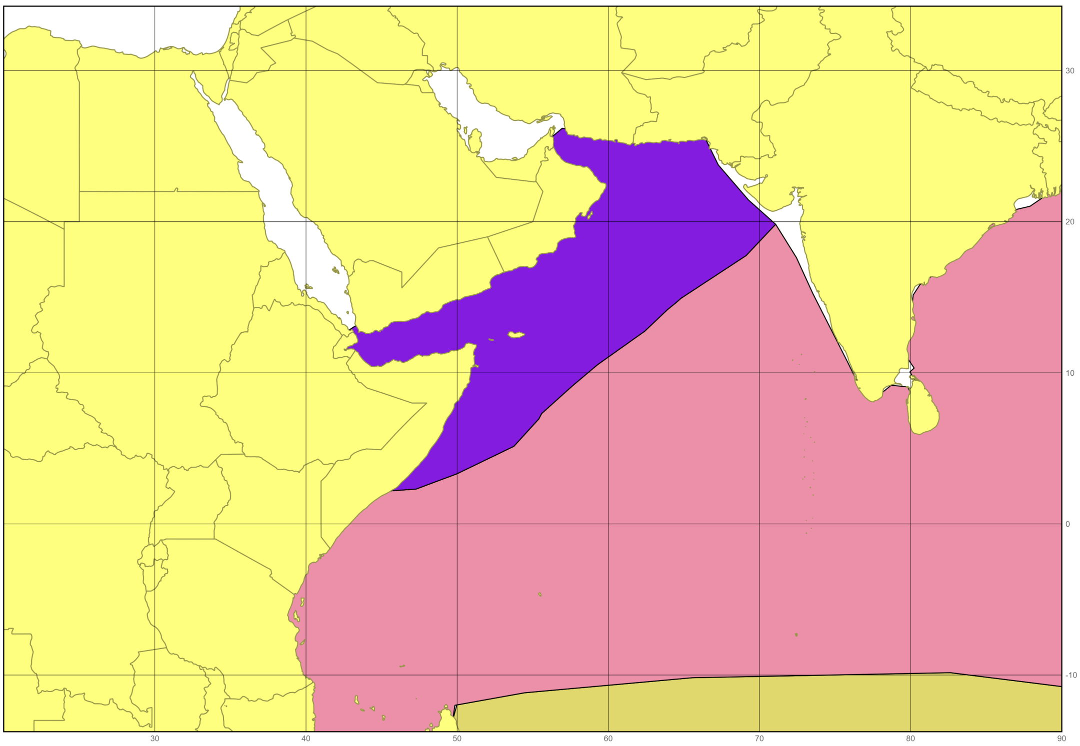


Figure 2.2: GOODS Pelagic Bioregions

3 Biological Data

3.1 Systematic Conservation Planning Assessments and Spatial Prioritizations for the Emirate of Abu Dhabi, the United Arab Emirates and the Arabian Peninsula

Systematic Conservation Planning (SCP) seeks to assess biodiversity in a robust, repeatable and scientific manner and thereby identify the best places in a landscape to undertake conservation activities such as Protected Area expansion. Systematic Conservation Plans were prepared, during a 15 month project, using available spatial data for the marine and terrestrial areas within the Emirate of Abu Dhabi (Abu Dhabi), the United Arab Emirates (UAE) and the Arabian Peninsula region, comprising the UAE together with the Hashemite Kingdom of Jordan (Jordan), the Kingdom of Bahrain (Bahrain), the Kingdom of Saudi Arabia (Saudi Arabia), the Republic of Yemen (Yemen), the State of Kuwait (Kuwait), the State of Qatar (Qatar), and the Sultanate of Oman (Oman). The Abu Dhabi and UAE analyses were run at a finer scale than the Arabian Peninsula.

Intensive and wide ranging stakeholder involvement, which eventually extended to 149 institutions and 270 individuals, was undertaken. This was required to obtain the the range of biodiversity and other associated data from across the region. Draft outputs were peer-reviewed through a series of technical workshops (four for Abu Dhabi/UAE and two for the region) which enabled experts to improve the mapping, fill data gaps, contribute to the Spatial Prioritization, and review and confirm findings.

The project collated available spatial data into six summary derived layers on GIS that were then used to run the spatial analyses. The six derived layers were: Habitat, Habitat Condition, Protected Areas, Species, Ecological Processes, and Opportunity and Constraints. As the project followed a SCP approach, targets were set for biodiversity features including for ecosystems, habitats and species.

The analysis phase of the project had three major components:

- Ecosystem Threat Status assessed the proportion of ecosystems that were in a natural or intact state compared to targets.
- Protection Level assessed the representation of ecosystems within the current Protected Area network (i.e. a gap analysis).
- Spatial Prioritizations using MARXAN were generated using the six derived layers.

The Ecosystem Threat Status and Protection Level assessments provided robust, objective, data derived headline indicators which inform a range of assessments and planning processes. The outputs of the MARXAN analyses were used to identify Priority Focus Areas to undertake area-based conservation activities such as Protected Area expansion and other mechanisms for securing areas for biodiversity and managing them sympathetically. In the finer scale analysis for the UAE, 22 Priority Focus Areas were identified, while 35 Priority Focus Areas were identified across the Arabian Peninsula.

The derived layers, particularly Habitat, Protected Area and Habitat Condition for the UAE and Arabian Peninsula have a value beyond the SCP analyses. The UAE and Arabian Peninsula Habitat maps are the first comprehensive maps of their kind for the region and useful for many aspects of ecology work including survey design and stratification.

The headline indicators from the Ecosystem Threat Status and Protection Level assessments are the first objective measure of conservation priority for Arabian Peninsula ecosystems and are linked to the emerging process of Ecosystem Red Listing. These indicators are ideal for reporting against international commitments, such as Convention on Biological Diversity targets, and potentially form the basis for the biodiversity component of national State of Environment reporting and national biodiversity assessments. The Spatial Prioritizations provide a range of products for planners to use in determining local spatial priorities, including identifying national and transboundary priority areas for Protected Area expansion, as well as identifying the areas where finer scale planning would be beneficial. These project outputs provide a sound basis for more detailed biodiversity and land use planning and a foundation for SCP in the future for Abu Dhabi, UAE and Arabian Peninsula.

The outputs are by no means the final conservation plans and represent the first iteration of a continually evolving process which can be strengthened by improved data inputs. Key data gaps include species data collected through atlas work and well-designed surveys. There is also an urgent need to better measure marine condition and terrestrial degradation. A critical impact on terrestrial ecosystems that is currently under-estimated in these analyses is that of overgrazing. AGEDI is enthusiastic for the project outputs to be shared throughout the region with all stakeholders that contributed data and the wide range of planners and others whom determine the fate of ecosystems and their constituent species.

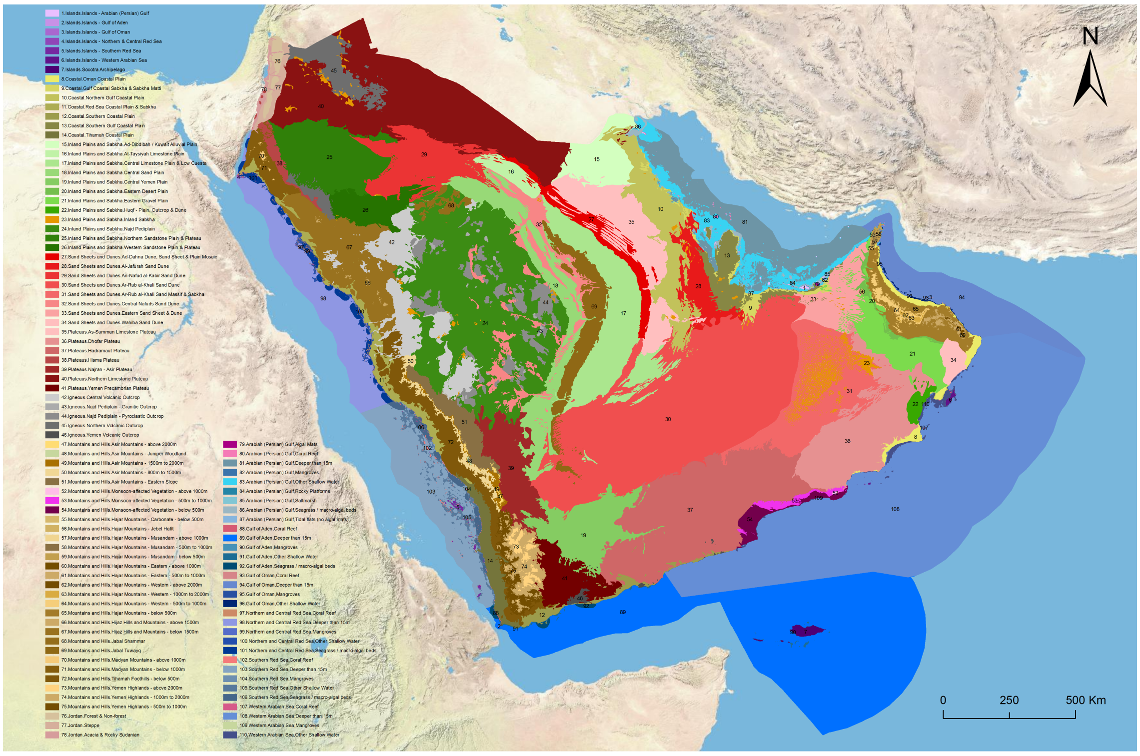


Figure 3.1: Integrated Terrestrial and Marine Habitat Map of the Arabian Peninsula

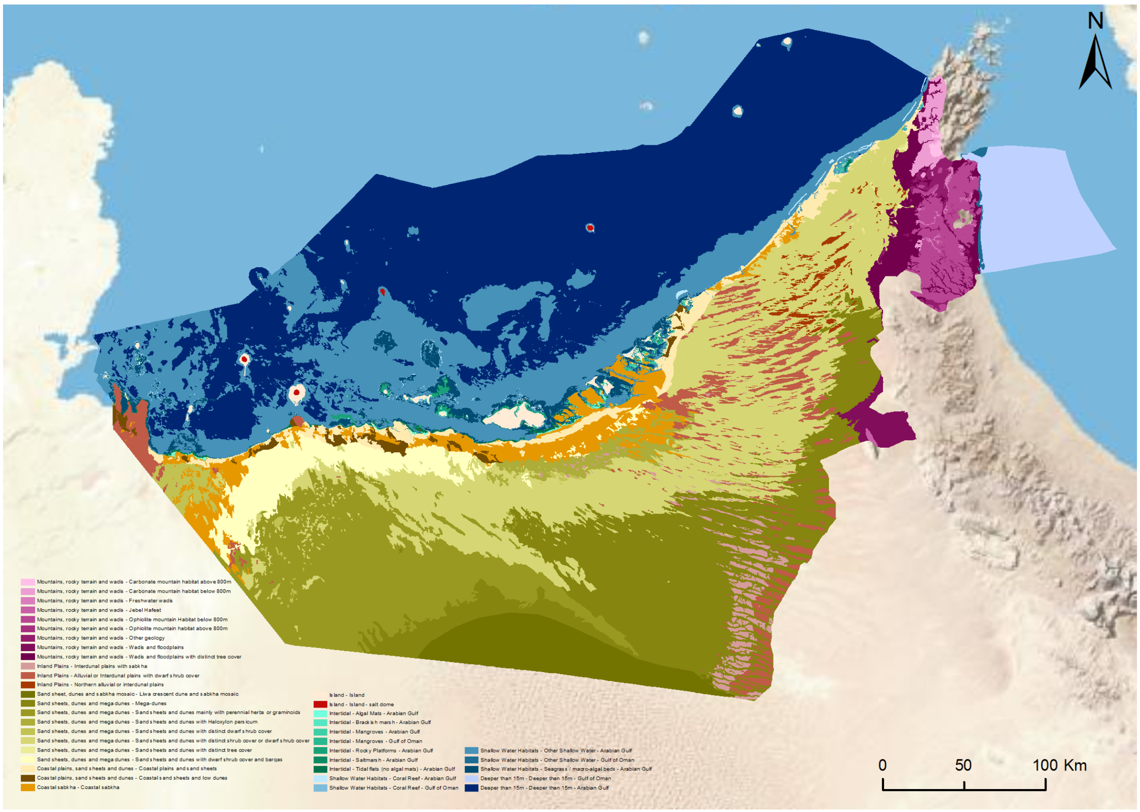


Figure 3.2: Integrated Terrestrial and Marine Habitat Map of the UAE

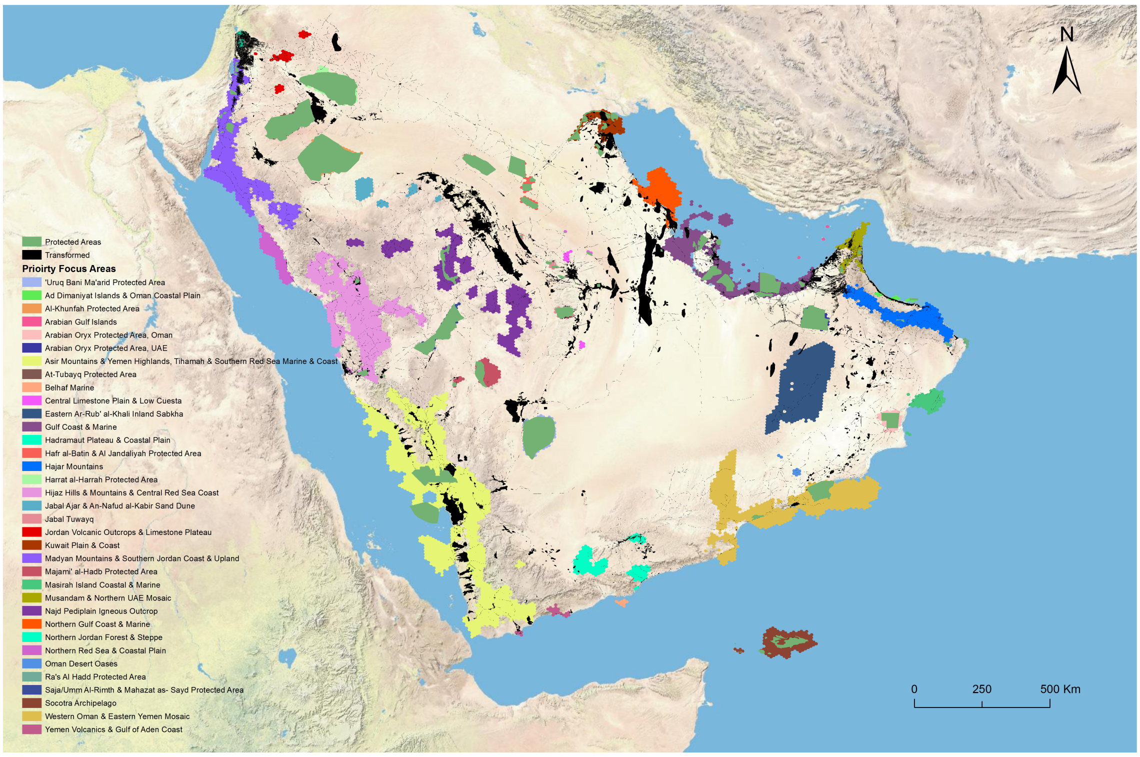


Figure 3.3: Arabian Peninsula Priority Focus Areas

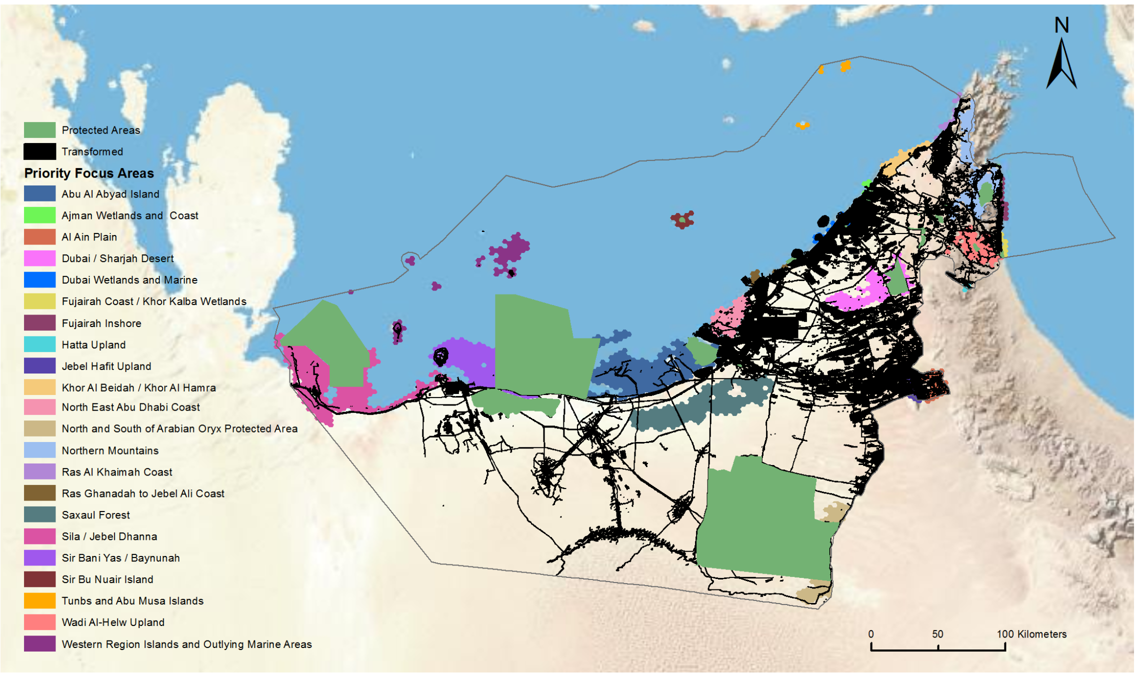


Figure 3.4: Twenty two identified Priority Focus Areas for the UAE

3.2 Turtle nesting and movement

3.2.1 Conservation related insights into the behaviour of the olive ridley sea turtle Lepidochelys olivacea nesting in Oman

We followed the movements of 9 adult female olive ridley turtles Lepidochelys olivacea after nesting on Masirah Island, Oman, using satellite tracking. Their post-breeding migrations ranged from 85 to 796 km. Three individuals travelled north to foraging grounds in Pakistan, Iran and the United Arab Emirates. The other 6 turtles remained in Omani seas for extended periods (mean $\pm$ SD = 171.3 $\pm$ 109.4 d; range = 40 to 310 d). These locally resident turtles experienced biannual cooling of sea temperatures due to the effect of the west Arabian Sea upwelling which was not experienced by those that migrated to the north. Indications of disparity in turtle size between foraging locations are identified for the first time in this species. The majority of turtles(8) settled in coastal areas of water depth $<$ 100 m. Two locally resident turtles remained in very shallow water ($<$ 40 m depth) where they were capable of extended dive durations ($>$ 100 min) in water warmer than 21C, which is a feature unique to olive ridleys amongst sea turtles. They displayed a shift to shorter diving after breeding, indicating increased activity levels. The entire spatial footprint of olive ridley dispersal remained within a putative regional management unit (RMU) for this species in the western Indian Ocean, supporting its delineation. We reveal Omans key role in conserving this demographic unit, with 6 turtles remaining within its national boundary. Our data add to the growing body of evidence that marine turtles show varied migration behaviours within populations, thus complicating their management.

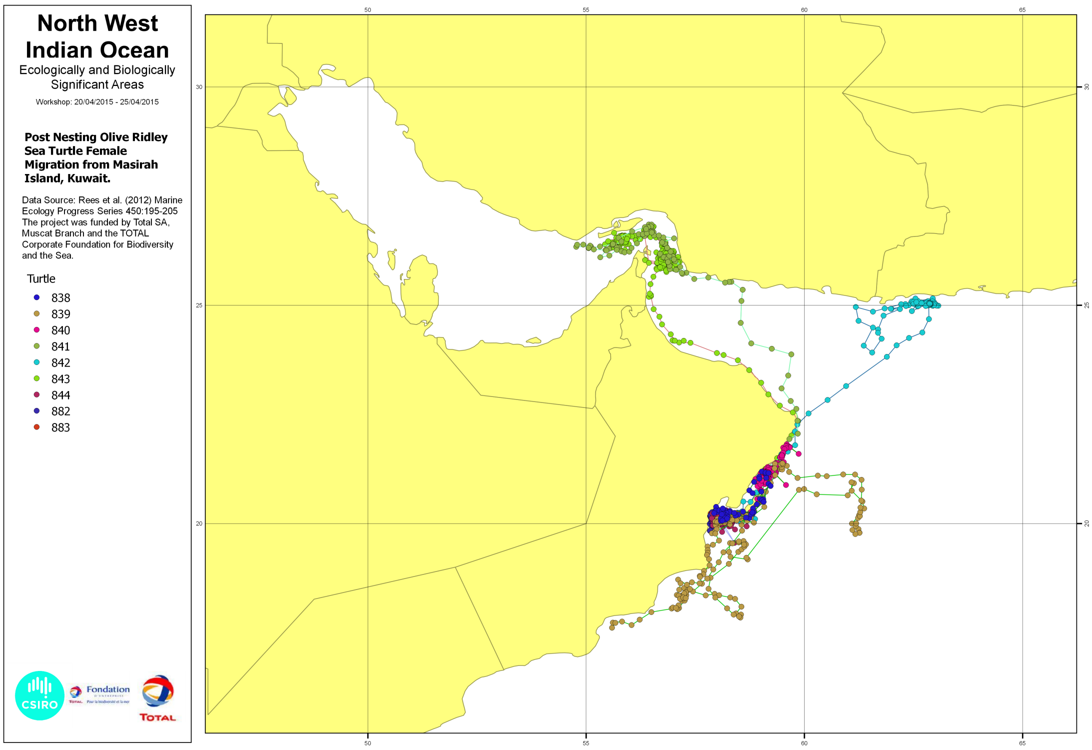


Figure 3.5: Lepidochelys olivacea. Post-breeding migrations and foraging habitat of the 9 olive ridley turtles tracked after nesting on Masirah Island, Oman. Long-distance directed and wandering migrations of 4 individuals. Tracks are smoothed from daily locations to improve visual impact. The remaining 5 individuals remained local to Masirah, : 2 individuals that migrated north to the entrance of the Gulf, 1 individual that migrated to the coastal waters of Pakistan, habitat use north of Masirah by 2 individuals, one of which also used the Gulf of Masirah and 3 individuals that exclusively used the Gulf of Masirah.

Rees et al. (2012) Marine Ecology Progress Series 450:195-205. doi: 10.3354/meps09527

3.2.2 Each to Their Own: Inter-Specific Differences in Migrations of Masirah Island Turtles

We tracked two adult female green turtles (Chelonia mydas) from their nesting location on Masirah Island, Oman (lat 20.441 6 N, long 58.843 6 E) into the Red Sea. Comparing these tracks with published movements of nesting loggerhead (Caretta caretta) and olive ridley (Lepidochelys olivacea) turtles, also tracked from Masirah, revealed remarkably different inter-specific patterns of post-nesting dispersal. High-capacity artisanal fisheries, with undescribed levels of sea turtle bycatch, exist within the region, making introduction of effective conservation measures difficult.

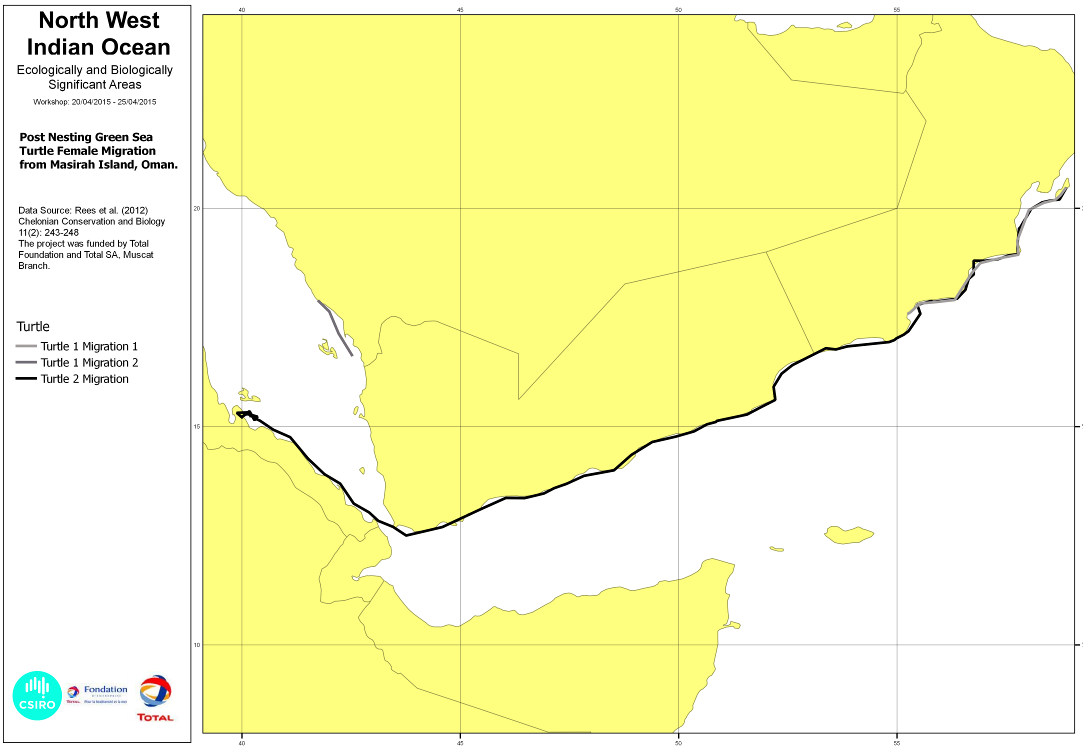


Figure 3.6: Post-nesting migrations of green turtles nesting on Masirah Island, Oman. Turtle 1 (black line) had settled in a foraging area before transmissions ceased. The inset shows the 50% (dark grey) and 75% (light grey) habitat use for turtle 1, derived from16 daily locations over a period of 31 d. Turtle 2 (two-part grey line) had a long period without data (between locations a [in Oman] and b [in Saudi Arabia] on map) before several signals were received in the Red Sea and showed no indication that a foraging area had been reached. The end points of both tracks are indicated by filled circles.

Rees et al. (2012) Chelonian Conservation and Biology, 2012, 11(2): 243248

3.2.3 Behavioural polymorphism in one of the worlds largest populations of loggerhead sea turtles Caretta caretta

To aid management and conservation of widely distributed marine vertebrate species, it is necessary to have a knowledge and understanding of their spatial ecology. We tracked 10 adult female loggerhead turtles Caretta caretta from Masirah Island, Sultanate of Oman, which hosts one of the worlds largest breeding aggregations. Transmitters were specifically deployed early in the nesting season to enable tracking throughout the internesting and post-nesting habitats. Turtles displayed a dichotomy in behaviour during the internesting period, with 6 remaining close to Masirah Island and the others undertaking circuitous oceanic loops, hundreds of kilometres in length. This behaviour did not appear to be related to body size. Tracking-derived minimum clutch frequency was on average ($\pm$ SD) 4.8 $\pm$ 1.2 nests (n = 8 ind.). Post-nesting migrations revealed a propensity towards long-term utilisation of oceanic habitats in the region between Socotra Island (Yemen) and the mainland of Yemen/Oman, with 76 $\pm$ 15.4% of time spent in oceanic habitat (n = 8 ind.). The spatial footprint of our tracked turtles was found to be far less than that of a similar number of turtles that were tagged later in the same season (from a separate unpublished study) and from long-distance returns of flipper tags. The spatial and temporal sub-structuring of the population highlights the need for more comprehensive tracking projects, with deployments across the breeding season in multiple years, in order to obtain reliable estimations of high-use foraging habitats of widely dispersed marine vertebrates. Variation in behaviour patterns suggests the need for diverse conservation measures.

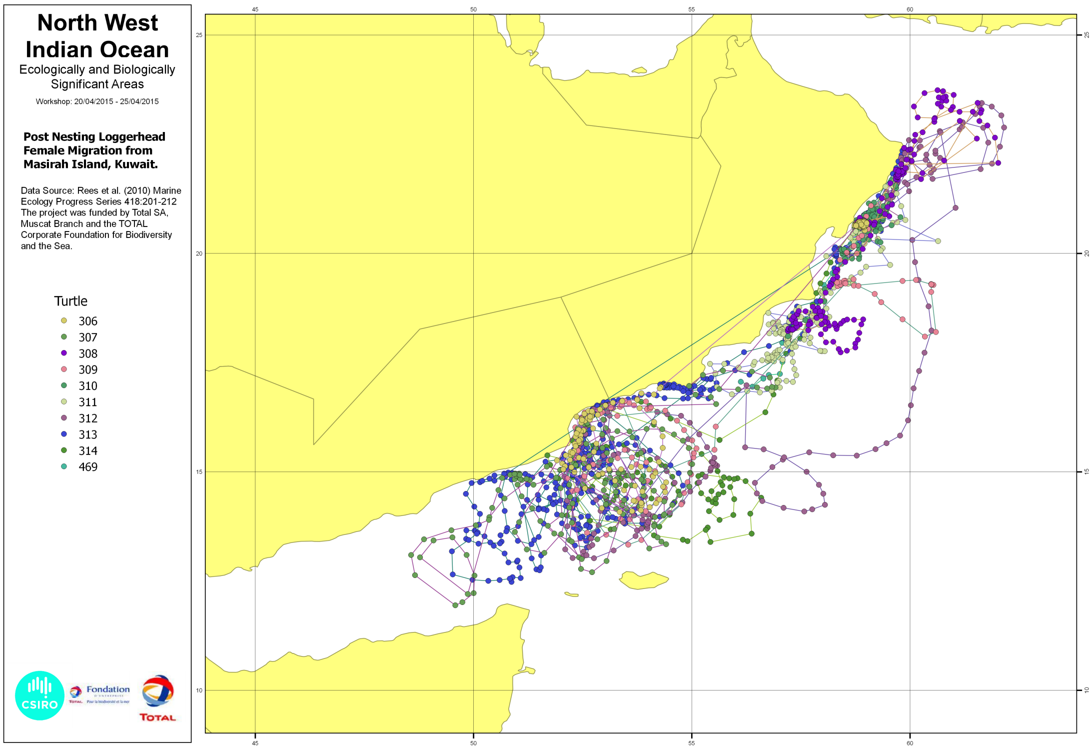


Figure 3.7: Caretta caretta. Post-nesting spatial utilisation of the 10 turtles tracked. Movements of 2 turtles which, despite lengthy tracking ($>$ 250 d), did not migrate into Yemeni waters. The other 6 turtles for which extensive post-nesting movements were obtained

Rees et al. (2010) Marine Ecology Progress Series 418:201-212. doi: 10.3354/meps08767

3.2.4 Green Turtles, Chelonia mydas, in Kuwait: Nesting and Movements

There is a paucity of information on the presence and nesting of green turtles, Chelonia mydas, in Kuwait, and known nesting habitats have been altered in recent years. Through beach monitoring and satellite telemetry, we determined that green turtle nesting is now limited to Qaru Island with 15 turtles nesting annually and that foraging habitats occur along the northern shore of Failaka Island (n = 2 turtles) and coastal region of central Saudi Arabia (n = 1 turtle). Foraging habitat in Kuwait overlaps with a coastal trap-fishery, raising concerns for the conservation of this depleted population

Rees et al. (2013) Chelonian Conservation and Biology, 2013, 12(1): 157163

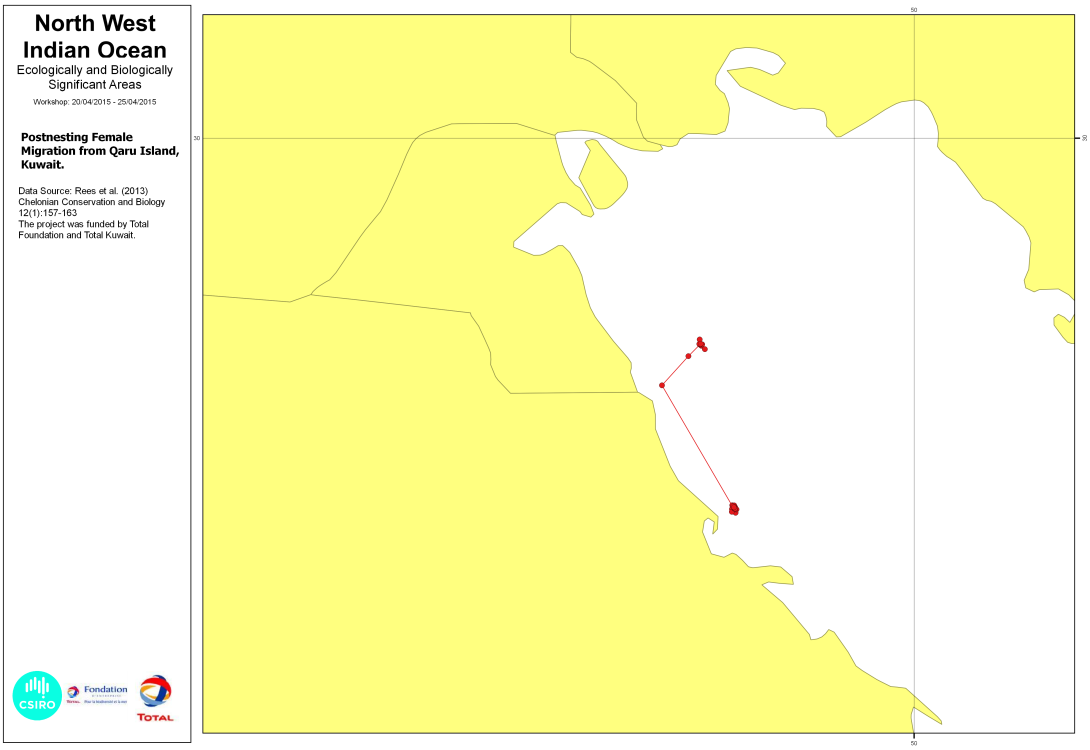


Figure 3.8: Postnesting migration and spatial use of an adult female green turtle tracked from Qaru Island, Kuwait. Basic route of the 3-d migration from the nesting site in the north to foraging location in the south

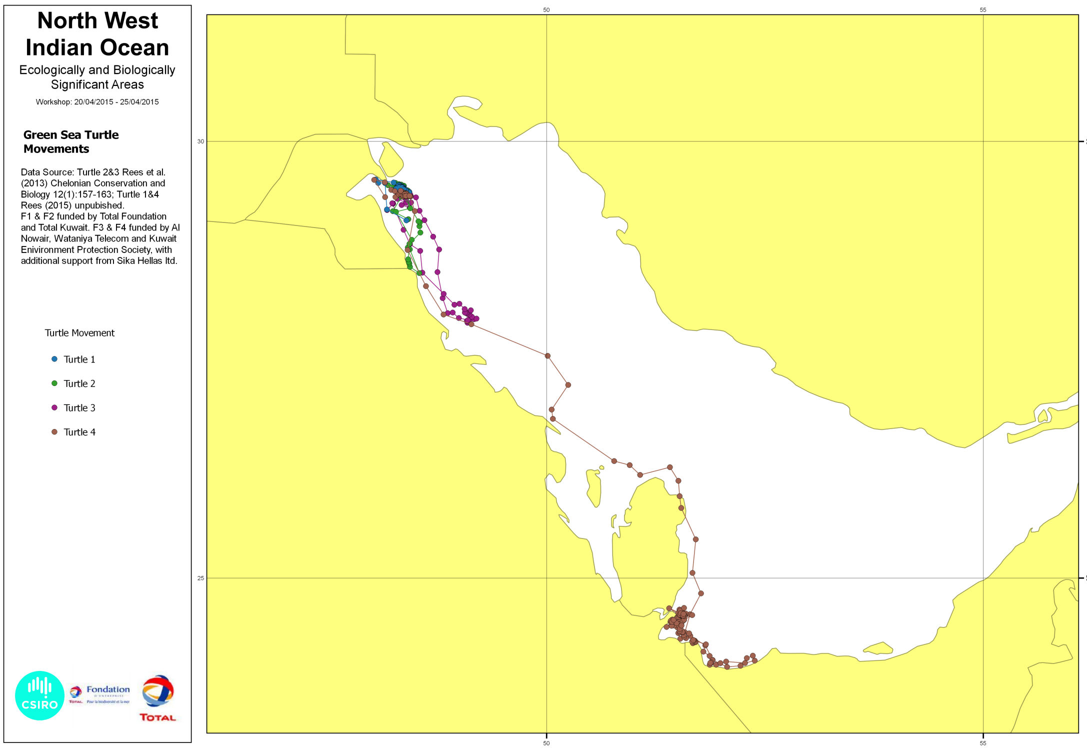


Figure 3.9: Movement patterns of the green turtle, Chelonia mydas.

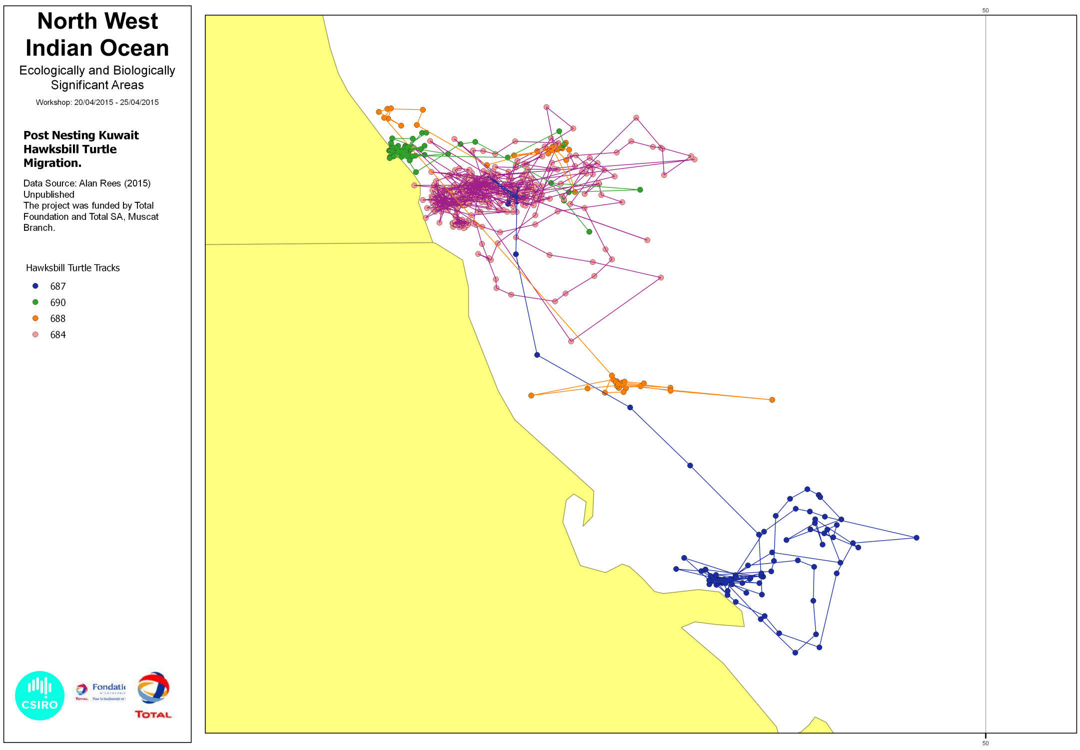
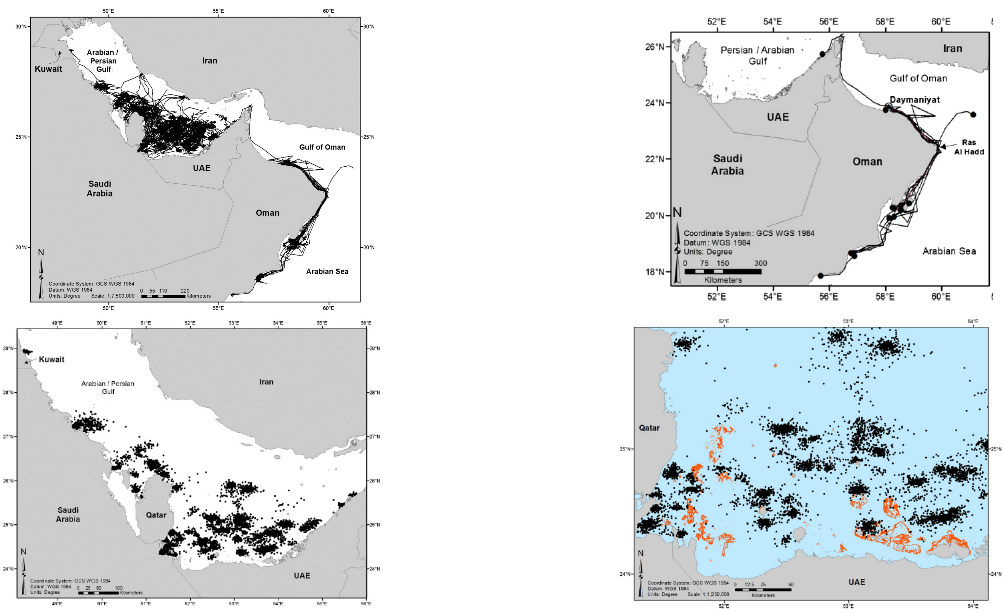


Figure 3.10: Post nesting migraton of Hawksbill Turtles

3.3 Identification of Important Sea Turtle Areas (ITAs) for hawksbill turtles in the Arabian Region

We present the first data on hawksbill turtle post-nesting migrations and behaviour in the Arabian region. Tracks from 90 post-nesting turtles (65 in the Gulf and 25 from Oman) revealed that hawksbills in the Arabian region may nest up to 6 times in a season with an average of 3 nests per turtle. Turtles from Qatar, Iran and the UAE generally migrated south and southwest to waters shared by the UAE and Qatar. A smaller number of turtles migrated northward towards Bahrain, Saudi Arabia and one reached Kuwait. Omani turtles migrated south towards Masirah island and to Quwayrah, staying close to the mainland and over the continental shelf. The widespread dispersal of hawksbill foraging grounds across the SW Gulf may limit habitat protection options available to managers, and we suggest these be linked to preservation of shallow water habitats and fishery management. In contrast, the two main foraging areas in Oman were small and could be candidates for protected area consideration. Critical migration bottlenecks were identified at the easternmost point of the Arabian Peninsula as turtles from Daymaniyat Islands migrate southward, and between Qatar and Bahrain. Overall, Gulf turtles spent 68% of the time in foraging ground with home ranges of 4060 km 2 and small core areas of 6 km 2 . Adult female turtles from Oman were significantly larger than Gulf turtles by 11 cm x 14 81:4 CCL and spent 83% of their time foraging in smaller home ranges with even smaller core areas (3 km 2), likely due to better habitat quality and food availability. Gulf turtles were among the smallest in the world x 14 70:3 CCL and spent an average of 20% of time undertaking summer migration loops, a thermoregulatory response to avoid elevated sea surface temperatures, as the Gulf regularly experiences sustained sea surface temperatures N 30 C. Fishery bycatch was determined for two of the 90 turtles. These spatio-temporal findings on habitat use will enable risk assessments for turtles in the face of multiple threats including oil and gas industries, urban and industrial development, fishery pressure, and shipping. They also improve our overall understanding of hawksbill habitat use and behaviour in the Arabian region, and will support sea turtle conservation-related policy decision-making at national and regional levels.



Pilcher et al. (2014) Short-term behavioural responses to thermal stress by hawksbill turtles in the Arabian region. Journal of Experiemntal Marine Biology and Ecology 457 (2014) 190198.

3.4 The spatial distribution and structure of reef communities in the northeastern Arabian Peninsula

Multivariate analysis revealed distinct sub-regional coral communities among the southern Gulf, the Strait, and Gulf of Oman. Differences in community structure among locations were associated with considerable spatial heterogeneity in oceanic conditions, and strong directional environmental gradients. Despite clear community differences, considerable changes to coral community structure have occurred throughout the northeastern Arabian Peninsula as compared with previous studies. The most dramatic of these are the apparent changes from Acropora dominated to poritid and faviid dominated communities, particularly in the southern Gulf and Strait. Although temperature and salinity have previously been cited as the major environmental factors structuring coral communities around the region, additional environmental parameters, including chlorophyll-a, surface currents and winds are shown to be important in structuring reef communities throughout the northeastern Arabian Peninsula.

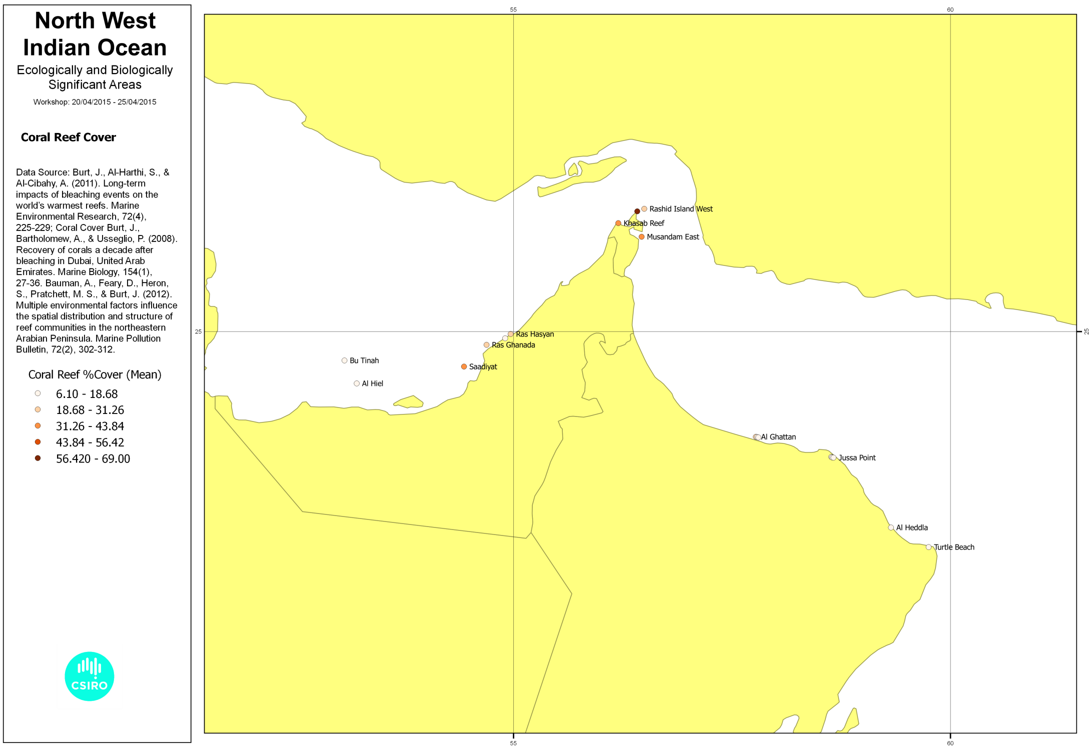


Figure 3.12: Coral Reef Percent Cover

Burt, J., Al-Harthi, S., & Al-Cibahy, A. (2011). Long-term impacts of bleaching events on the worlds warmest reefs. Marine Environmental Research, 72(4), 225-229.

Burt, J., Bartholomew, A., & Usseglio, P. (2008). Recovery of corals a decade after bleaching in Dubai, United Arab Emirates. Marine Biology, 154(1), 27-36.

Bauman, A., Feary, D., Heron, S., Pratchett, M. S., & Burt, J. (2012). Multiple environmental factors influence the spatial distribution and structure of reef communities in the northeastern Arabian Peninsula. Marine Pollution Bulletin, 72(2), 302-312.

3.5 Important Bird Areas

The Important Bird Areas (IBAs) programme of BirdLife International seeks to identify, document and conserve sites that are critical for the long-term viability of bird populations. The programme began in the 1980s and the process of site inventory is very well advanced in the terrestrial environment, with more than 10,000 sites already identified around the world. Conservation actions are underway at many of these sites, many now benefiting from enhanced protection status. Following the success of the IBA approach in the terrestrial and freshwater environment, BirdLife is now adapting and extending the programme to the oceans. BirdLife International (2009) found that there is considerable overlap and congruence between the criteria used to identify marine IBAs and those adopted by the CBD to identify EBSAs. This is particularly so for criteria relating to vulnerability and irreplaceability. BirdLife International manages the Global Procellariiform Tracking Database (www.seabirdtracking.org) a unique collaboration between many of the worlds seabird tracking scientists. The relevant data were made available to run an IBA analysis for this region, and the resulting sites are included on the map. Three types of tracking device are available; Platform Transmitter Transponders (PTT), Global Positioning Systems (GPS) and Geolocators (GLS). Location estimates derived from each of these systems have different accuracies, GPS data being accurate to meters, PTT to within 50km and GLS data being the most erroneous, with a mean error of 186km. PTT and GPS data were combined and analysed together because erroneous fixes were within the large-scale foraging movements being investigated. However, Because GLS data include much more error (and also only provides two fixes per day) they are treated separately, and only used directly for triggering sites as IBA during non-breeding migrations, when the birds movements were much larger than (and therefore distinguishable from) the erroneous locations.

BirdLife International maintains an online database (http://seabird.wikispaces.com/) of seabird ecology and foraging ranges, as a basis for identifying key foraging areas around breeding sites that qualify as IBAs. The majority of congregatory seabirds are central place foragers during the breeding season returning to their breeding colony regularly to share incubation duties or feed chicks. These species, many of which forage in association with pelagic fish schools, radiate from colonies with individual and inter-trip variation in the distance travelled from the colony. Identifying foraging areas up to the maximum foraging range recorded would be a poor representation of the foraging area for the majority of birds, since these extremes apply to only a small percentage of birds. The approach adopted here was to define sites based on their importance to a greater proportion of the colony, and this was done by selecting the maximum range to which IBA threshold numbers of a trigger species travelled.

BirdLife International (2010). Marine Important Bird Areas toolkit: standardised techniques for identifying priority sites for the conservation of seabirds at sea. BirdLife International, Cambridge UK. Version 1.2: February 2011 http://www.birdlife.org/eu/pdfs/Marinetoolkitnew.pdf

BirdLife International (2009). Designing networks of marine protected areas: exploring the linkages between Important Bird Areas and ecologically or biologically significant marine areas. Cambridge, UK: BirdLife International. http://www.cbd.int/doc/meetings/mar/ewbcsima-01/other/ewbcsima-01-birdlife-02-en.pdf

O'Brien, M., and Waugh, S.M. 2010. Important Bird Areas in the Pacific 2010. Unpublished report to BirdLife International. http://www.sprep.org/publication/pub_detail.asp?id=857

Ramrez I., P. Geraldes, A. Meirinho, P. Amorim & V. Paiva (2008). reas Marinhas Importantes para as Aves em Portugal. Projecto LIFE04NAT/PT/000213 - Sociedade Portuguesa Para o Estudo das Aves. Lisboa

Arcos, J.M., J. Bcares, B. Rodrguez y A. Ruiz. 2009. reas Importantes para la Conservacin de las Aves marinas en Espaa. LIFE04NAT/ES/000049-Sociedad Espaola de Ornitologa (SEO/BirdLife). Madrid.

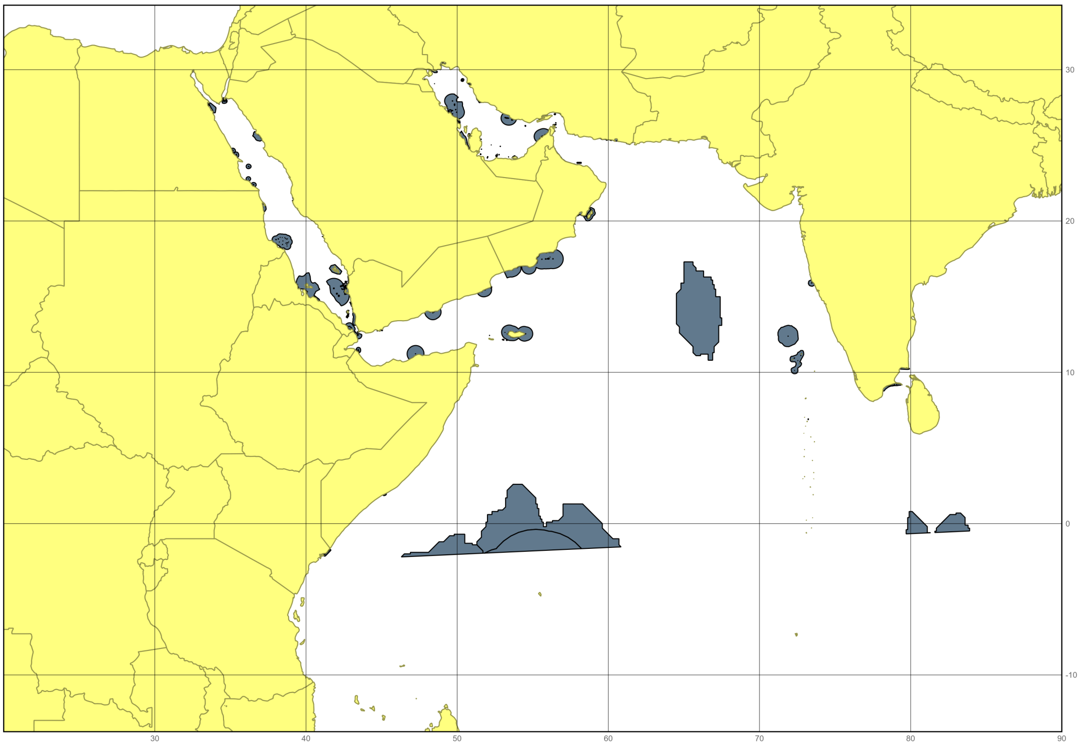


Figure 3.13: Important Bird Areas (IBA)

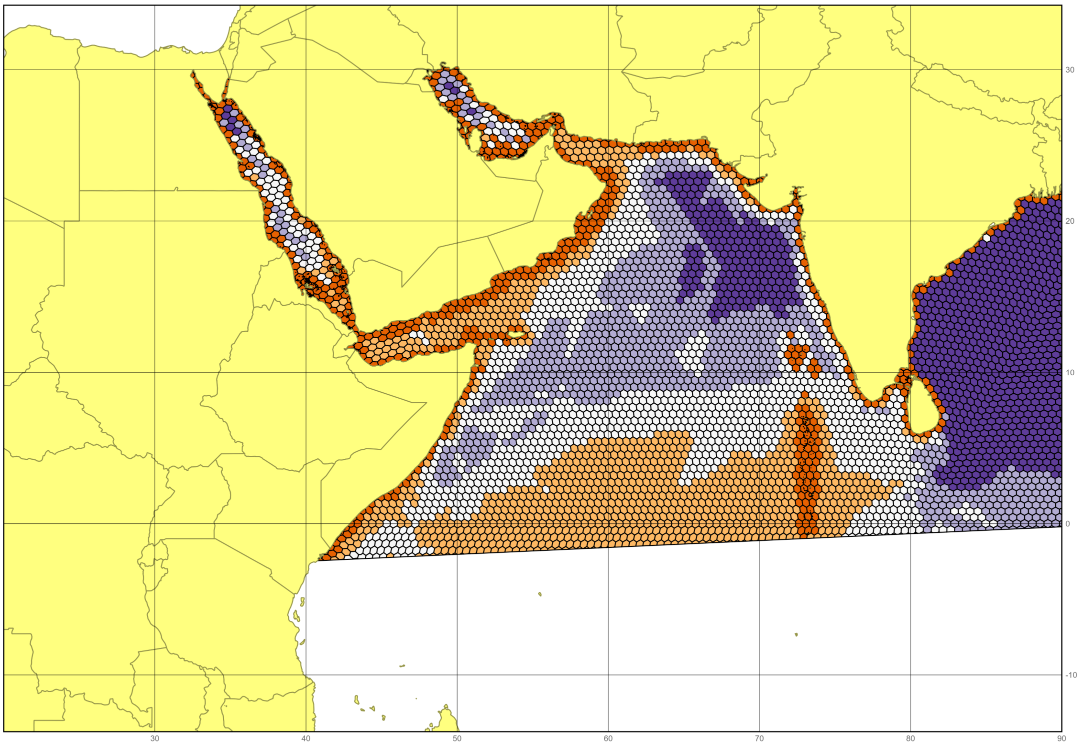


Figure 3.14: Important Bird Areas (IBA)

3.6 Predictions of Deep Sea Corals

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 km2) global grids for environmental, chemical and physical data of the worlds 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 modelling efforts to identify vulnerable marine ecosystems for inclusion in future marine protected areas and reduce coral bycatch by commercial fisheries.

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

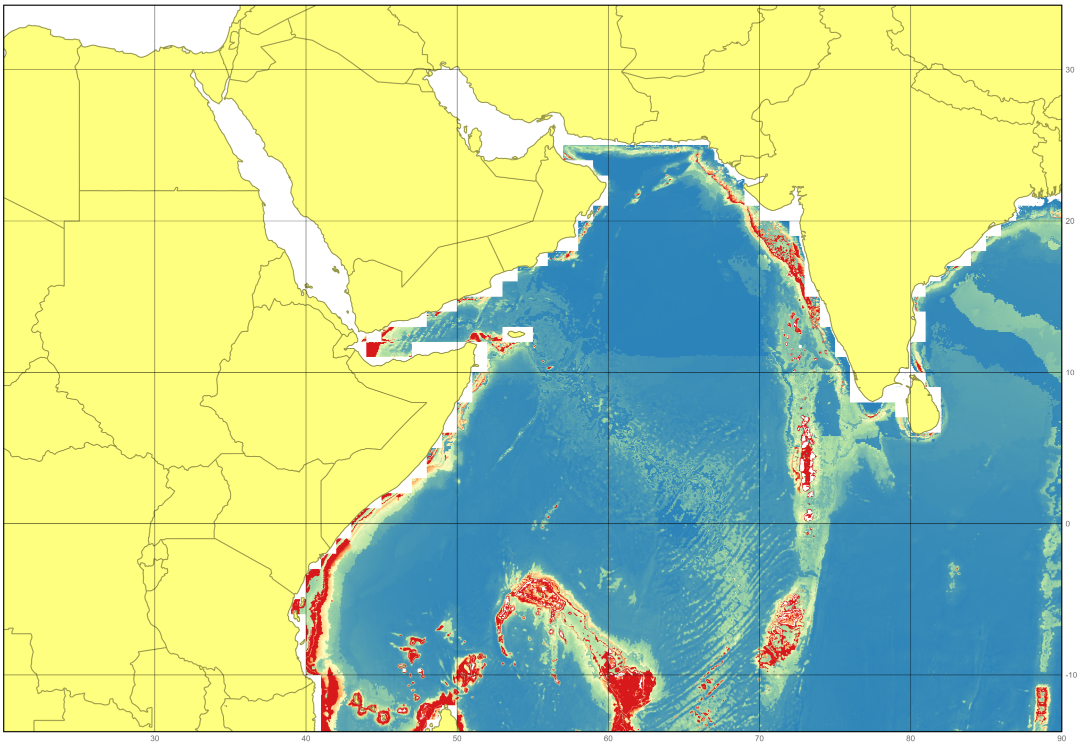


Figure 3.15: Predictions for Solenosmillia variabilis

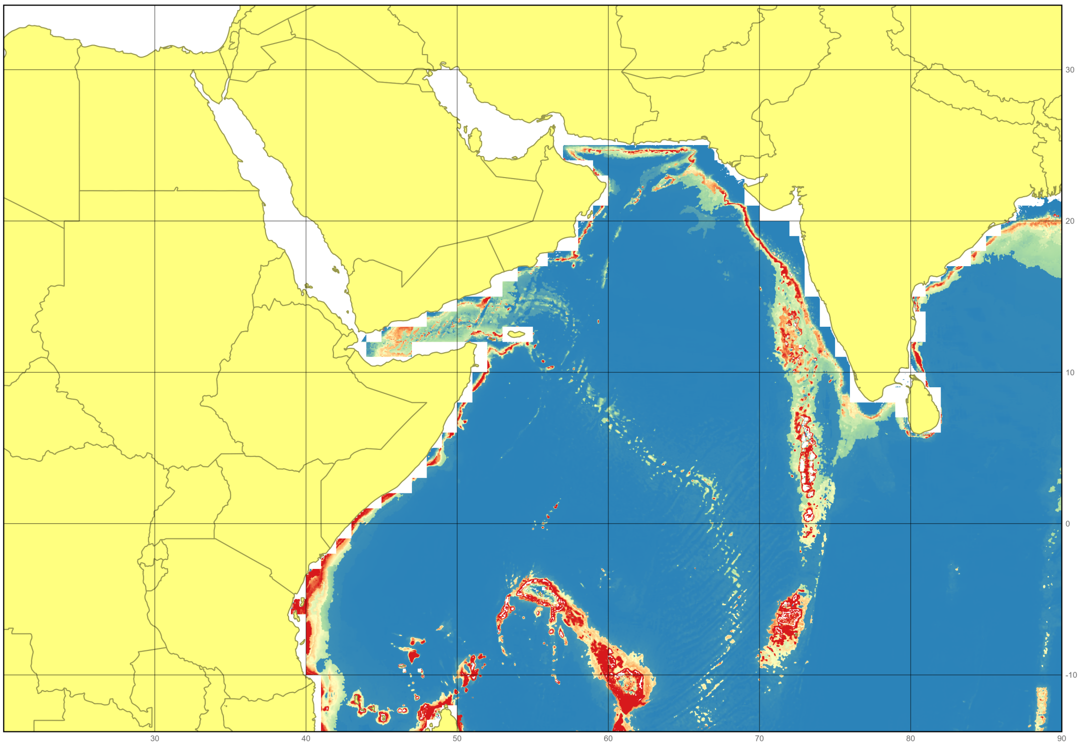


Figure 3.16: Predictions for Enallopsammia rostrata

3.7 OBIS Data

The concept of OBIS was first developed at a conference sponsored by the Census of Marine Life (CoML) in 1997. At the time, a comprehensive system for the retrieval of ocean biological data did not exist. The databases that did exist to distribute ocean biological data failed to ”usefully summarize known distributions and abundance of marine life nor are they organized to encouraged frequent use or intercomparison of datasets” (Grassle 2000). The problems generated by this disenfranchisement of marine data from the frequent user are very serious ones: if scientists cannot efficiently collect and effectively share data about the oceans with each other, how will anyone be able to generate new, comprehensive hypotheses about our oceans? If new findings about the oceans remain localized and hidden from the rest of the marine science community, then the data fails to have an impact on research in the marine science community at large.

Not long after the initial meeting, OBIS was established as a project of the Census of Marine Life to help facilitate global enfranchisement of data within the scientific community. The goal of OBIS was simple: to create ”an online, user-friendly system for absorbing, integrating, and accessing data about life in the oceans” (Grassle 2000). The system would stimulate taxonomic and systematic research and generate new hypotheses concerning: - evolutionary processes - factors related to maintainance of species distributions - roles of marine organisms in marine ecosystem function (Grassle 2000).

For the last decade, the OBIS community has worked tirelessly to make sure that all data contributed to OBIS from hundreds of providers is available to the public through its search interface. In many ways, the OBIS database has become the database that the OBIS community envisioned at its creation.

But OBIS is still evolving: OBIS hopes to become even more user friendly, appealing to both the scientific community and the common internet user. The OBIS community promotes an open access policy and believes that data collected about the oceans should be easily accessible to a diverse set of users.

The data provided here are summaries of OBIS data avaiable. Species Richness and ES(50) data summaries for 1^o grids in the Western South Pacific are provided for all species, deep species($>$100m depth), shallow species ($<$100m depth), all mammals and turtles.

http://www.iobis.org/

3.7.1 All Species

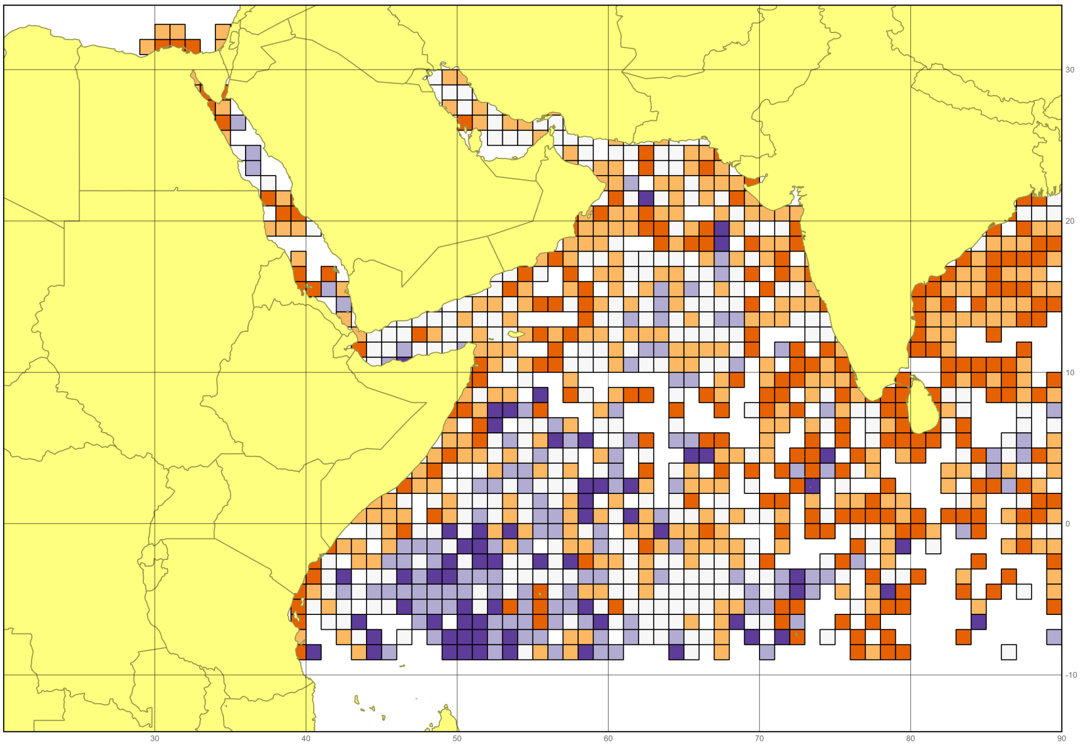


Figure 3.17: OBIS ES(50) for all species

3.7.2 Shallow Species

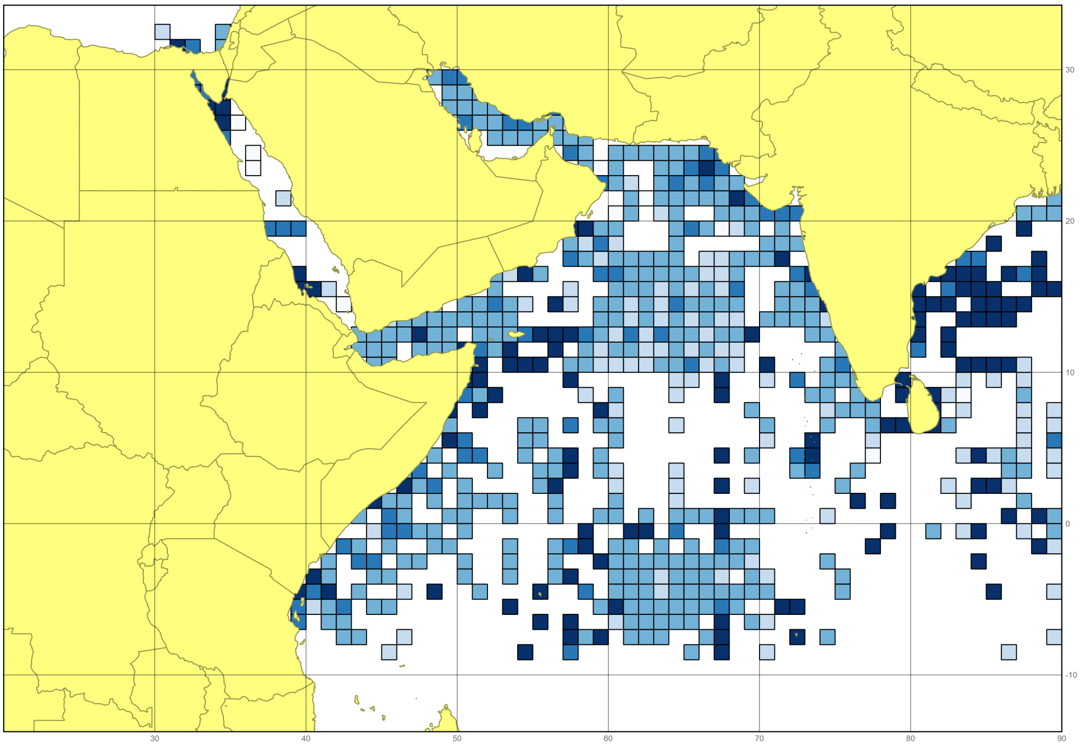


Figure 3.18: OBIS ES(50) for shallow species

3.7.3 Deep Species

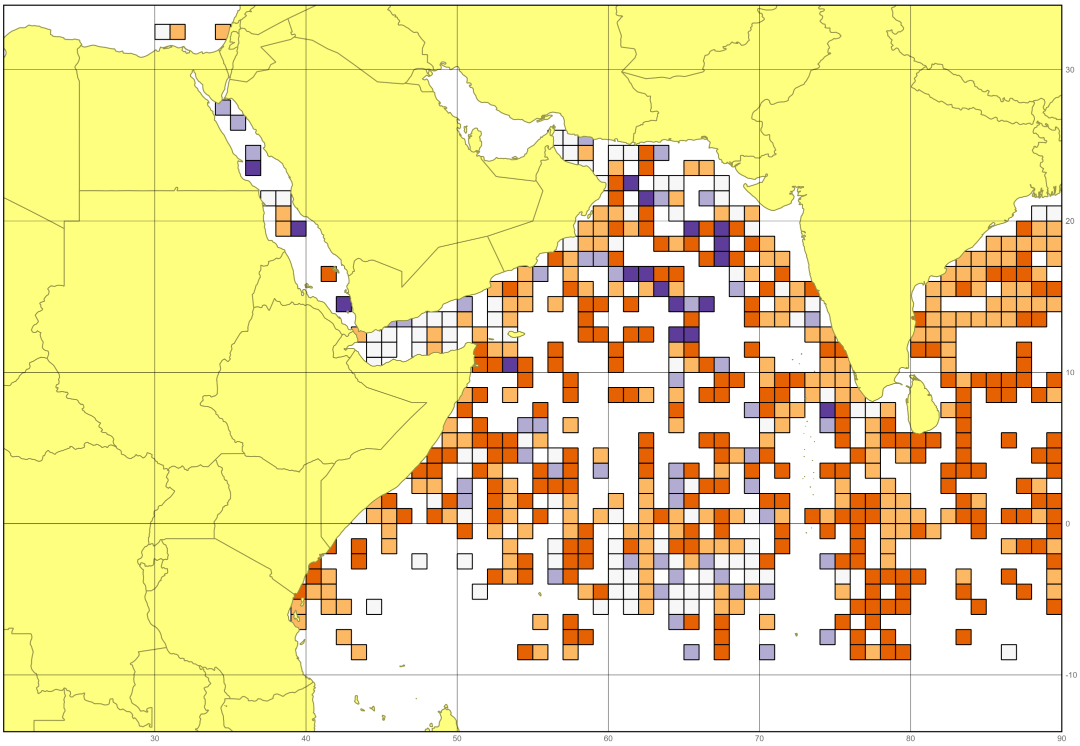


Figure 3.19: OBIS ES(50) for deep species

3.8 Historical Whale Catches

The Wildlife Conservation Society has digitally captured the Townsend Whaling Charts that were published as a series of 4 charts with the article titled ”The distribution of certain whales as shown by logbook records of American whale ships” by Charles Haskins Townsend in the journal Zoologica in 1935.

The 4 charts (of which three are used here) show the locations of over 50,000 captures of 4 whale species; sperm whales (36,908), right whales (8,415), humpback whales (2,883) and bowhead whales(5,114). Capture locations were transcribed from North American (Yankee) pelagic whale vessel log books dating from 1761 to 1920 and plotted onto nautical charts in a Mercator projection by a cartographer. Each point plotted on the charts represents the location of a whaling ship on a day when one or more whales were taken and is symbolized by month of the year using a combination of color and open and closed circles.

Townsend and his cartographer plotted vessel locations as accurately as possible according to log book records. When plotting locations on an earlier sperm whale chart published in 1931 the cartographer spaced points where locations were very dense, extending areas slightly for a number of whaling grounds. However for charts in preparation at this time Townsend states that this difficulty is avoided by omitting some of the data, rather than extend the ground beyond actual whaling limits. We assume that this statement refers to the 1935 charts but there is still some question as to whether the cartographer did in fact space locations and thus expand whaling grounds

Digitizing errors include missed points, particularly from areas of dense chart locations, and incorrect assignment of month of capture because of difficulty distinguishing between chart colors. However to limit these errors multiple checks of digitized and chart locations were made and color enhancements of chart scans were used to ensure correct month assignments. Overall we are confident that at least 95% of catch locations have been digitized and that at least 95% of month attributes are correct.

Townsend, C.H. 1935. The distribution of certain whales as shown by logbook records of American whaleships. Zoologica 19, No. 1:1-50, 4 charts.

Townsend, C.H. 1931. Where the nineteenth century whaler made his catch. Zoologica 34, No. 6:173-179.

Reeves, R., Smith, T.D. Josephson, E.A., Clapham, P.J. and Woolmer, G. 2004. Historical observations of humpback and blue whales in the North Atlantic Ocean: Clues to migratory routes and possibly additional feeding grounds. Marine Mammal Science. Vol. 20 (4), pg 774-786.

http://web.archive.org/web/20070926224128/http:/wcs.org/townsend_charts

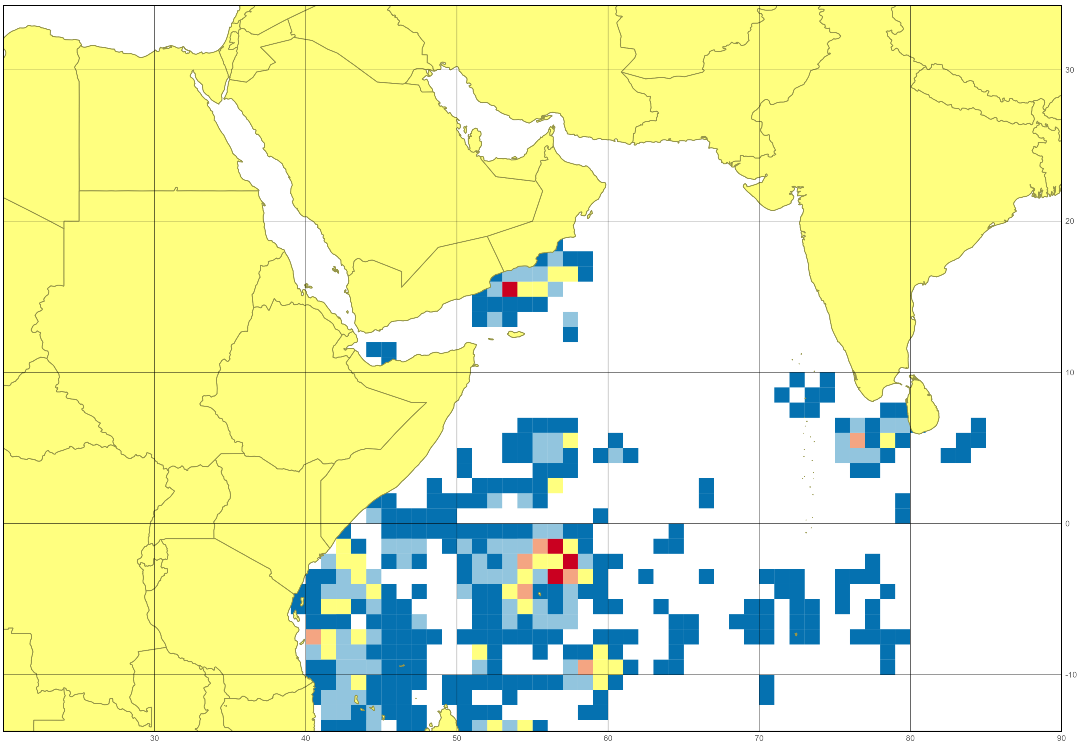


Figure 3.20: Annual Historical Captures of Sperm Whales per 1^o square

3.9 Global Distribution of Coral Reefs (2010)

The dataset represents the global distribution of warm water coral reefs and should be seen an interim global product. It has been compiled from a number of data sources which have been merged together by UNEP-WCMC and the WorldFish Centre in collaboration with WRI and TNC. It supersedes the dataset used in the World Atlas of Coral Reefs (2001), although some aspects of this product still originate from that data source. This amalgamated dataset has been created to further mobilise the Millennium Coral Reef Map Products and their validation. This data set should by no means replace the official release of the Millennium coral reef map and users should always check at the official sites for the most up-to-date available information. This dataset does not contain the full 5 level geomorphological categorisation. In part, for the validated products, it maintains the simplified Reefbase subset but for the remaining areas i.e. the unvalidated data and data from other sources, there is only a single class to indicate coral reef.

The Approximate coverage of data sources are as follows - Millennium Coral Reefs (Unvalidated) 50 - Millennium Coral Reefs (Validated) 30 - Other sources 20

The dataset comprises 3 main components and must be cited in the following manner strictly maintaining the three separate entities in their entirety: -

1. Millennium Coral Reef Mapping Project validated maps provided by the Institute for Marine Remote Sensing, University of South Florida (IMaRS/USF) and Institut de Recherche pour le Dveloppement (IRD, Centre de Nouma), with support from NASA.
2. Millennium Coral Reef Mapping Project unvalidated maps provided by the Institute for Marine Remote Sensing, University of South Florida (IMaRS/USF), with support from NASA. Unvalidated maps were further interpreted by UNEP-WCMC. Institut de Recherche pour le Dveloppement (IRD, Centre de Nouma) do not endorse these products.
3. Other data have been compiled from multiple sources by UNEP-WCMC. Full source information is attached to individual polygons. For display and use of data below the global scale please check and cite individual data sources according to the citations within the full source table provided with this dataset

http://data.unep-wcmc.org/datasets/13

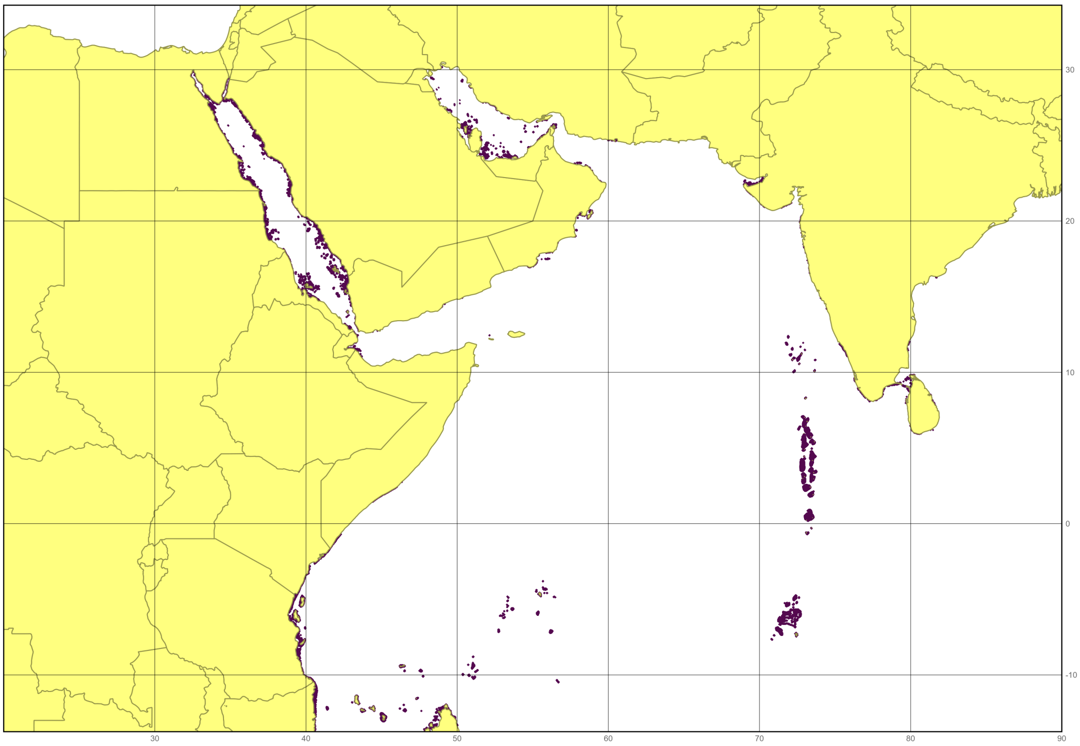


Figure 3.21: Global Distribution of Coral Reefs (2010)

3.10 Global Mangroves USGS (2011)

Status and distributions of global mangroves have been mapped using recently available Global Land Survey (GLS) data and the Landsat archive. Approximately 1000 Landsat scenes were interpreted using hybrid supervised and unsupervised digital image classification techniques. Each image was normalized for variation in solar angle and earth-sun distance by converting the digital number values to the top-of-the-atmosphere reflectance. Ground truth data and existing maps and databases were used to select training samples and also for iterative labelling. Results were validated using existing GIS data and the published literature to map true mangroves.

Citation: C. Giri [1]*, E. Ochieng [2], L. L. Tieszen [3], Z. Zhu [4], A. Singh [5], T. Loveland [3], J. Masek [6] and N. Duke [7] [1] ARSC Research and Technology Solutions, contractor to US Geological Survey (USGS) Earth Resources Observation and Science Center (EROS), Sioux Falls, SD 57198, USA, [2] United Nations Environment Programme, United Nations Avenue, Gigiri, PO Box 30552, 00100, Nairobi, Kenya, [3] US Geological Survey, Earth Resources Observation and Science Center (EROS), Sioux Falls, SD 57198, USA, [4] US Geological Survey, Reston, VA 20192, USA, [5] United Nations Environment Programme, Washington, DC 20006, USA, [6] Goddard Space Flight Center, National Aeronautics and Space Administration, Greenbelt, MD 20771, USA, [7] Centre for Marine Studies, Marine Botany Group, c/-Gehrmann Building (60), Level 8, The University of Queensland, Brisbane, QLD 4072, Australia

http://data.unep-wcmc.org/datasets/21

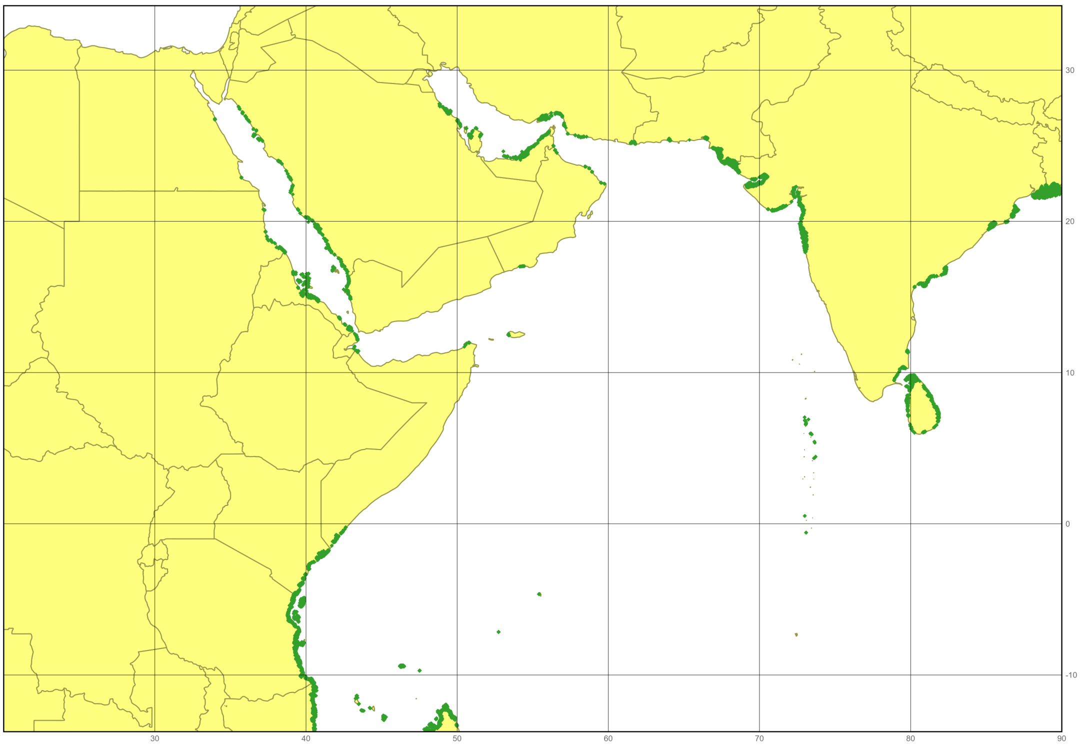


Figure 3.22: Global Distribution of Coral Reefs Mangroves (2011)

3.11 Global Distribution of Seagrass Species

The seagrass dataset has been compiled by UNEP-WCMC in collaboration with Dr Frederick T. Short, University of New Hampshire, USA to show the global distribution of seagrass species. This dataset has been created from multiple sources and was used in the creation of the World Atlas of Seagrasses(2003). This polygon feature dataset is an update of the data used in the Atlas and is a unique data holding about the state of the worlds seagrasses. For a complete overview of global seagrass distribution this dataset should be displayed together with the associated point dataset.

http://data.unep-wcmc.org/datasets/10

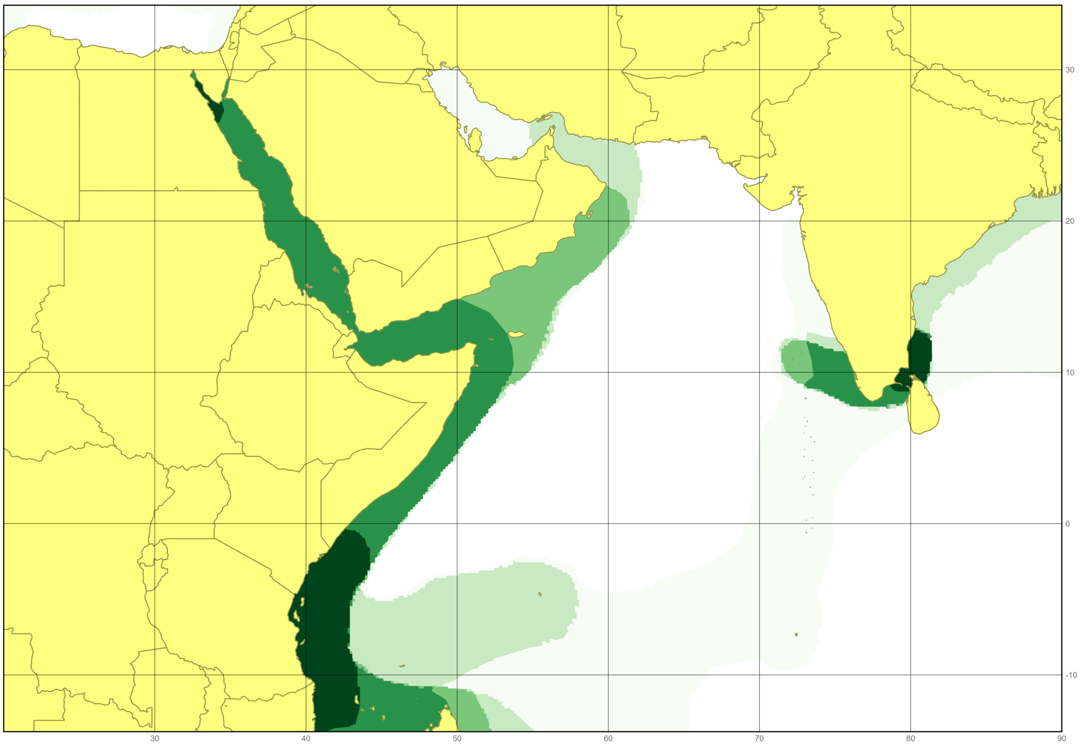


Figure 3.23: Global Distribution of Seagrass Species

4 Physical Data

4.1 Seamount Locations

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-sec 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 o 1.5 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.

Yesson, C., et al., The global distribution of seamounts based on 30 arc seconds bathymetry data. Deep-Sea Research I (2011), doi:10.1016/j.dsr.2011.02.004

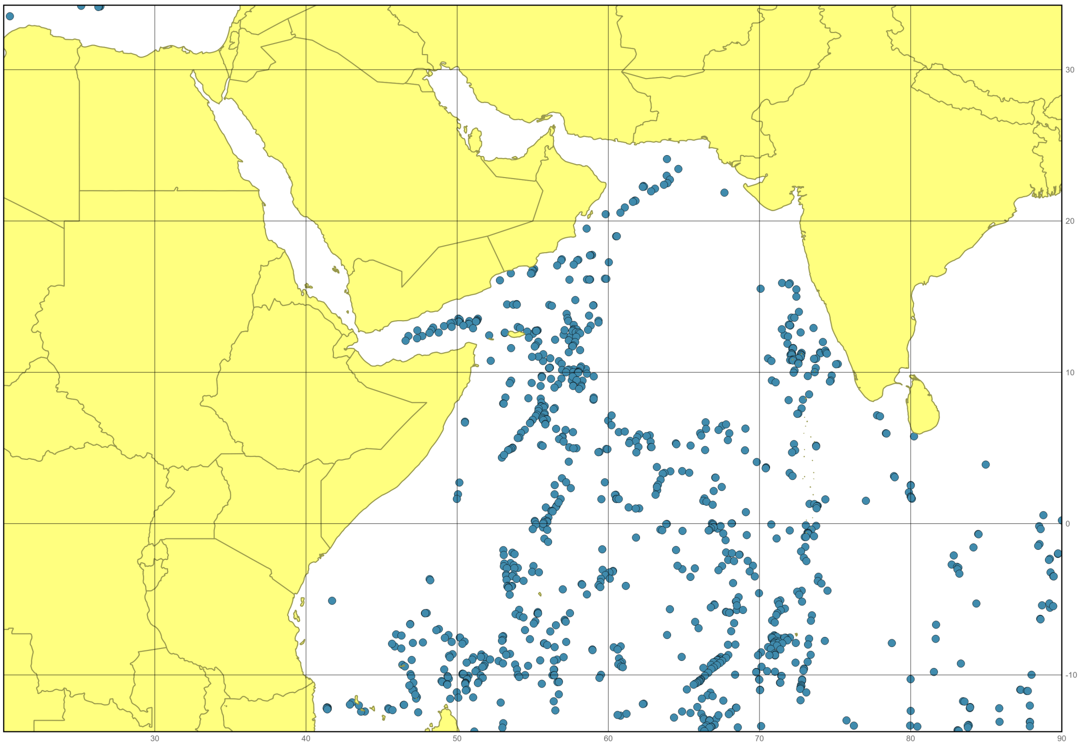


Figure 4.1: Locations of seamounts

4.2 Geomorphology of the oceans

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 km 2 where the gradient exceeds 5, compared with 1.3 million km 2 on passive margin slopes; the continental rise covers 27 million km 2 adjacent to passive margins and less than 2.3 million km 2 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.

Harris, P.T., et al., Geomorphology of the oceans, Marine Geology (2014) http://dx.doi.org/10.1016/j.margeo.2014.01.011

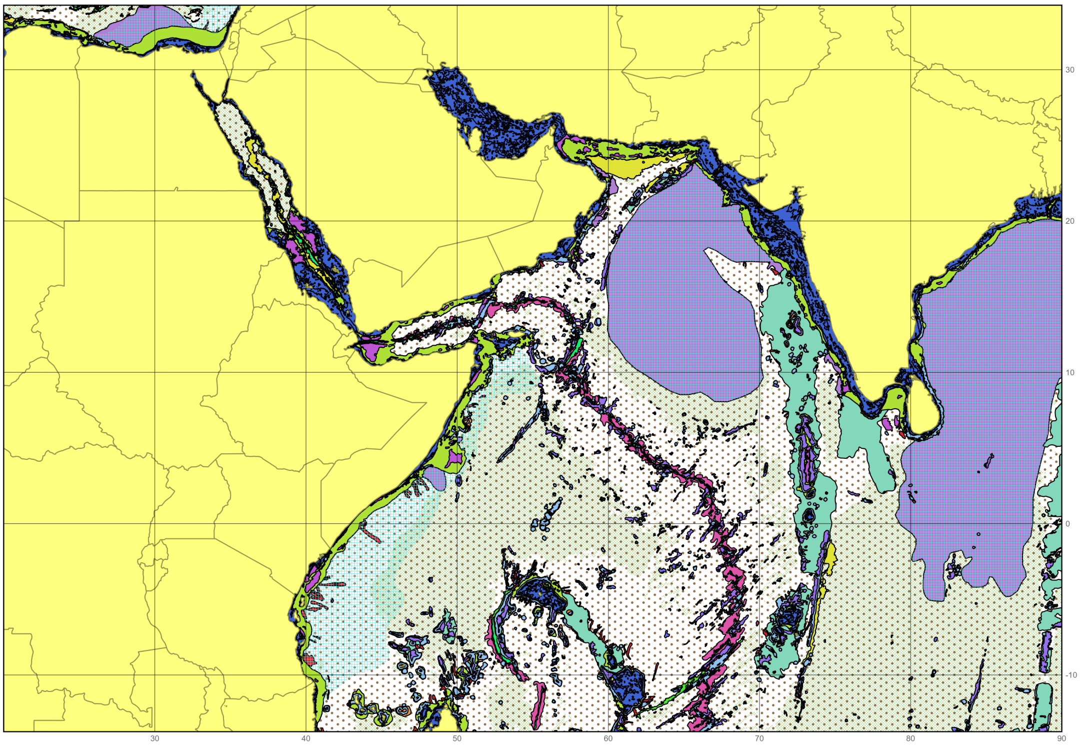


Figure 4.2: Geomorphology of the oceans

4.3 Global Seascapes

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.

Harris and Whiteway 2009. High seas marine protected areas: Benthic environmental conservation priorities from a GIS analysis of global ocean biophysical data.Ocean & Coastal Management 52 2238. doi:10.1016/j.ocecoaman.2008.09.009
http://www.gebco.net/data_and_products/gridded_bathymetry_data/
http://www.ngdc.noaa.gov/mgg/sedthick/sedthick.html
http://www.nodc.noaa.gov/OC5/WOA09/pr_woa09.html

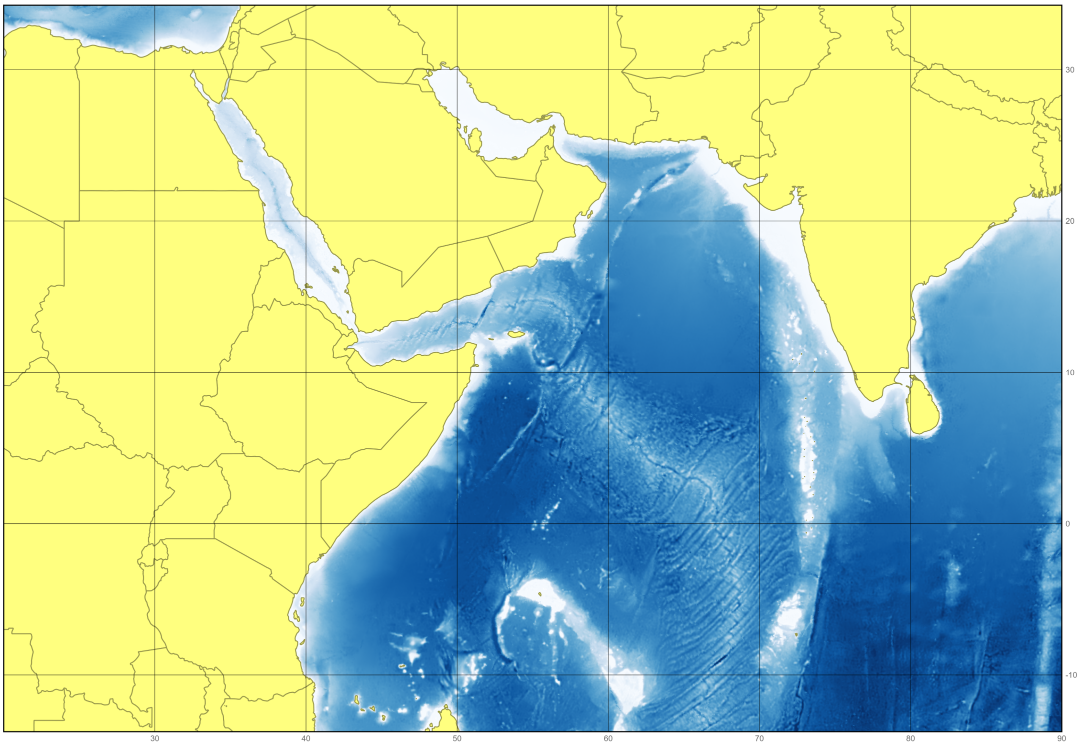


Figure 4.3: GEBCO, a global 30 arc-second grid largely generated by combining quality-controlled ship depth soundings with interpolation between sounding points guided by satellite-derived gravity data. However, in areas where they improve on the existing GEBCO 08 grid, data sets generated by other methods have been included. Land data are largely based on the Shuttle Radar Topography Mission (SRTM30) gridded digital elevation model.

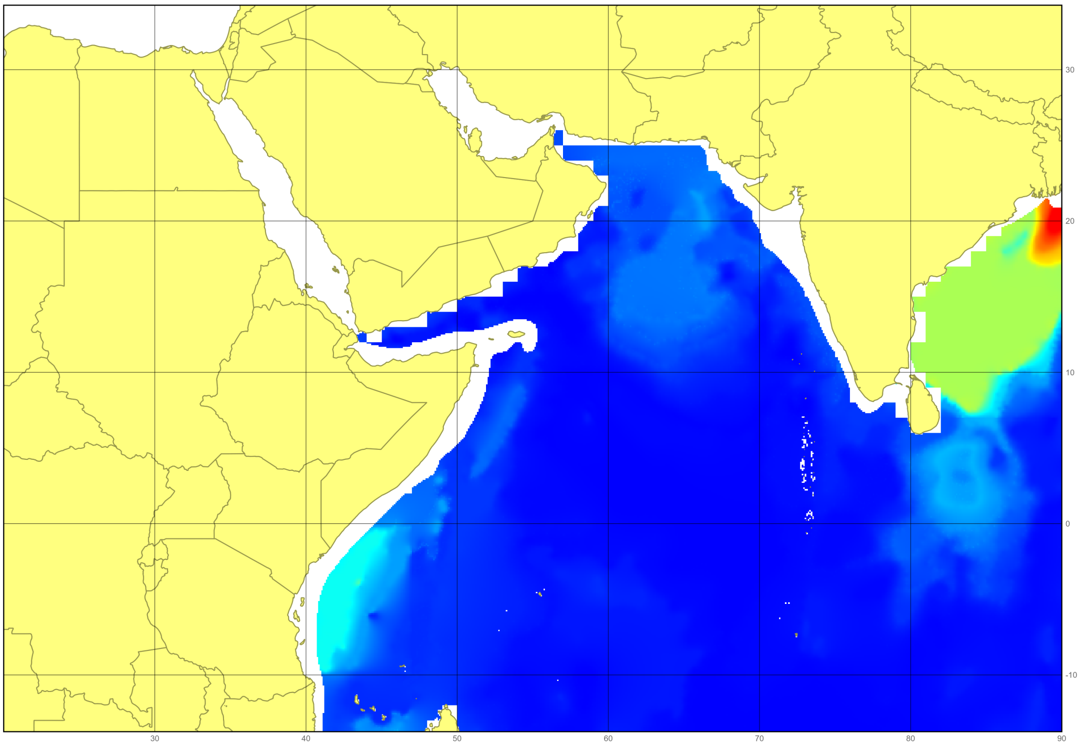


Figure 4.4: Total Sediment Thickness of the Worlds Oceans & Marginal Seas is a digital total sediment thickness database for the worlds oceans and marginal seas compiled by the National Geophysical Data Center (NGDC). The 5 min (w9 km) grid of sediment thickness data were derived from a number of sources by Divins [24]. Note data gaps occur in the area south of Japan, in the Arctic Ocean and Mediterranean Sea, which are not included in this analysis. Sediment thickness Divins DL. National geophysical data center total sediment thickness of the world's oceans and marginal seas.

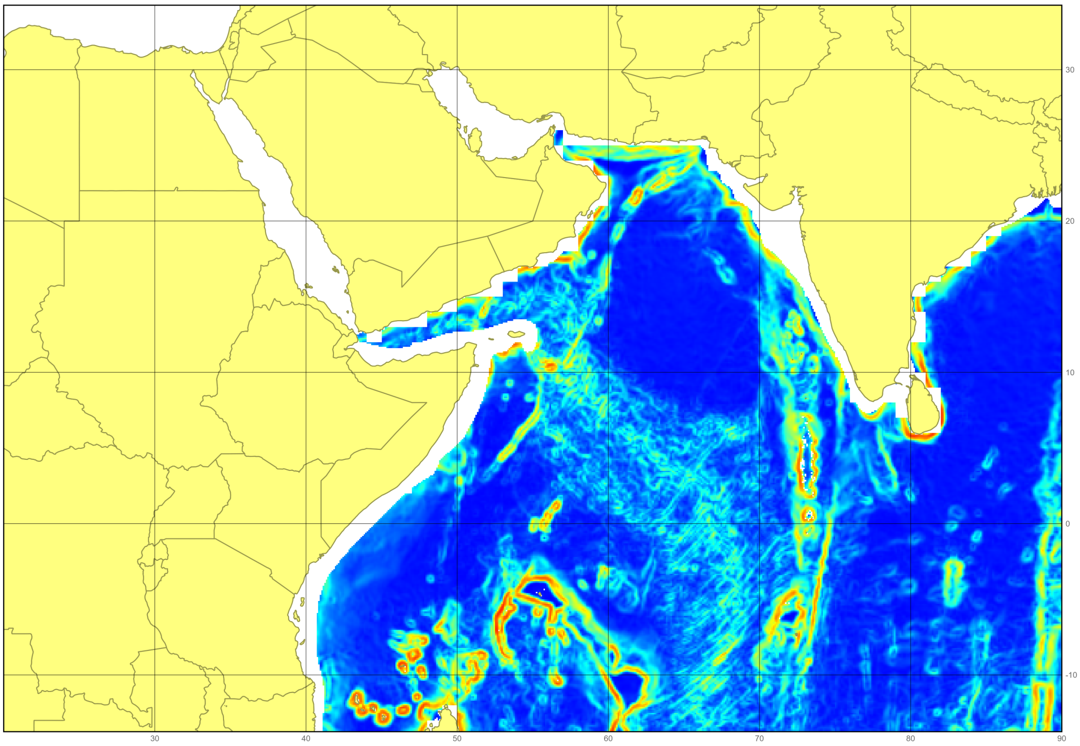


Figure 4.5: Map showing the distribution of seabed slope. Derivation of seabed slope from the ETOPO-2 bathymetry grid used an algorithm in ArcGIS that calculates the maximum slope in a grid cell from the surrounding 8 cells. We found this method gave unrealistically high slope values, presumably due to the noise inherent in the ETOPO-2 bathymetry grid which is accentuated when the maximum slope values between adjacent cells are measured. In order to produce a more realistic estimate of slope, we first smoothed the ETOPO-2 bathymetry grid using a 10-cell moving average filter which we found gave reasonable slope values. Slope derived from ETOPO-2. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Geophysical Data Center. 2-minute Grided Global Relief Data; 2006.

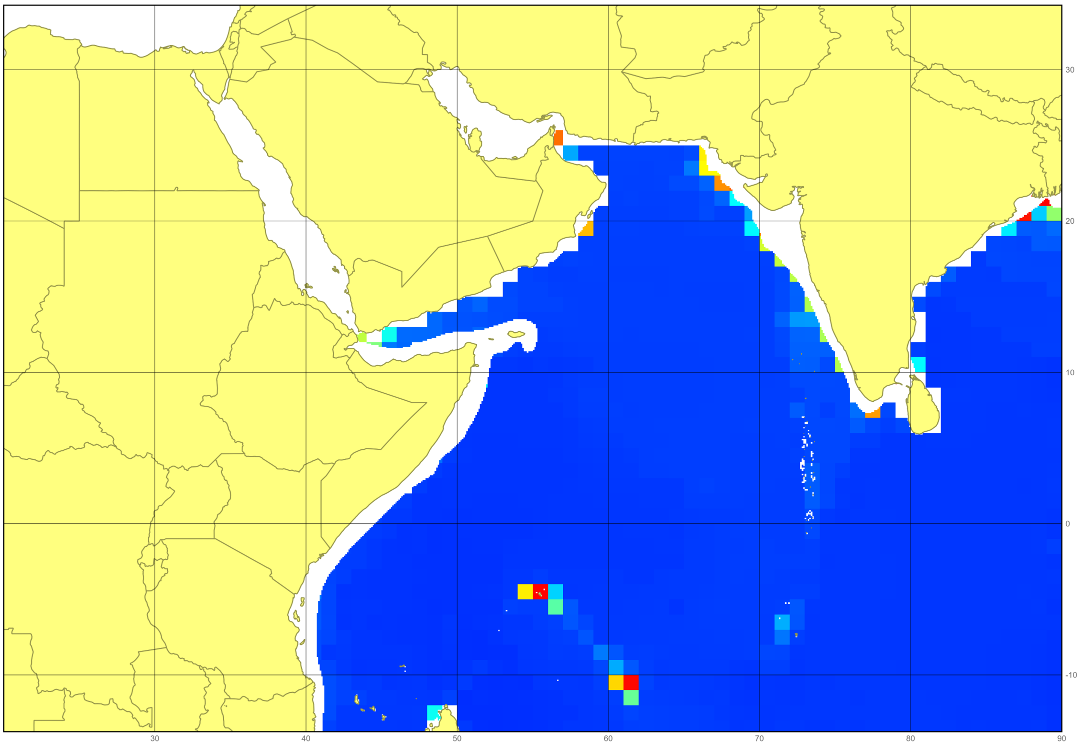


Figure 4.6: Ocean bottom water temperature from the NOAA World Ocean Atlas

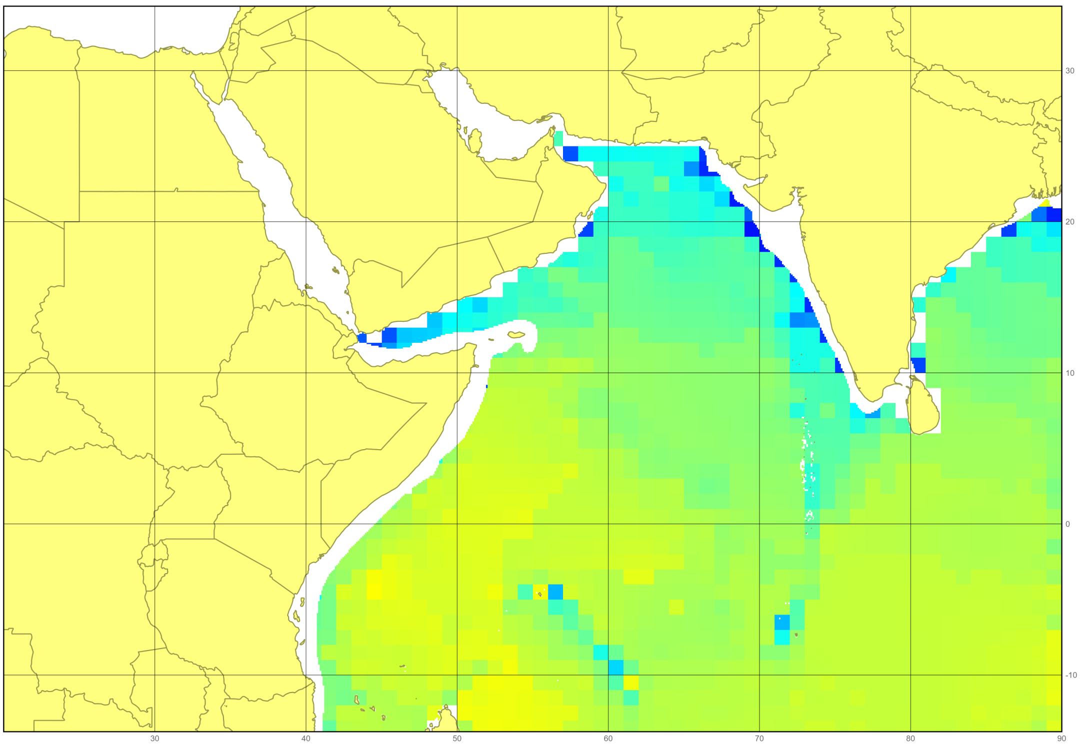


Figure 4.7: Ocean bottom water dissolved oxygen from the NOAA World Ocean Atlas

4.4 Distribution of Canyons

The aim of this study is to assess the global occurrence of large submarine canyons to provide context and guidance for discussions regarding canyon occurrence, distribution, geological and oceanographic significance and conservation. Based on an analysis of the ETOPO1 data set, this study has compiled the first inventory of 5849 separate large submarine canyons in the world ocean. Active continental margins contain 15% more canyons (2586, equal to 44.2% of all canyons) than passive margins (2244, equal to 38.4%) and the canyons are steeper, shorter, more dendritic and more closely spaced on active than on passive continental margins. This study confirms observations of earlier workers that a relationship exists between canyon slope and canyon spacing (increased canyon slope correlates with closer canyon spacing). The greatest canyon spacing occurs in the Arctic and the Antarctic whereas canyons are more closely spaced in the Mediterranean than in other areas. River-associated, shelf-incising canyons are more numerous on active continental margins (n = 119) than on passive margins (n = 34). They are most common on the western margins of South and North America where they comprise 11.7% and 8.6% of canyons respectively, but are absent from the margins of Australia and Antarctica. Geographic areas having relatively high rates of sediment export to continental margins, from either glacial or fluvial sources operating over geologic timescales, have greater numbers of shelf-incising canyons than geographic areas having relatively low rates of sediment export to continental margins. This observation is consistent with the origins of some canyons being related to erosive turbidity flows derived from fluvial and shelf sediment sources. Other workers have shown that benthic ecosystems in shelf-incising canyons contain greater diversity and biomass than non-incising canyons, and that ecosystems located above 1500 m water depth are more vulnerable to destructive fishing practices (bottom trawling) and ocean acidification caused by anthropogenic climate change. The present study provides the means to assess the relative significance of canyons located in different geographic regions. On this basis, the importance of conservation for submarine canyon ecosystems is greater for Australia, islands and northeast Asia than for other regions. Three different types were identified; (1) incise the shelf and connect to rivers, (2) incise the shelf and (3) confined to the slope.

Harris and Whiteway 2011. Global distribution of large submarine canyons: Geomorphic differences between active and passive continental margins. Marine Geology 285 (2011) 6986. doi:10.1016/j.margeo.2011.05.008

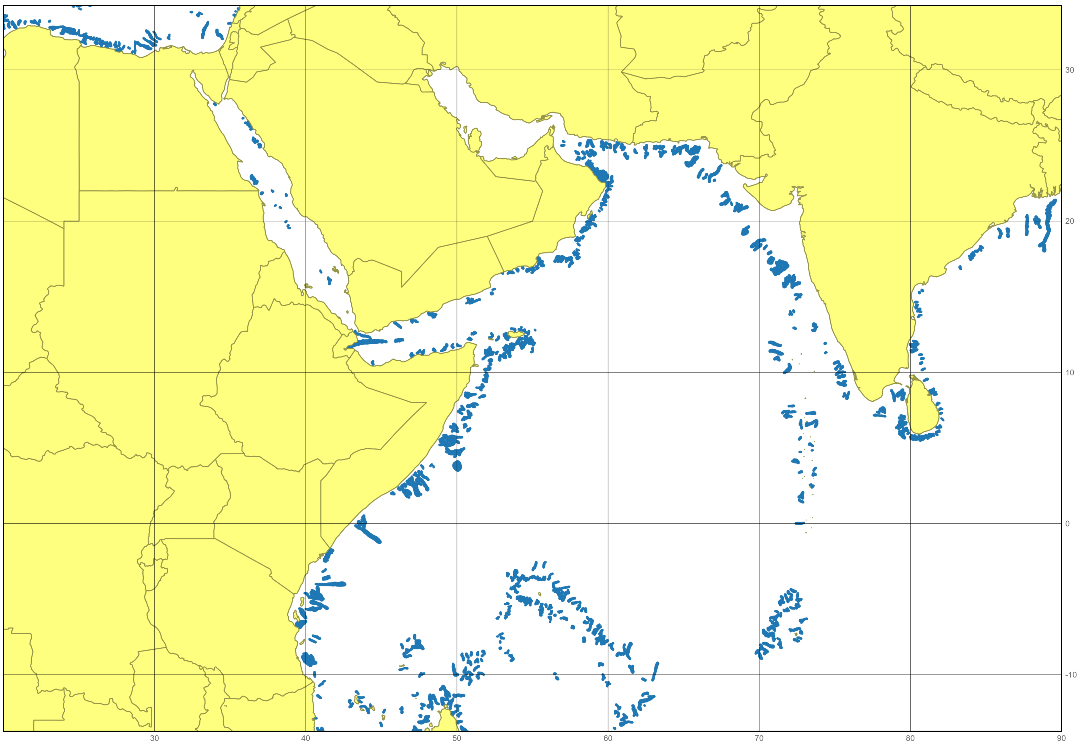


Figure 4.8: Large Submarine Canyons

4.5 Vents and Seeps

ChEss (Chemosynthetic Ecosystem Science) was a field project of the Census of Marine Life programme (CoML). The main aim of ChEss was to determine the biogeography of deep-water chemosynthetic ecosystems at a global scale and to understand the processes driving these ecosystems. ChEss addressed the main questions of CoML on diversity, abundance and distribution of marine species, focusing on deep-water reducing environments such as hydrothermal vents, cold seeps, whale falls, sunken wood and areas of low oxygen that intersect with continental margins and seamounts. Since the discovery of hydrothermal vents in 1977 and of cold seep communities in 1984, over 500 species from vents and over 200 species from seeps have been described (Van Dover et al., 2002. Science 295: 1253-1257). The discovery of chemosynthetically fuelled communities on benthic OMZs and large organic falls to the deep-sea such as whales and wood have increased the number of habitats and fauna for investigation. New species are continuously being discovered and described from sampling programmes around the globe and therefore ChEssBase is in active development and new data are being entered periodically. Currently, ChEssBase includes data on 1739 species from 193 chemosynthetic sites around the globe. These data contain information (when available) on the taxonomy, diagnosis, trophic level, reproduction, endemicity and habitat types and distribution. There are now 1879 papers in our reference database.
http://www.noc.soton.ac.uk/chess/database/db_home.php

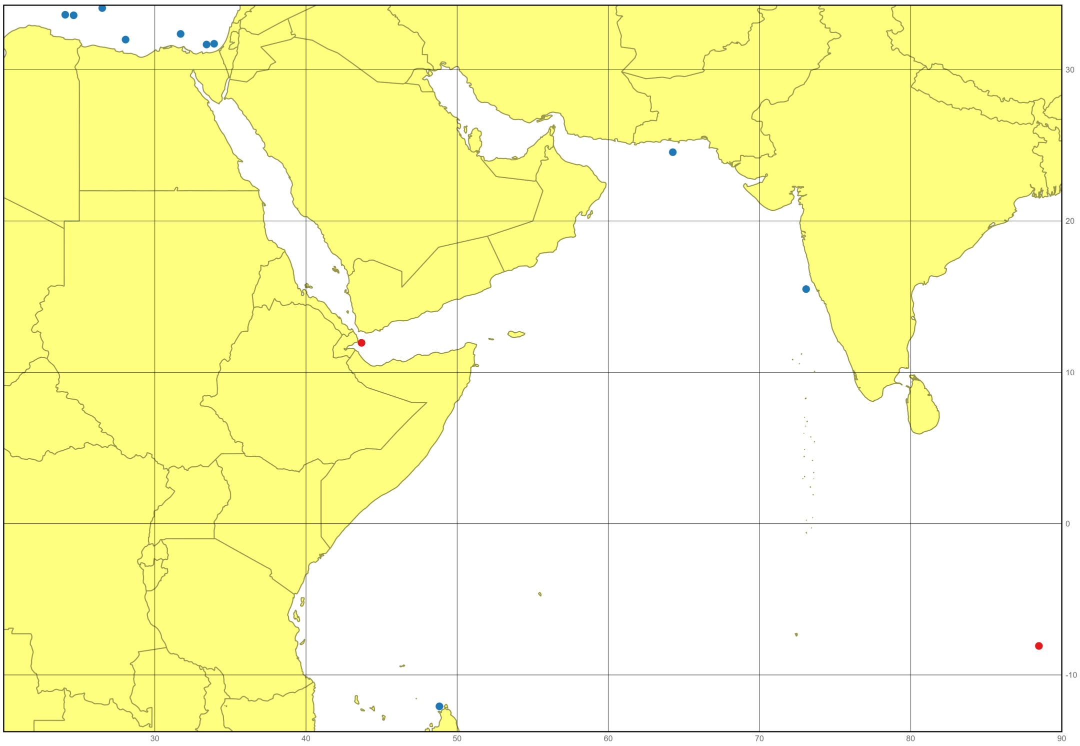


Figure 4.9: Vents and Seeps

4.6 Physical Ocean Climatologies

4.6.1 Temperature Climatology (degrees C)

CARS is a digital climatology, or atlas of seasonal ocean water properties. It comprises gridded fields of mean ocean properties over the period of modern ocean measurement, and average seasonal cycles for that period. It is derived from a quality-controlled archive of all available historical subsurface ocean property measurements - primarily research vessel instrument profiles and autonomous profiling buoys. As data availability has enormously increased in recent years, the CARS mean values are inevitably biased towards the recent ocean state.

A number of global ocean climatologies are presently available, such as NODC's World Ocean Atlas. CARS is different as it employs extra stages of in-house quality control of input data, and uses an adaptive-lengthscale loess mapper to maximise resolution in data-rich regions, and the mapper's "BAR" algorithm takes account of topographic barriers. The result is excellent definition of oceanic structures and accuracy of point values.

http://www.marine.csiro.au/~dunn/cars2009/

CARS2009 covers the full global oceans on a 1/2 degree grid, but until June 2011 only included temperature and salinity fields. The T and S fields were created in July 2009 and were was based on World Ocean Database 2005 (WOD05) [July 2008 Update], surface-pressure-corrected Argo global archives to May 2009, WOCE Global Hydrographic Program (v3.0), and many other datasets available up to 2008. See the updates section below for history of occasional sub-version releases. The nutrient fields created in June 2011 were based on WOCE and WOD09 (March 2011 download).

References - primary CARS citation:

Ridgway K.R., J.R. Dunn, and J.L. Wilkin, Ocean interpolation by four-dimensional least squares -Application to the waters around Australia, J. Atmos. Ocean. Tech., Vol 19, No 9, 1357-1375, 2002

- algorithm details:

Dunn J.R., and K.R. Ridgway, Mapping ocean properties in regions of complex topography, Deep Sea Research I : Oceanographic Research, 49 (3) (2002) pp. 591-604 - CARS seasonal fields and MLD:

Scott A. Condie and Jeff R. Dunn (2006) Seasonal characteristics of the surface mixed layer in the Australasian region: implications for primary production regimes and biogeography. Marine and Freshwater Research, 2006, 57, 1-22.

Metadata

CARS2009 metadata record: MarLIN record: 8539, Anzlic identifier: ANZCW0306008539

The webpage is itself the authoritative reference for CARS2009.

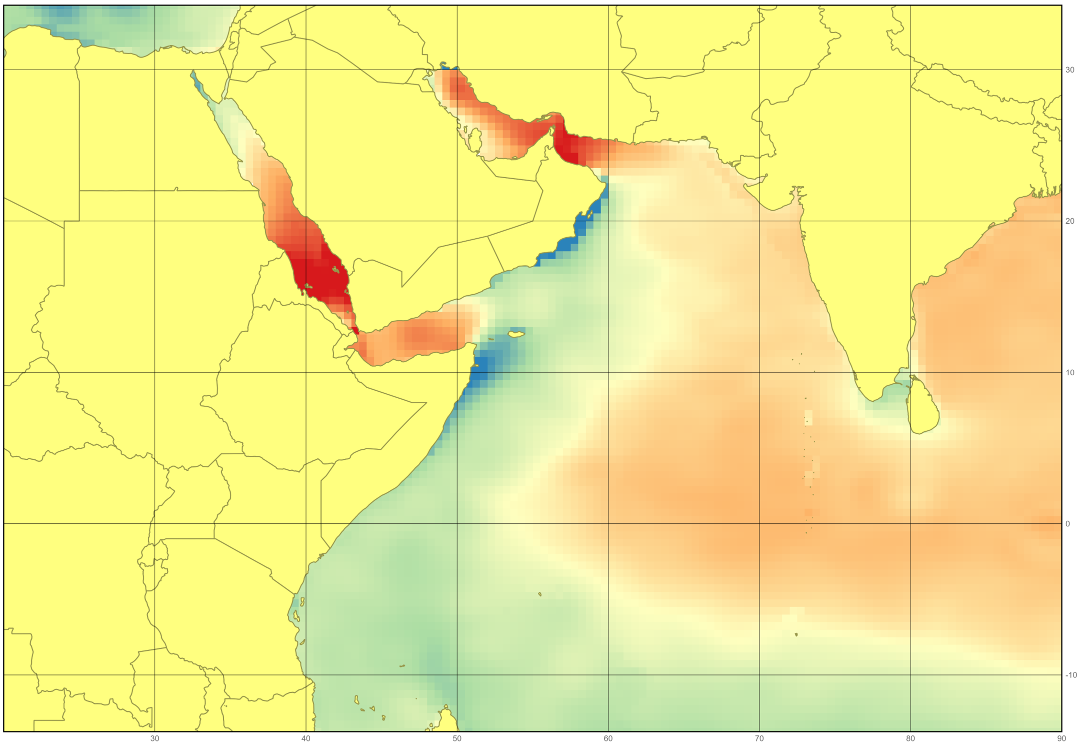


Figure 4.10: SST - December to February

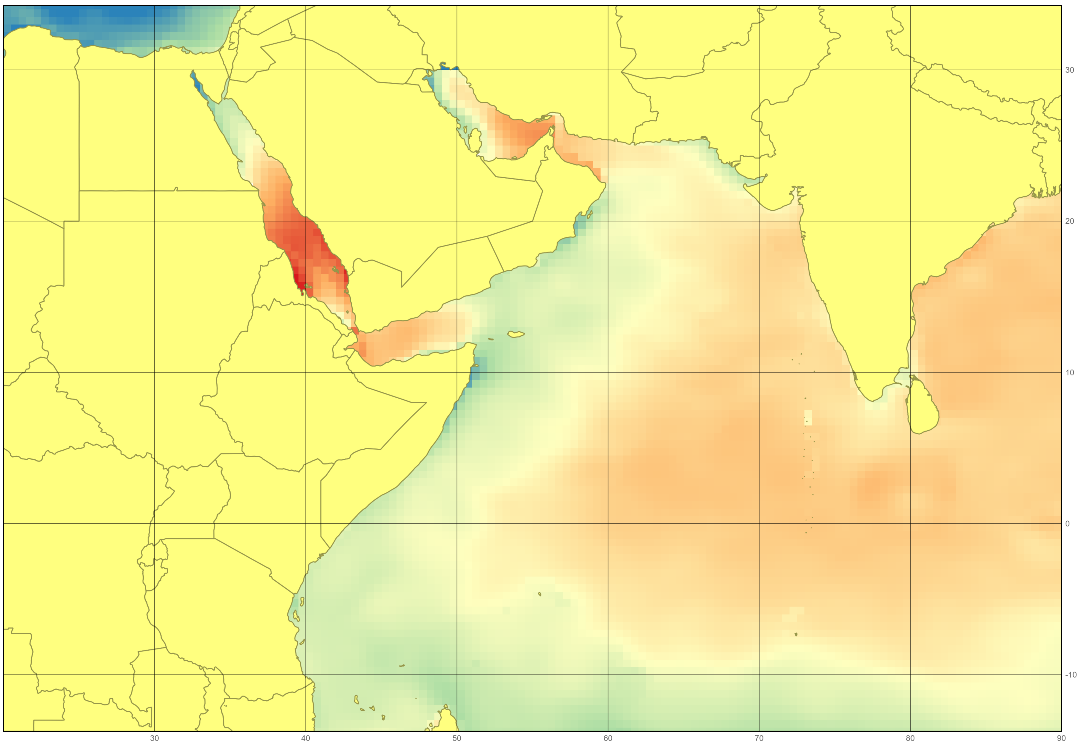


Figure 4.11: SST - March to May

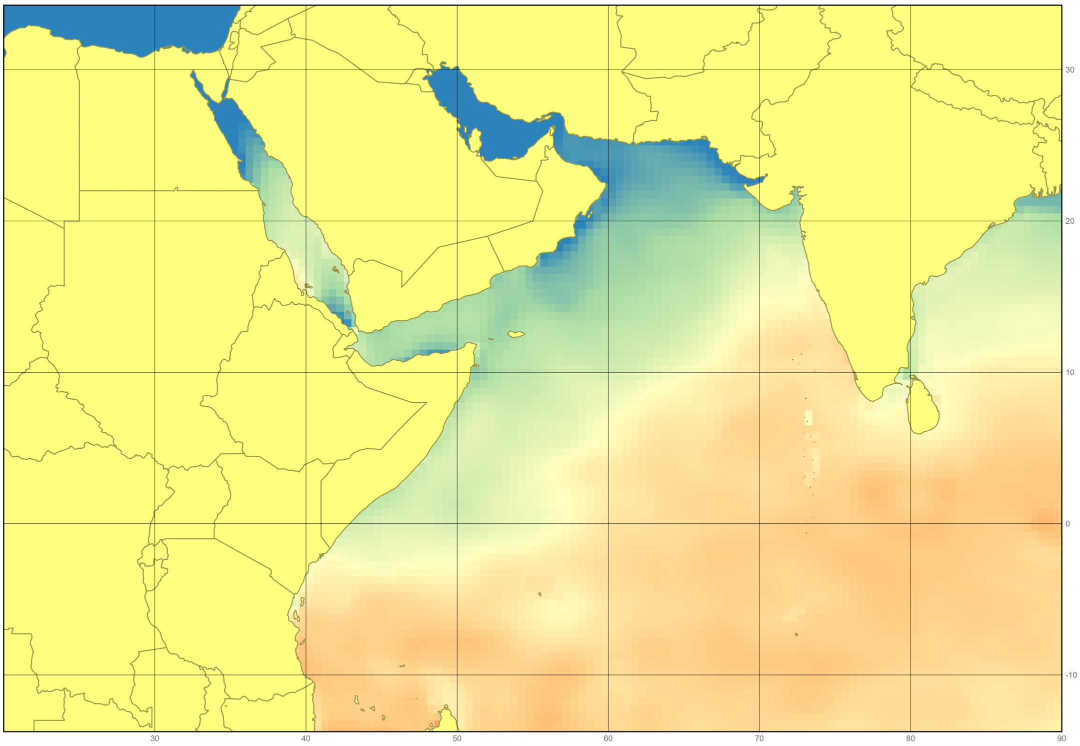


Figure 4.12: SST - June to August

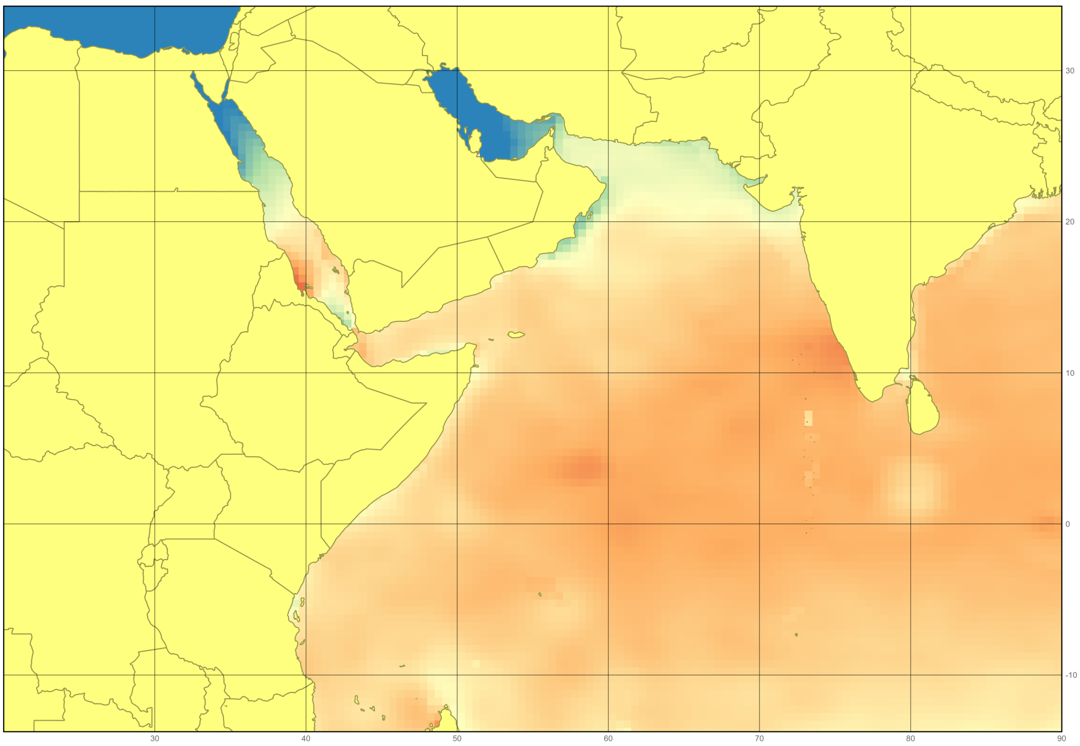


Figure 4.13: SST - September to November

4.6.2 Salinity Climatology (PSU)

CARS is a digital climatology, or atlas of seasonal ocean water properties. It comprises gridded fields of mean ocean properties over the period of modern ocean measurement, and average seasonal cycles for that period. It is derived from a quality-controlled archive of all available historical subsurface ocean property measurements - primarily research vessel instrument profiles and autonomous profiling buoys. As data availability has enormously increased in recent years, the CARS mean values are inevitably biased towards the recent ocean state.

4.6.3 Oxygen Climatology (ml/l)

CARS is a digital climatology, or atlas of seasonal ocean water properties. It comprises gridded fields of mean ocean properties over the period of modern ocean measurement, and average seasonal cycles for that period. It is derived from a quality-controlled archive of all available historical subsurface ocean property measurements - primarily research vessel instrument profiles and autonomous profiling buoys. As data availability has enormously increased in recent years, the CARS mean values are inevitably biased towards the recent ocean state.

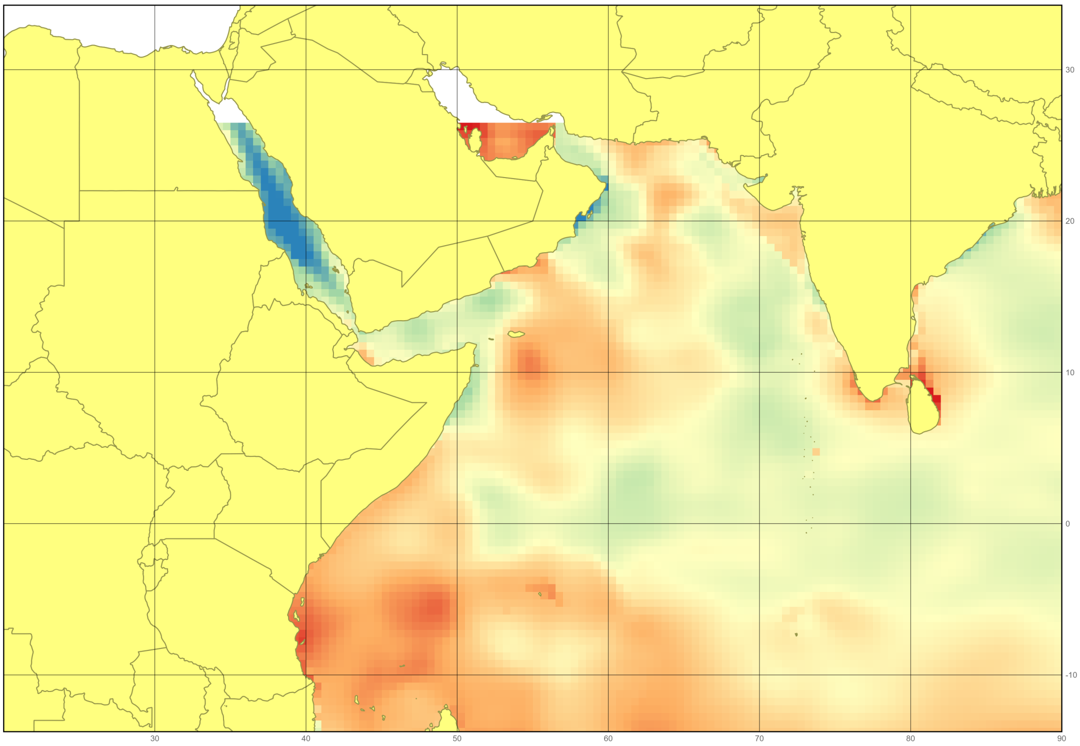


Figure 4.14: Surface Disolved Oxygen - December to February

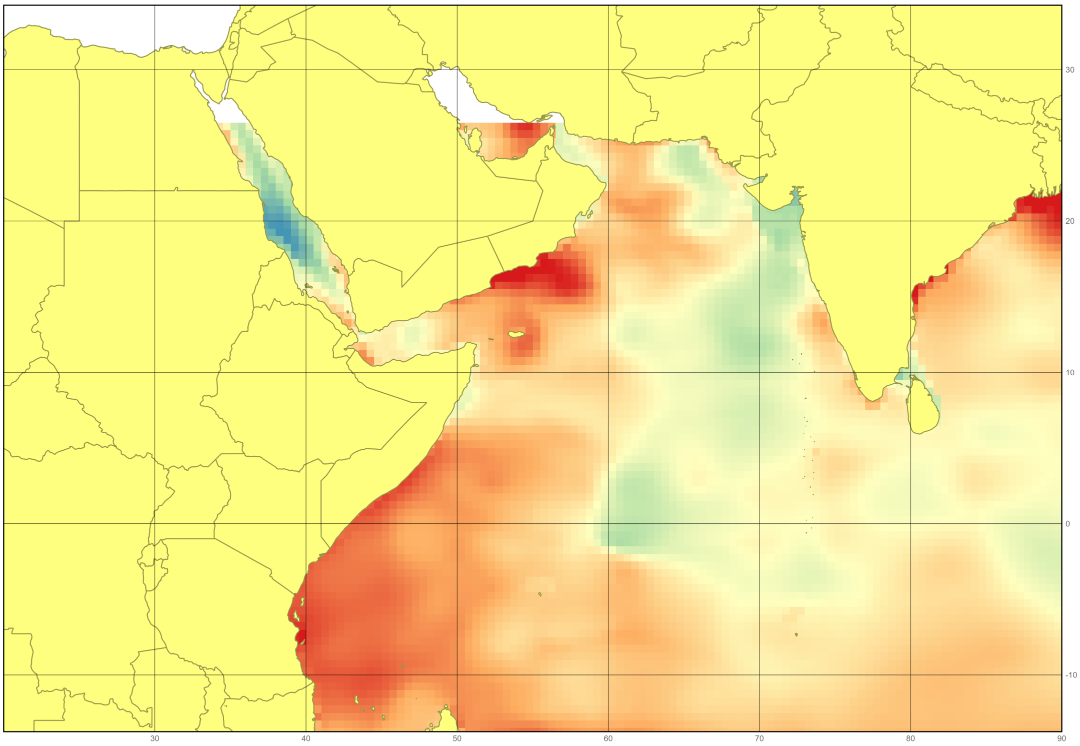


Figure 4.15: Surface Disolved Oxygen - March to May

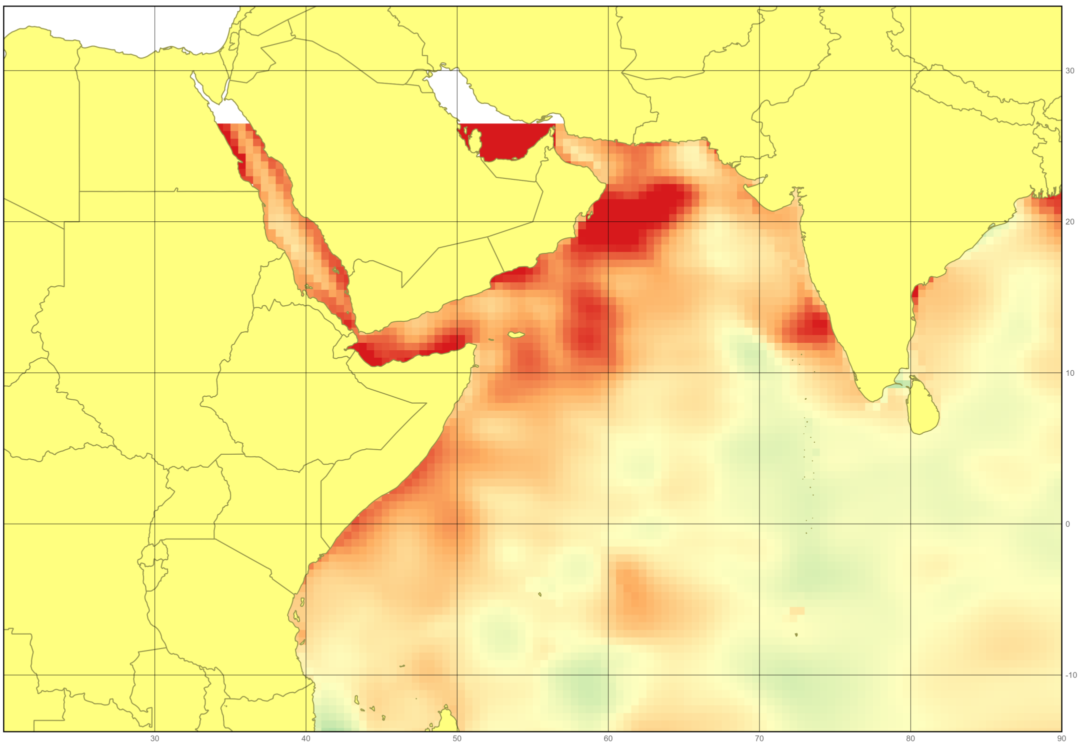


Figure 4.16: Surface Disolved Oxygen - June to August

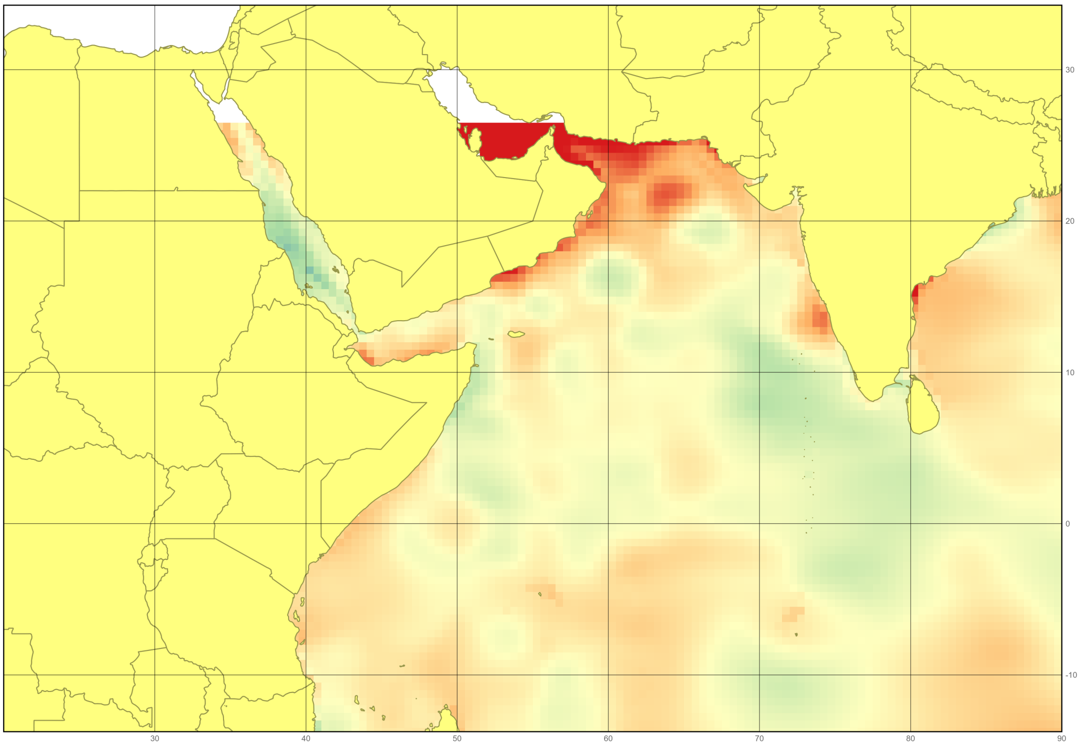


Figure 4.17: Surface Disolved Oxygen - September to November

4.6.4 Nitrate Climatology (uM)

CARS is a digital climatology, or atlas of seasonal ocean water properties. It comprises gridded fields of mean ocean properties over the period of modern ocean measurement, and average seasonal cycles for that period. It is derived from a quality-controlled archive of all available historical subsurface ocean property measurements - primarily research vessel instrument profiles and autonomous profiling buoys. As data availability has enormously increased in recent years, the CARS mean values are inevitably biased towards the recent ocean state.

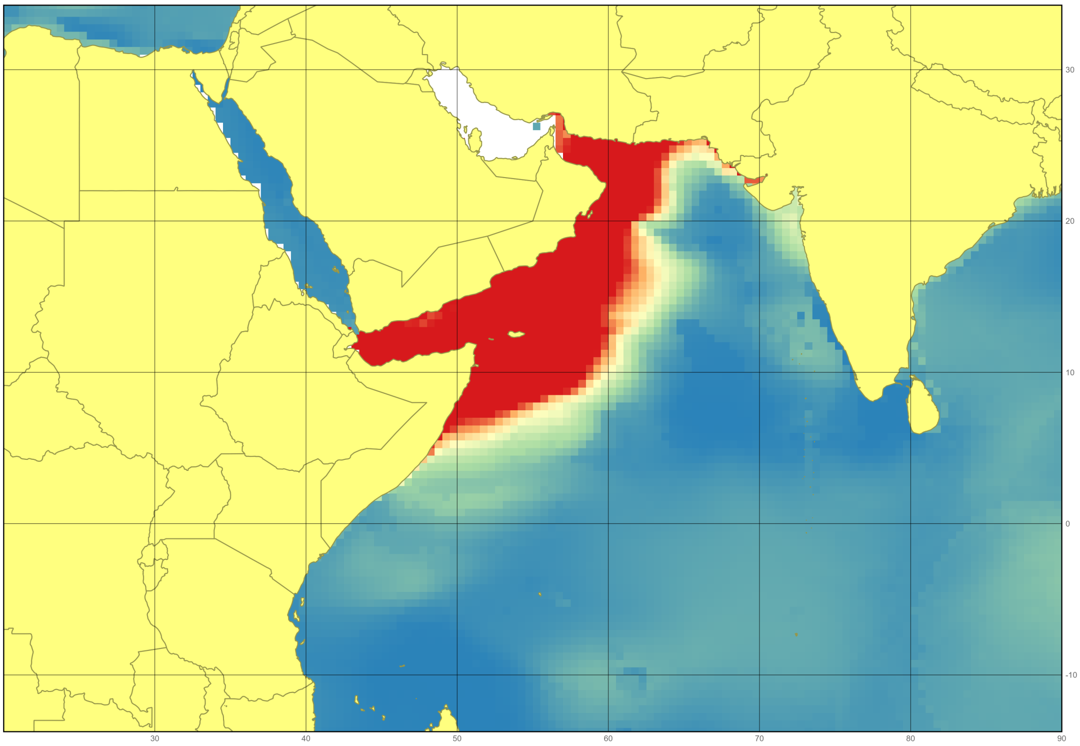


Figure 4.18: Surface Disolved Nitrate - December to February

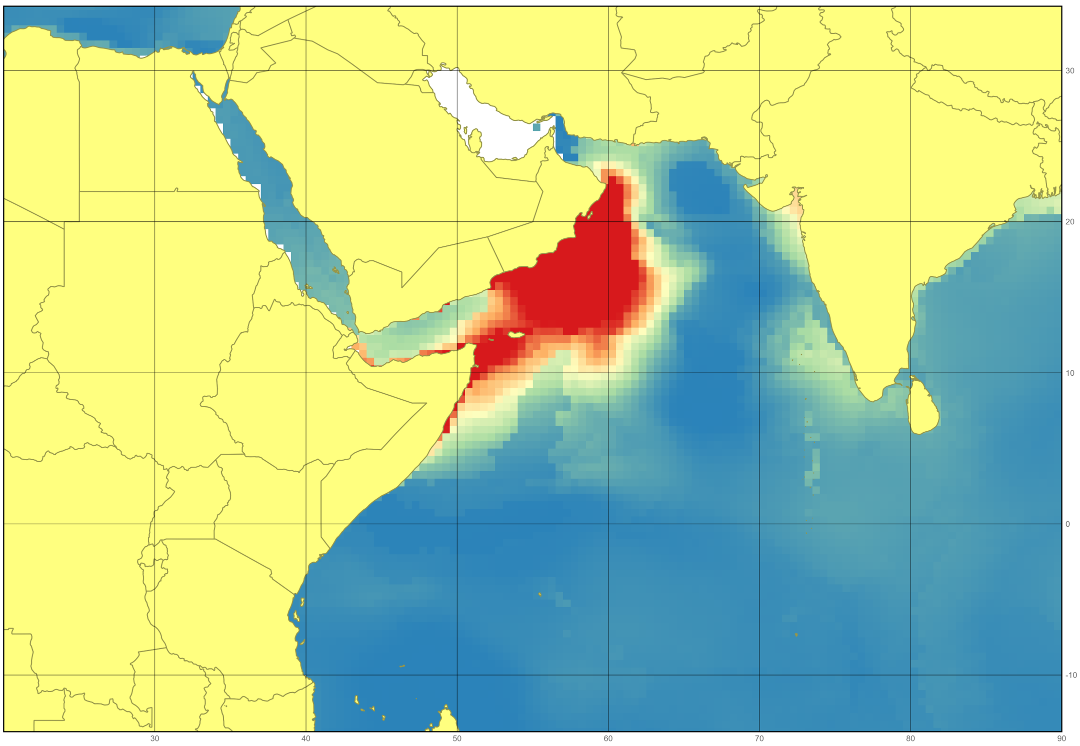


Figure 4.19: Surface Disolved Nitrate - March to May

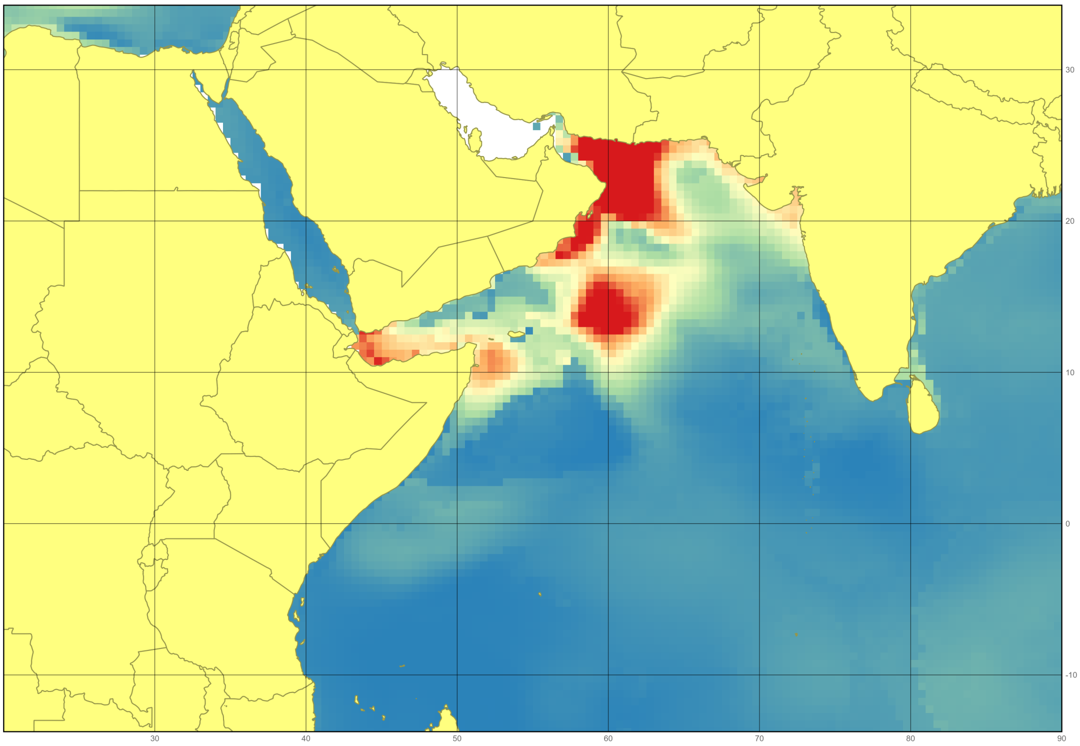


Figure 4.20: Surface Disolved Nitrate - June to August

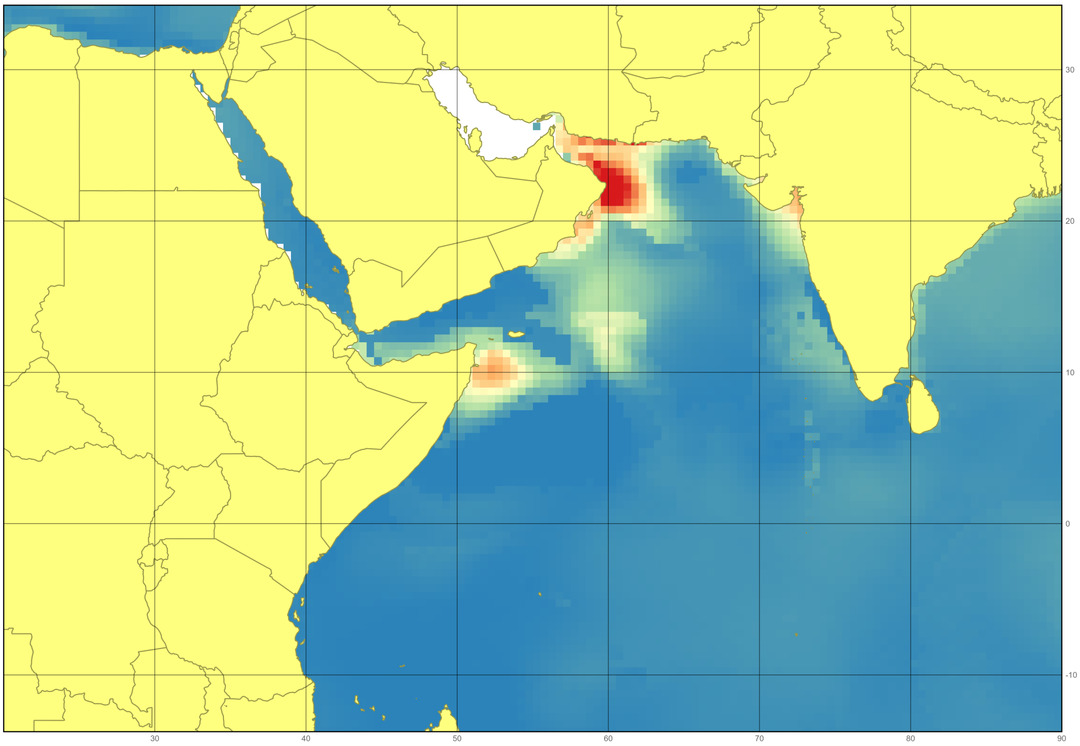


Figure 4.21: Surface Disolved Nitrate - September to November

4.6.5 Silicate Climatology (uM)

CARS is a digital climatology, or atlas of seasonal ocean water properties. It comprises gridded fields of mean ocean properties over the period of modern ocean measurement, and average seasonal cycles for that period. It is derived from a quality-controlled archive of all available historical subsurface ocean property measurements - primarily research vessel instrument profiles and autonomous profiling buoys. As data availability has enormously increased in recent years, the CARS mean values are inevitably biased towards the recent ocean state.

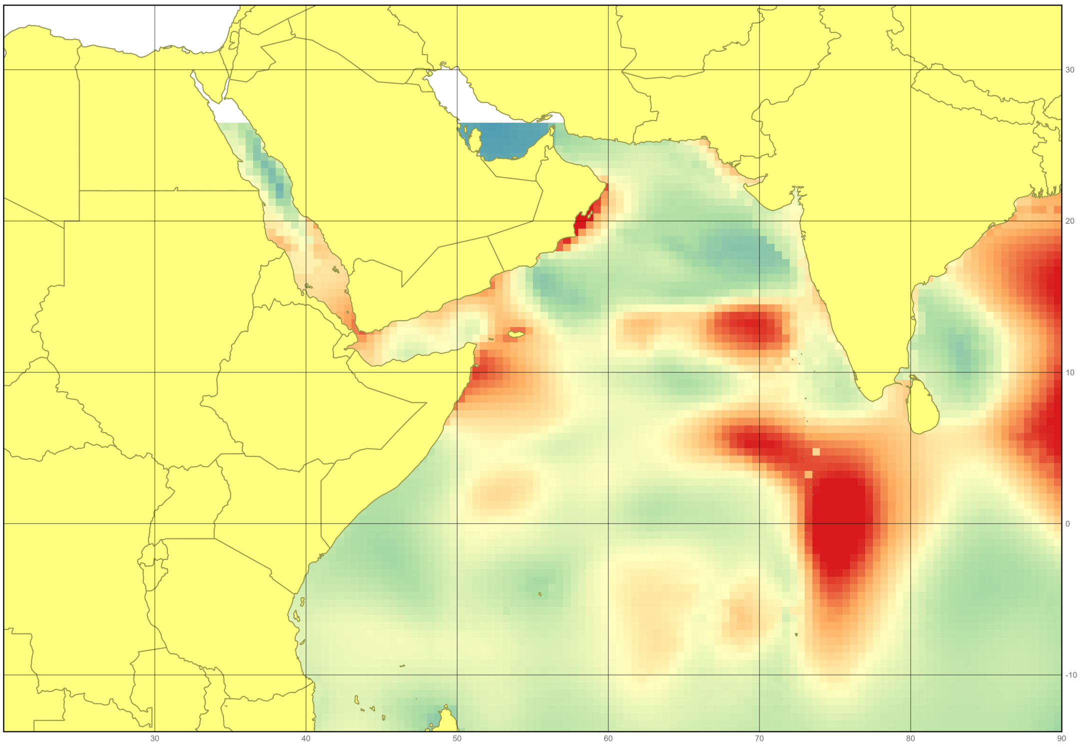


Figure 4.22: Surface Disolved Silicate - December to February

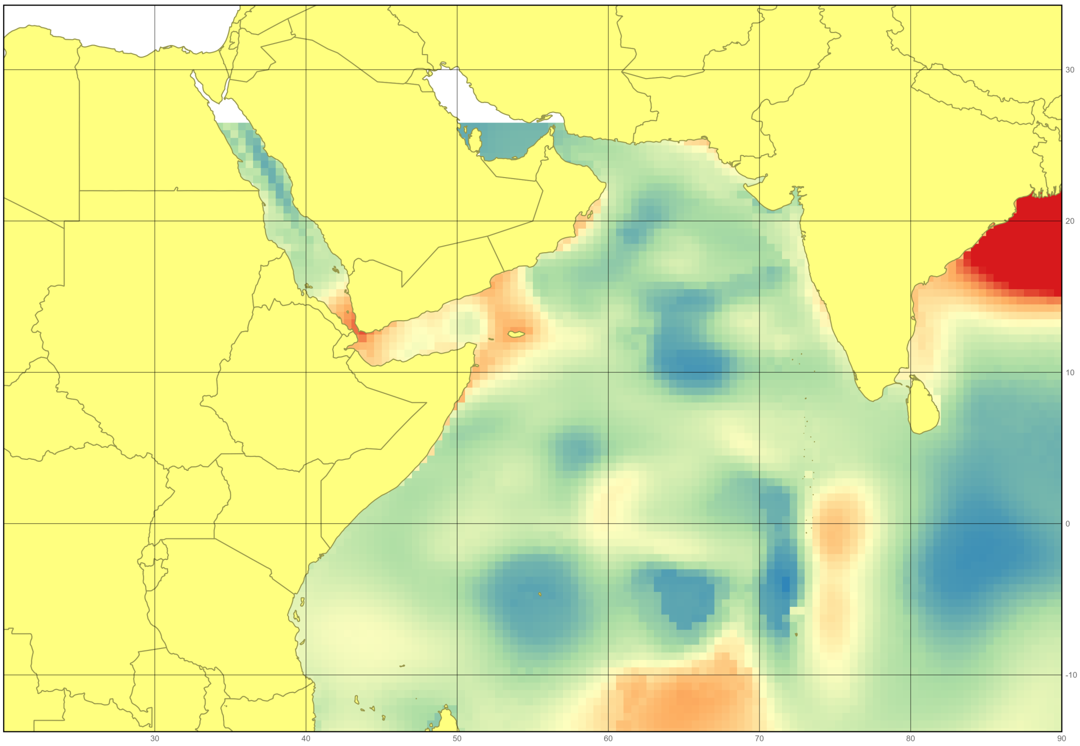


Figure 4.23: Surface Disolved Silicate - March to May

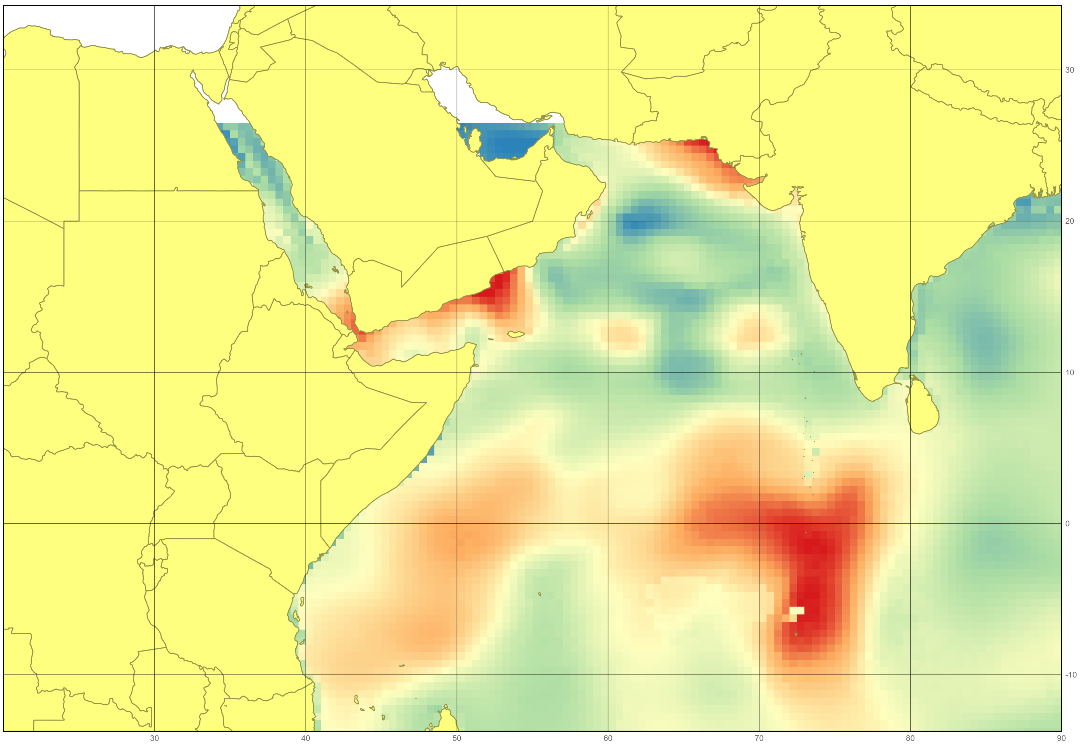


Figure 4.24: Surface Disolved Silicate - June to August

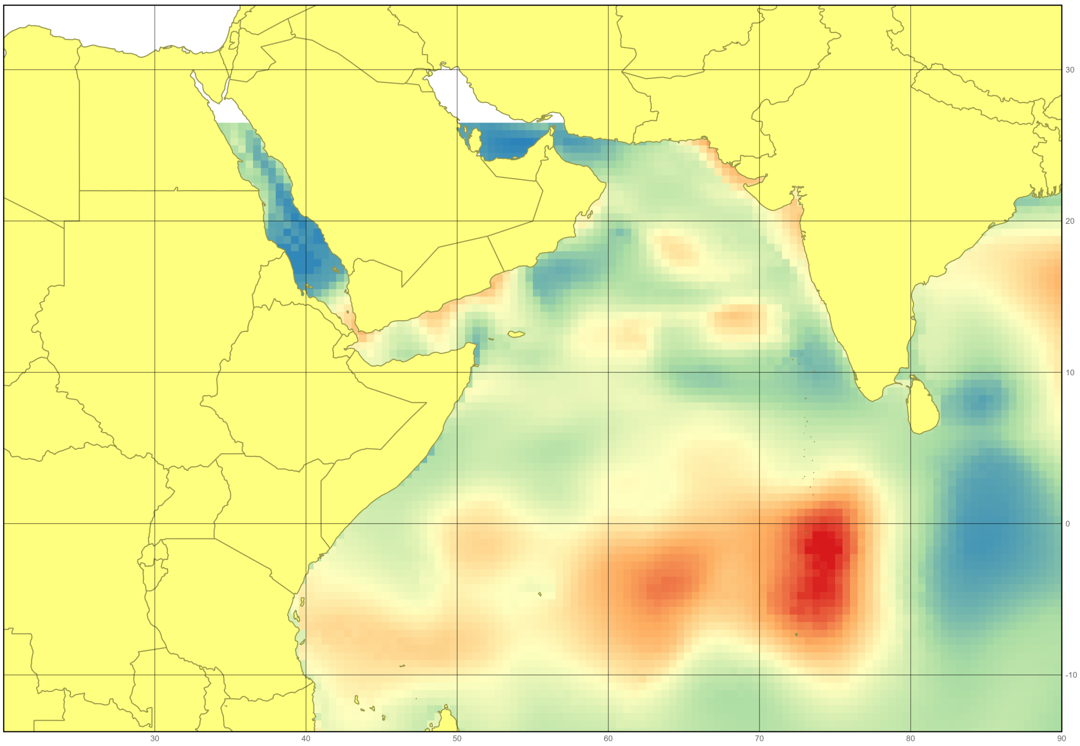


Figure 4.25: Surface Disolved Silicate - September to November

4.6.6 Phosphate Climatology (uM)

CARS is a digital climatology, or atlas of seasonal ocean water properties. It comprises gridded fields of mean ocean properties over the period of modern ocean measurement, and average seasonal cycles for that period. It is derived from a quality-controlled archive of all available historical subsurface ocean property measurements - primarily research vessel instrument profiles and autonomous profiling buoys. As data availability has enormously increased in recent years, the CARS mean values are inevitably biased towards the recent ocean state.

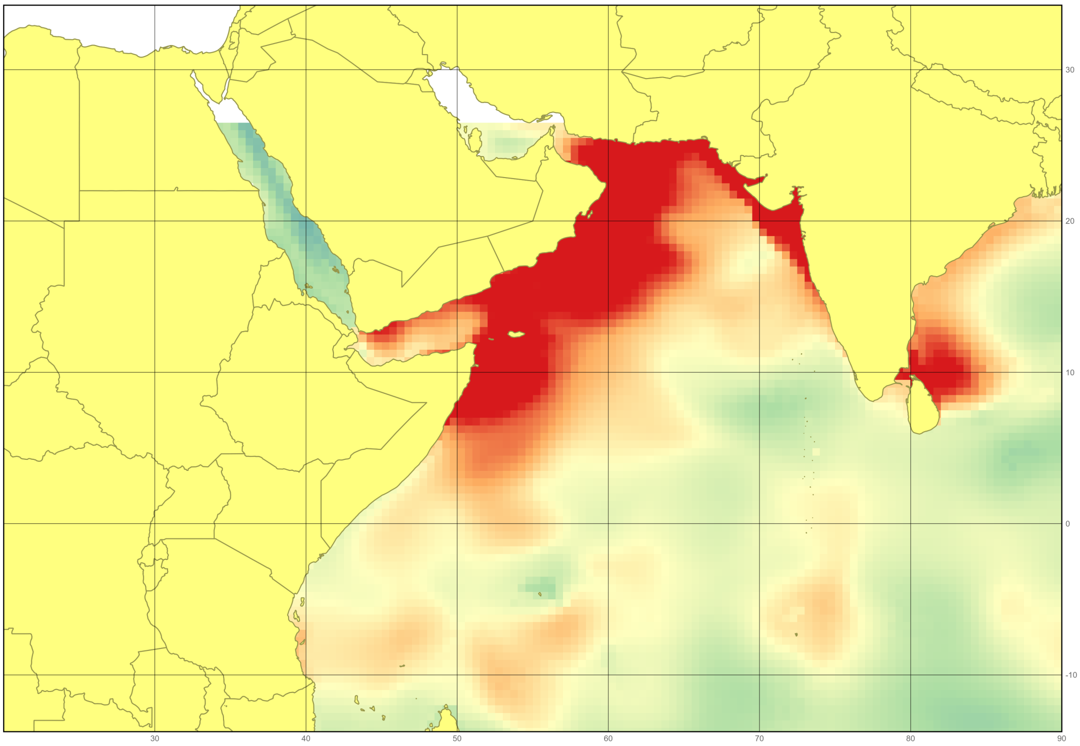


Figure 4.26: Surface Disolved Phosphate - December to February

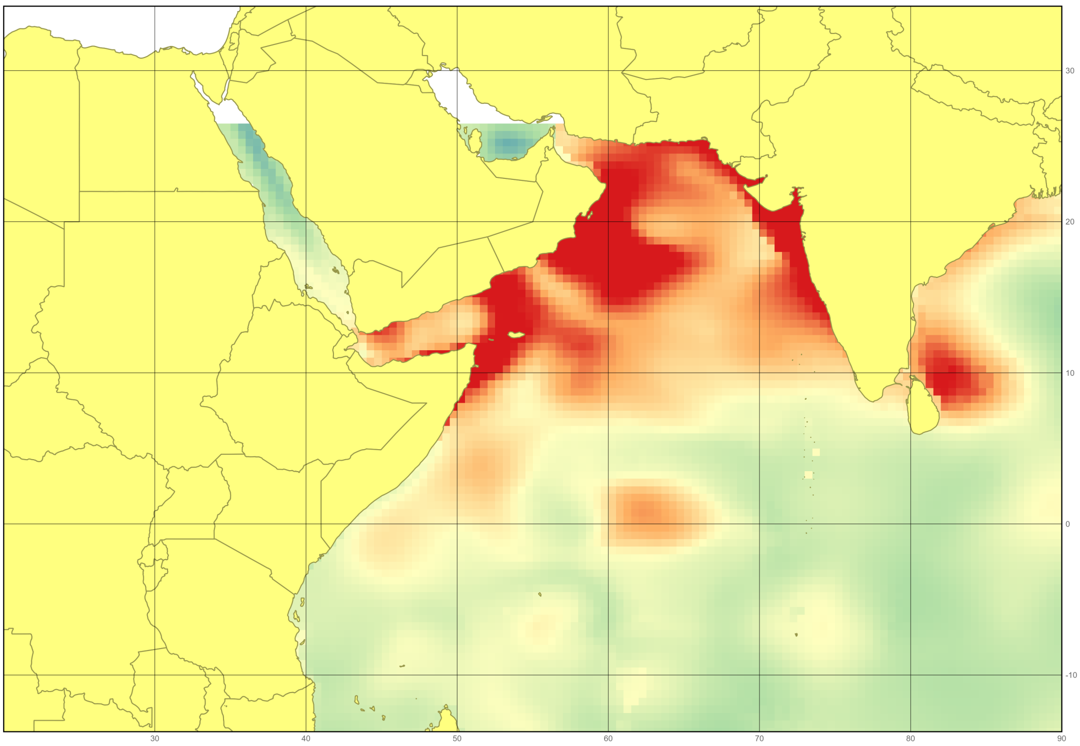


Figure 4.27: Surface Disolved Phosphate - March to May

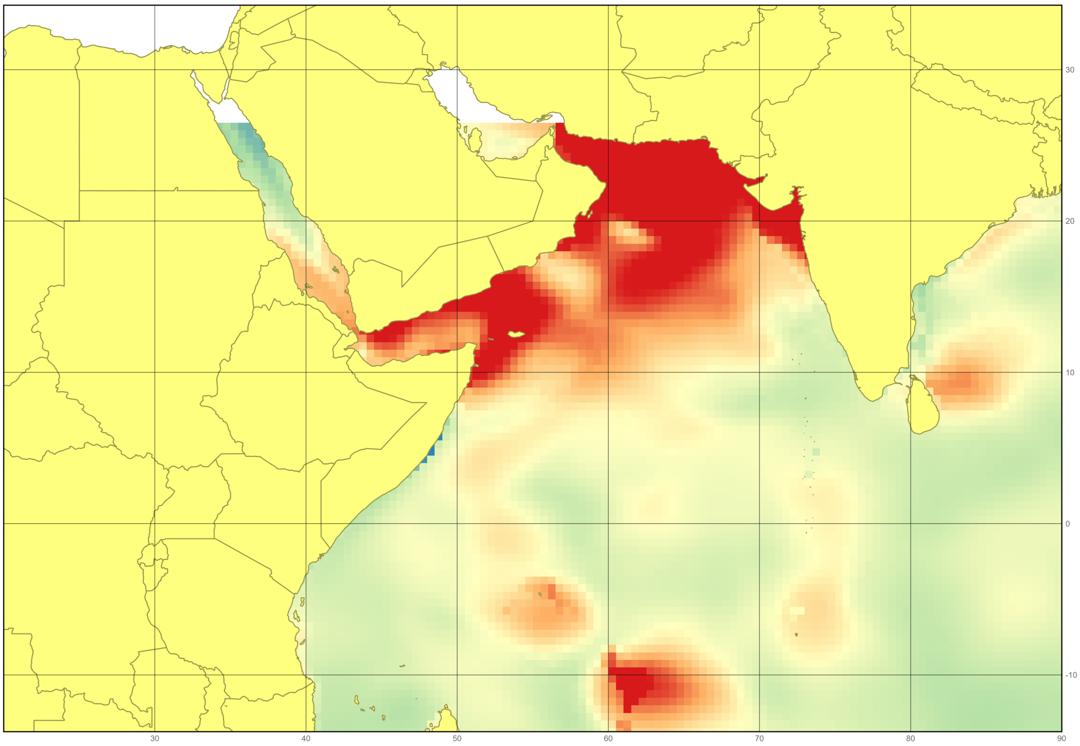


Figure 4.28: Surface Disolved Phosphate - June to August

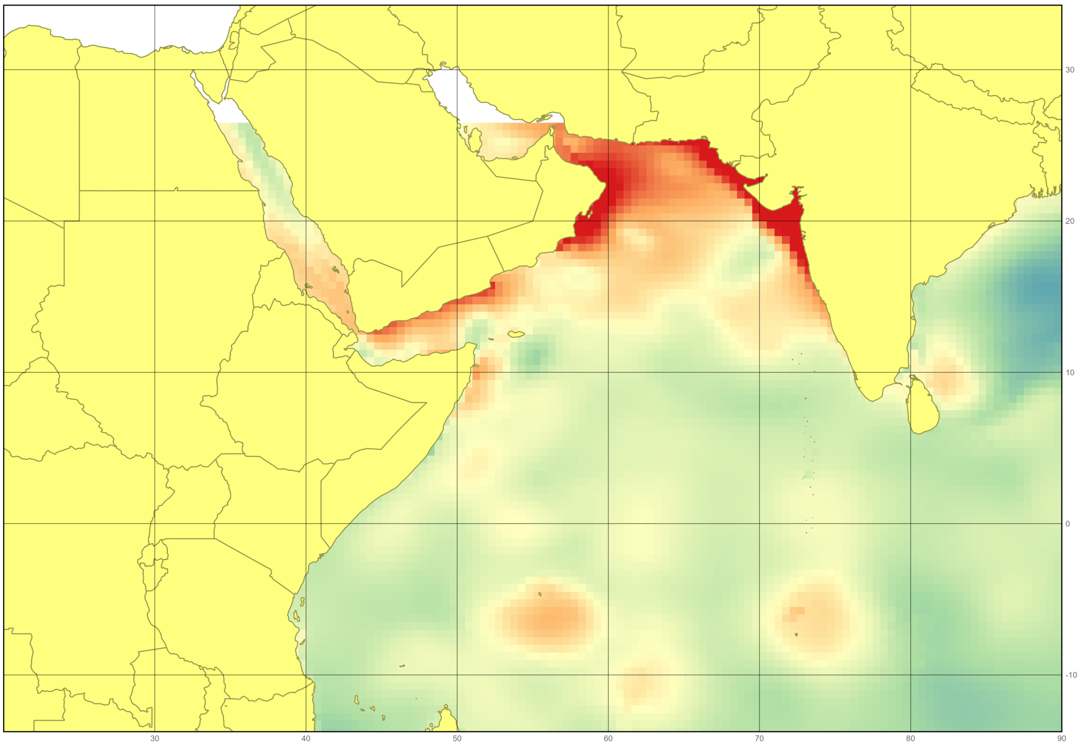


Figure 4.29: Surface Disolved Phosphate - September to November

4.6.7 Sea Surface Altimetry

Average annual sea surface height. Data derived from satelite measurment (TOPEX/POSEIDON and ERS-1) and gives the annual sea surface height.

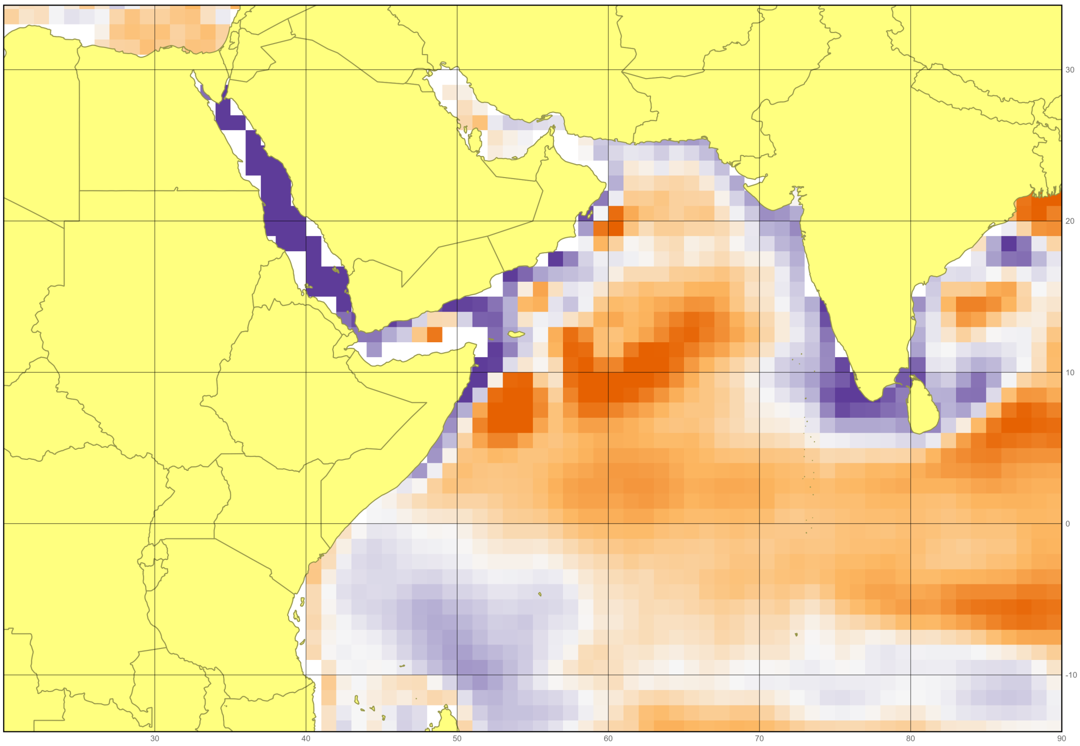


Figure 4.30: Sea Surface Height - December to February

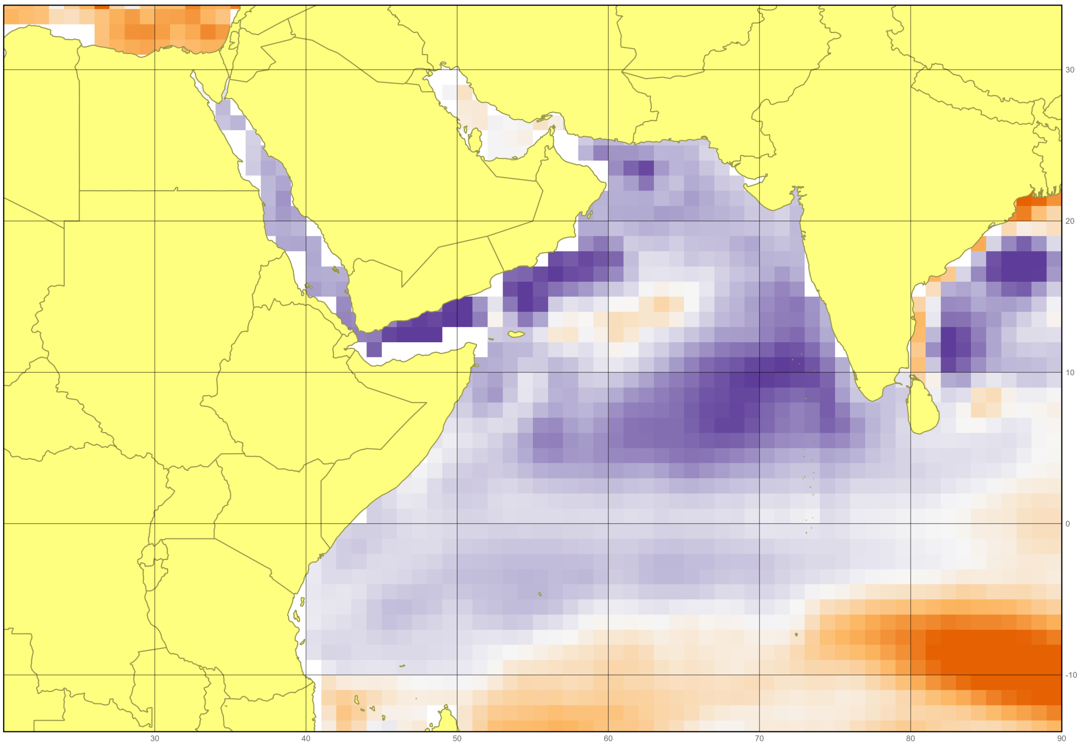


Figure 4.31: Sea Surface Height - March to May

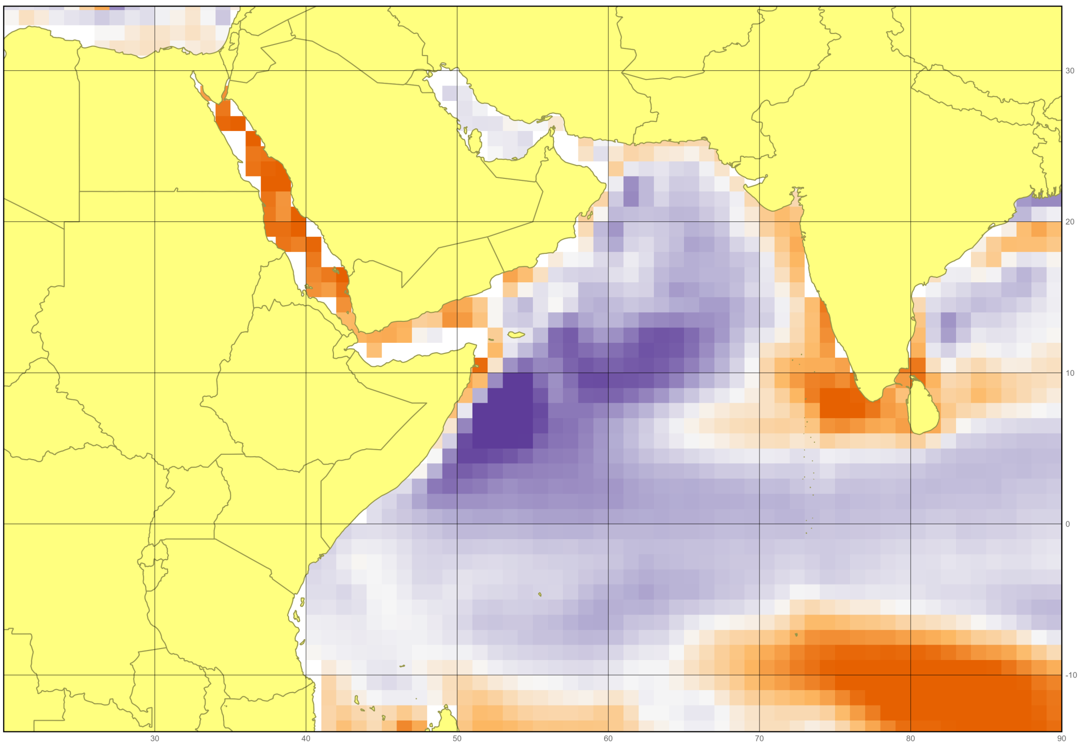


Figure 4.32: Sea Surface Height - June to August

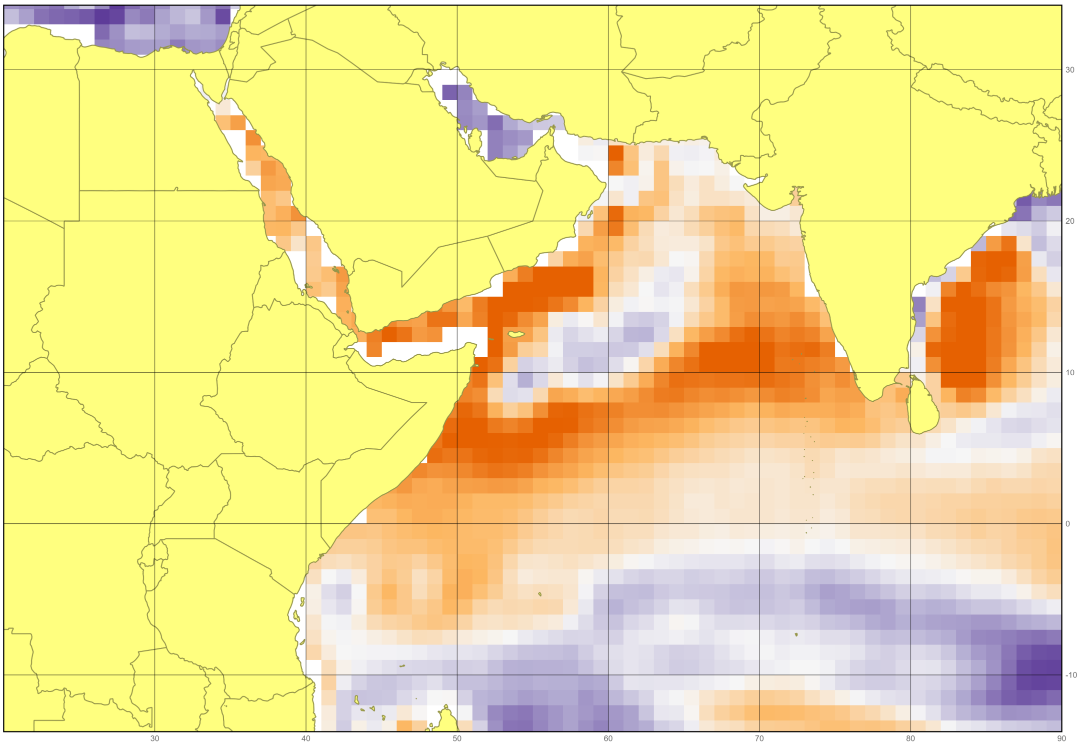


Figure 4.33: Sea Surface Height - September to November

4.6.8 SeaWiFS Chlorophyll A concentration

SeaWiFS data compiled by Thomas Moore and CMR Remote Sensing, courtesy of the NASA SeaWiFS Project and Orbimage. NASA also expects at least one author of any paper using Seawifs to be personally on their registered Seawifs users list. This is done by applying to NASA and can easily be done via the web at `http://seawifs.gsfc.nasa.gov/SEAWIFS/LICENSE/checklist.html`.

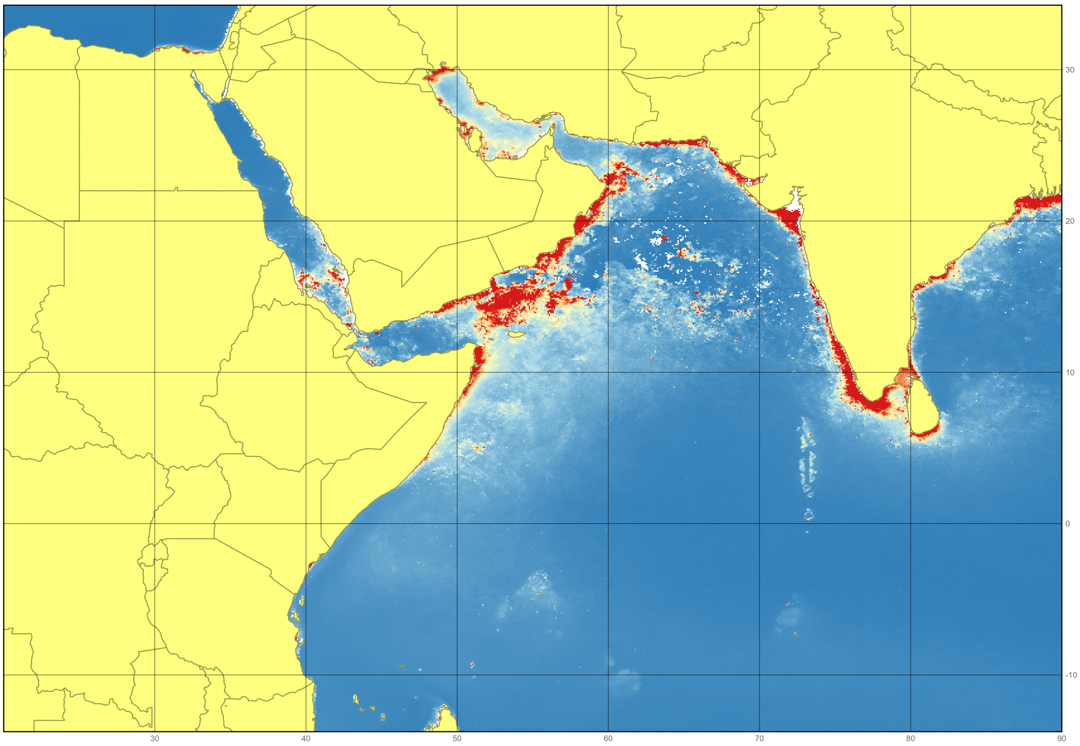


Figure 4.34: Chlorophyll A concentration - December to February

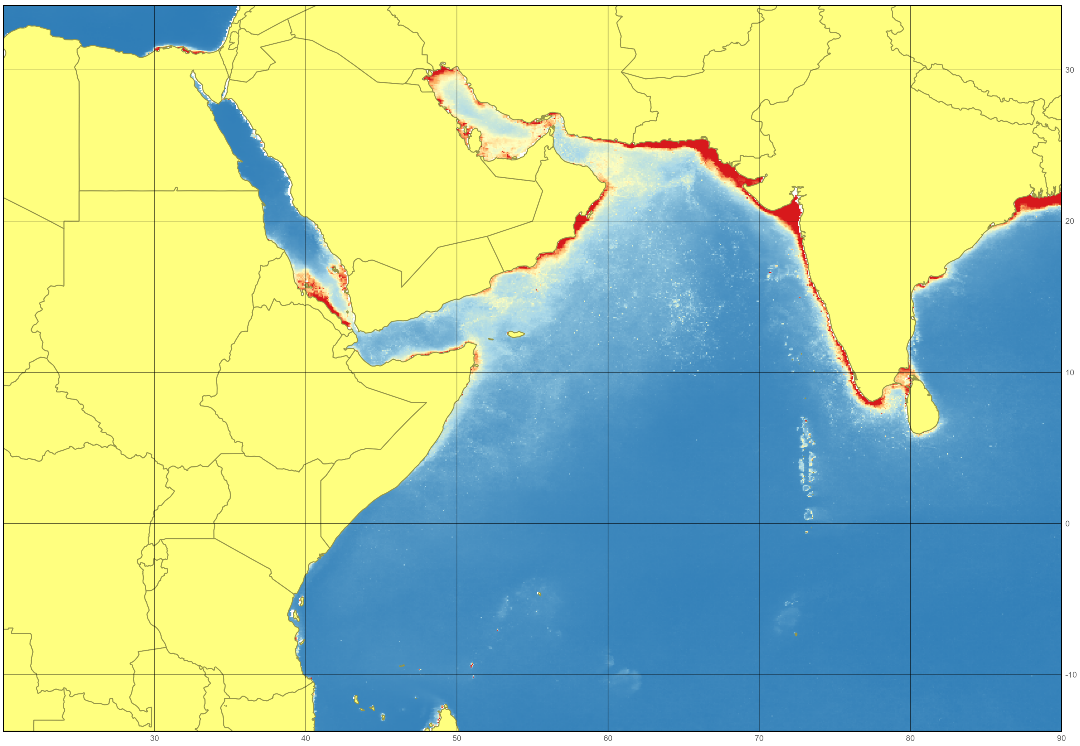


Figure 4.35: Chlorophyll A concentration - March to May

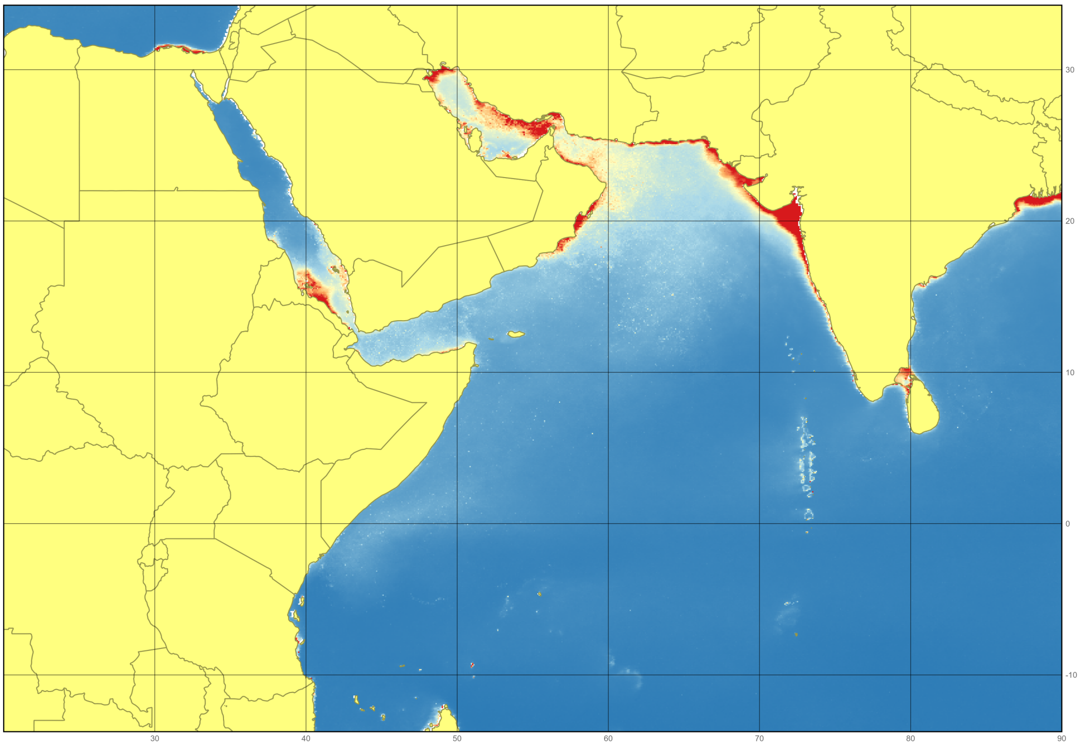


Figure 4.36: Chlorophyll A concentration - June to August

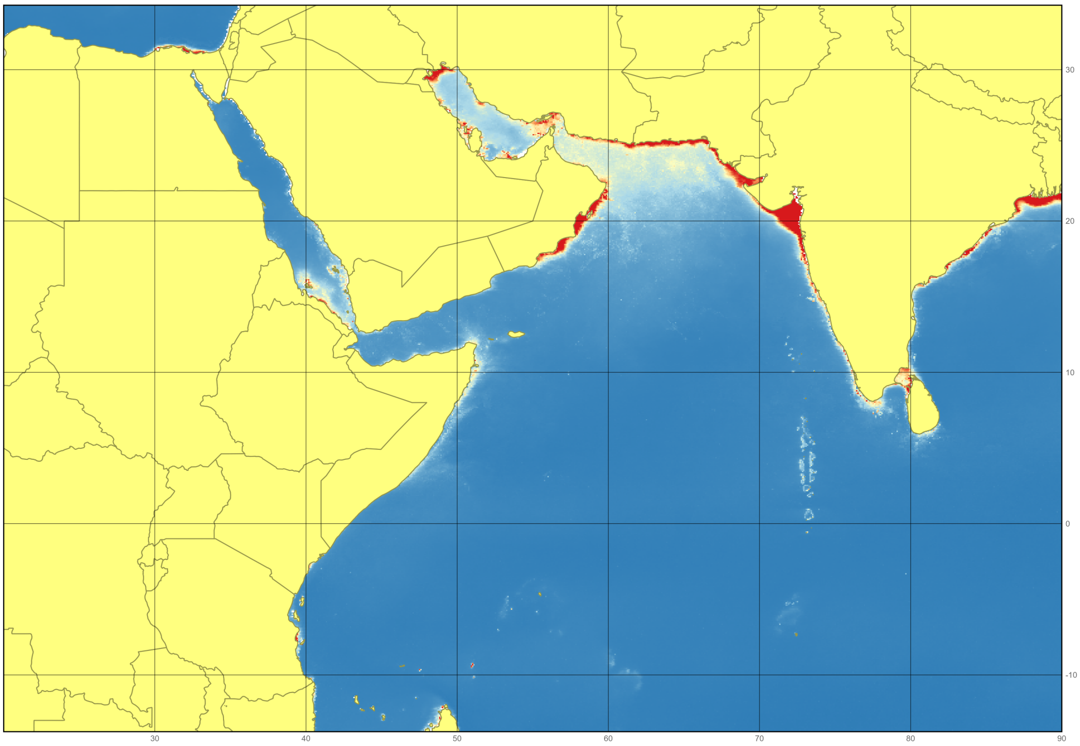


Figure 4.37: Chlorophyll A concentration - September to November

4.6.9 VGPM Global Ocean Productivity

The VGPM is a "chlorophyll-based" model that estimate net primary production from chlorophyll.

Community guidance for developing this website was to provide a single productivity product as a Standard product.For this, we have initially chosen the Vertically Generalized Production Model (VGPM) (Behrenfeld and Falkowski, 1997a) as the standard algorithm. The VGPM is a "chlorophyll-based" model that estimate net primary production from chlorophyll using a temperature-dependent description of chlorophyll-specific photosynthetic efficiency.For the VGPM, net primary production is a function of chlorophyll, available light, and the photosynthetic efficiency.

http://www.science.oregonstate.edu/ocean.productivity/VGPMGlobalOceanPro
png

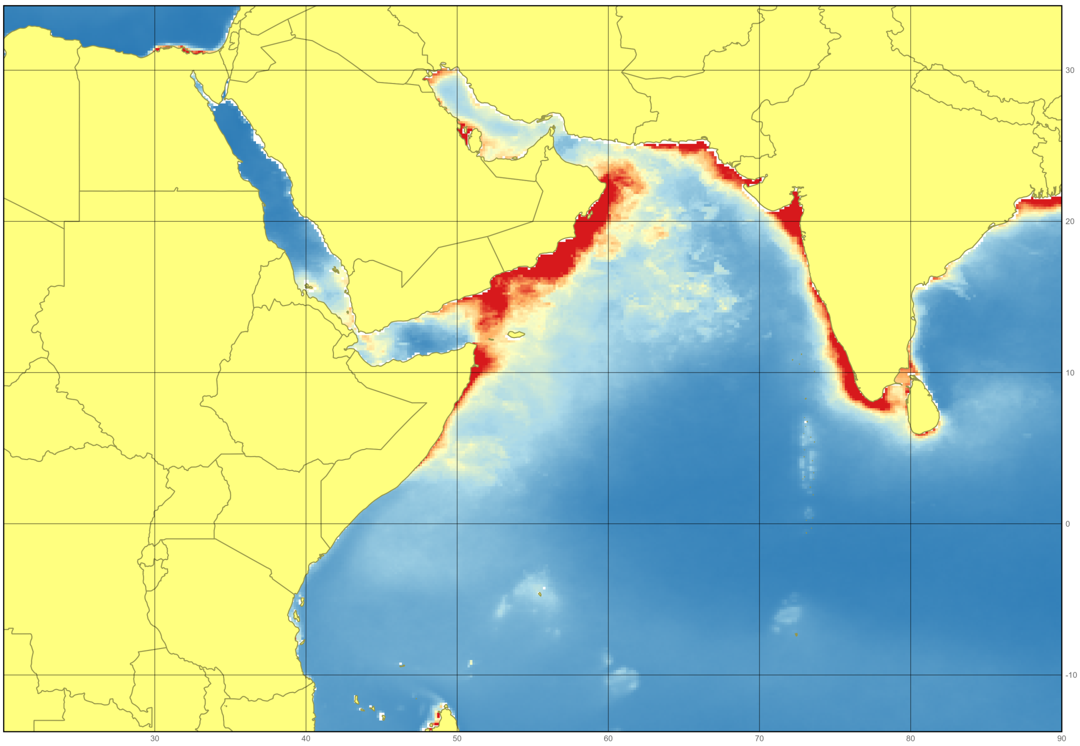


Figure 4.38: VGPM Global Ocean Productivity - December to February

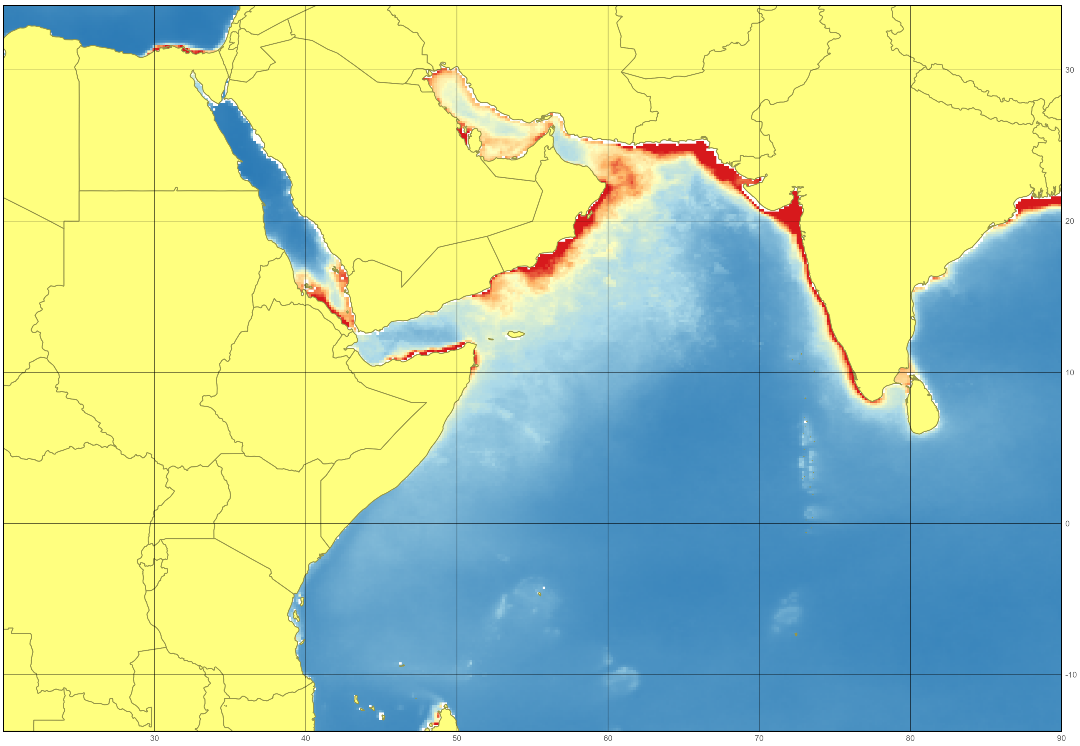


Figure 4.39: VGPM Global Ocean Productivity - March to May

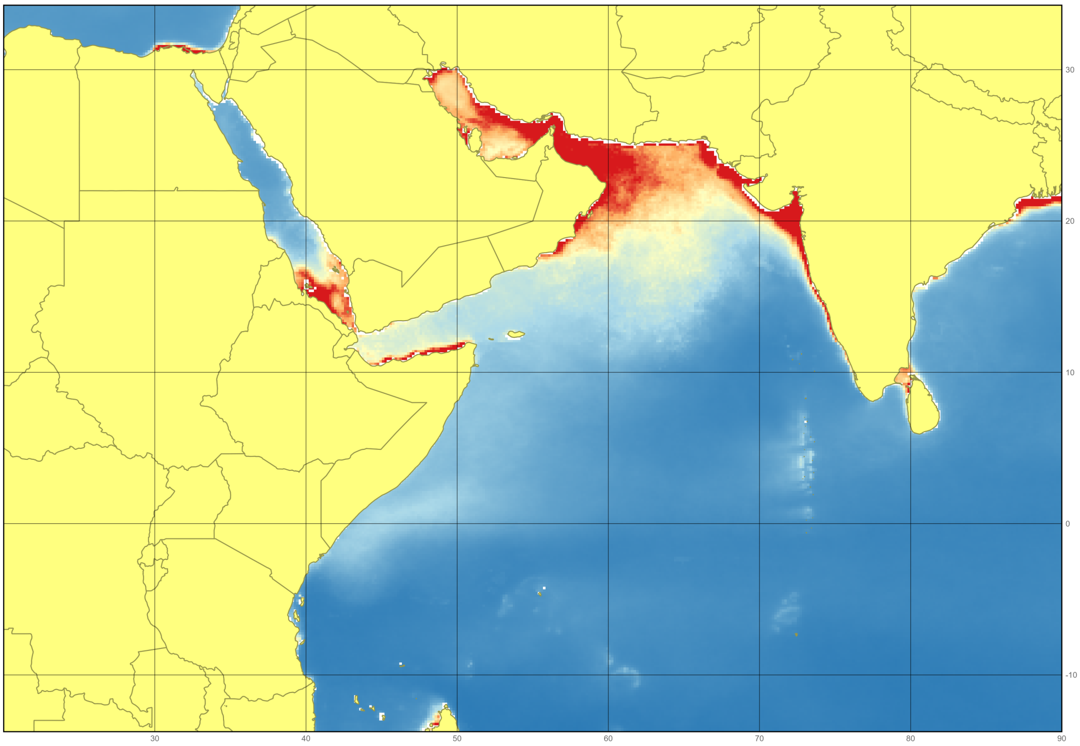


Figure 4.40: VGPM Global Ocean Productivity - June to August

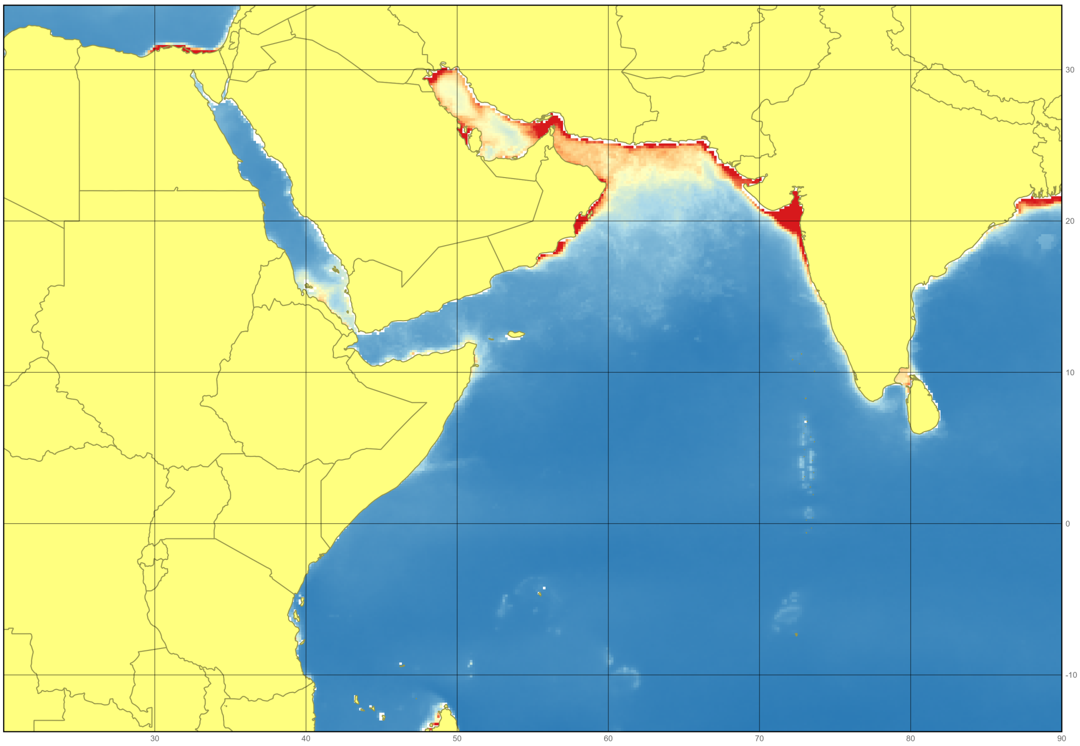


Figure 4.41: VGPM Global Ocean Productivity - September to November

4.6.10 Mixed Layer Depth Climatology (m)

Production in the surface ocean is constrained by nutrient availability (at depth) and sufficient light (from the surface). The MLD can influence this productivity and has a seasonal cycle, being deeper due to wind mixing in winter, and shallow in summer due to warming and stratification.

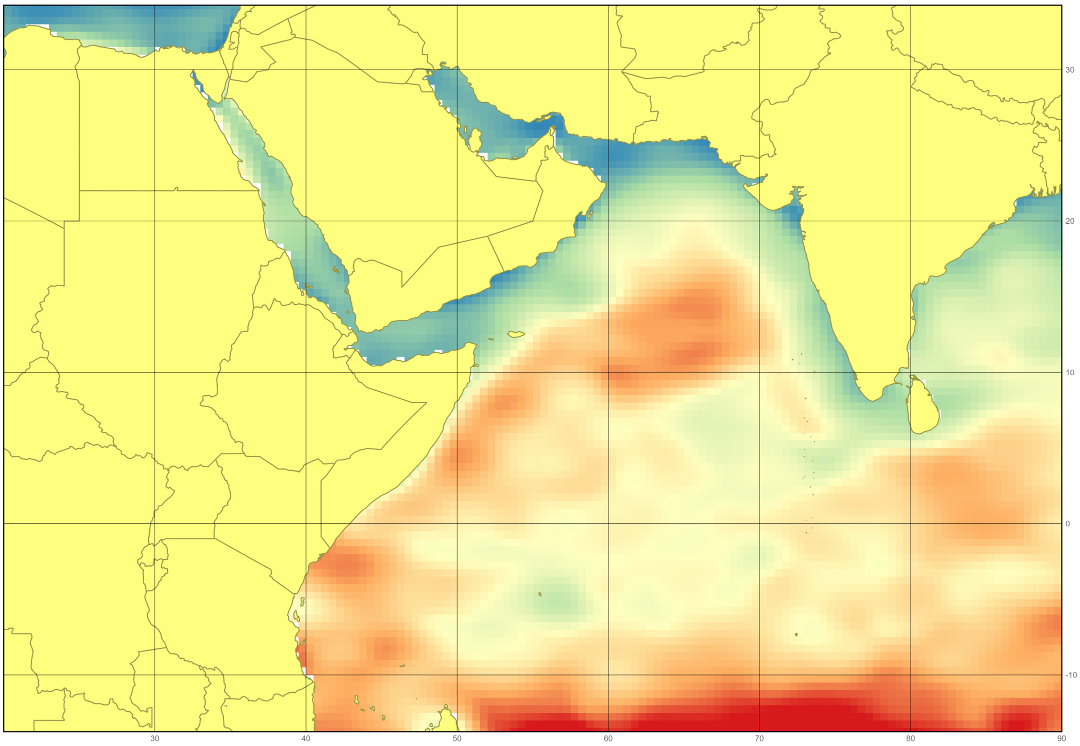


Figure 4.42: Mixed Layer Depth - December to February

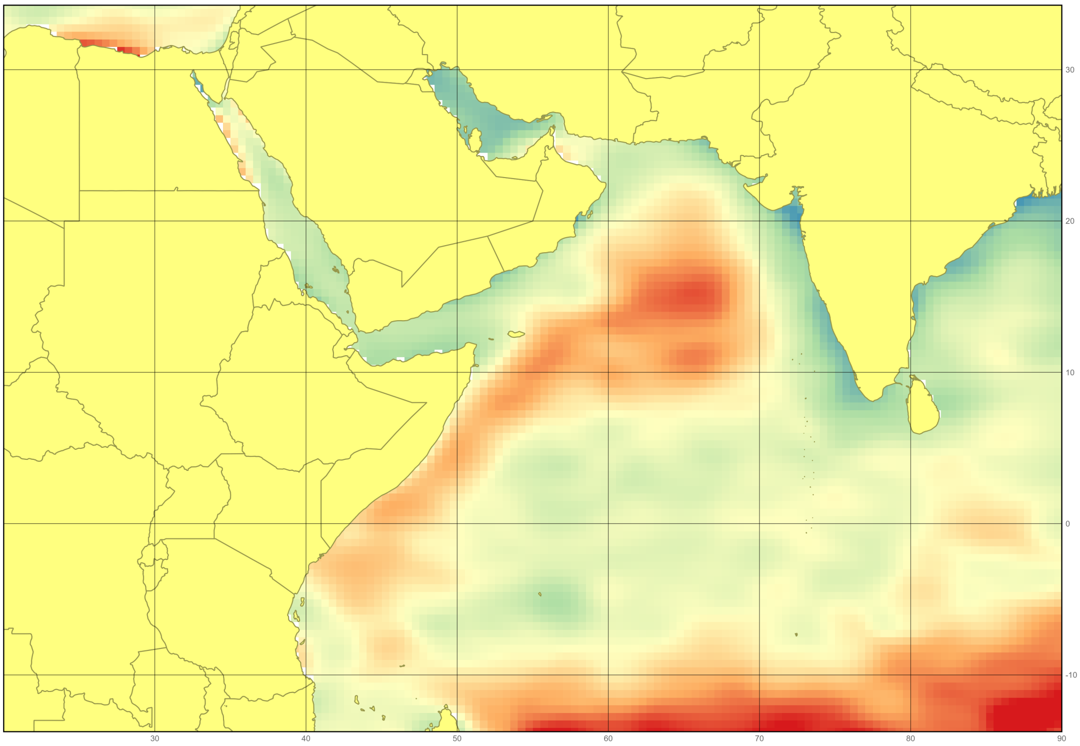


Figure 4.43: Mixed Layer Depth - March to May

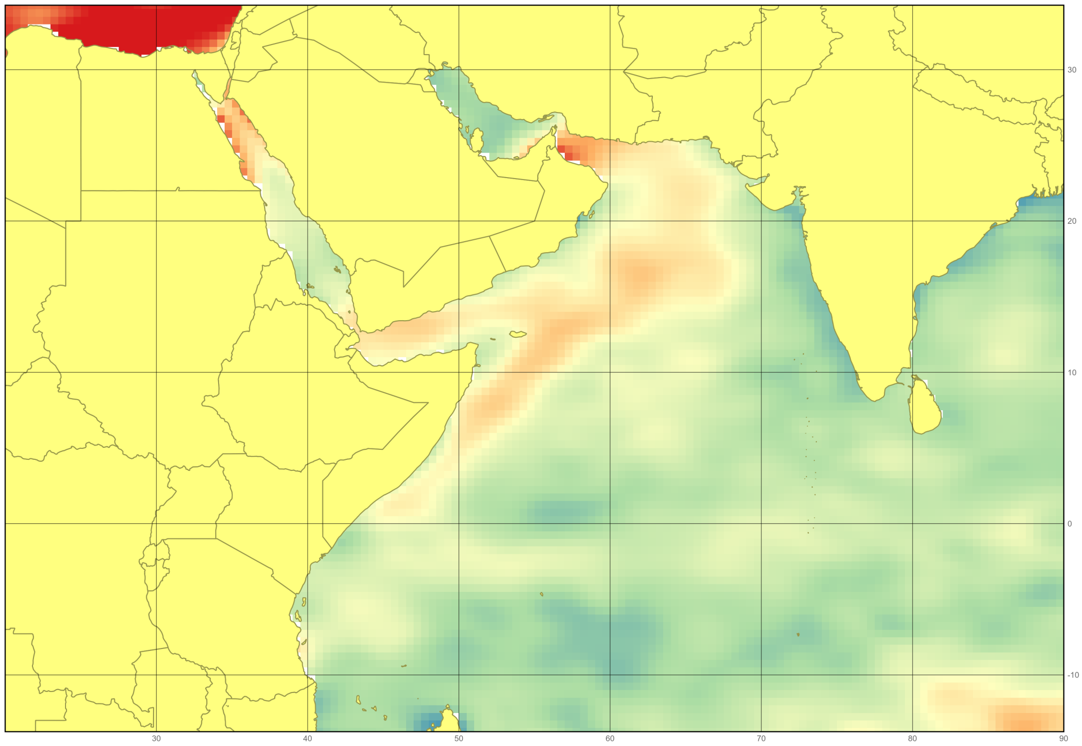


Figure 4.44: Mixed Layer Depth - June to August

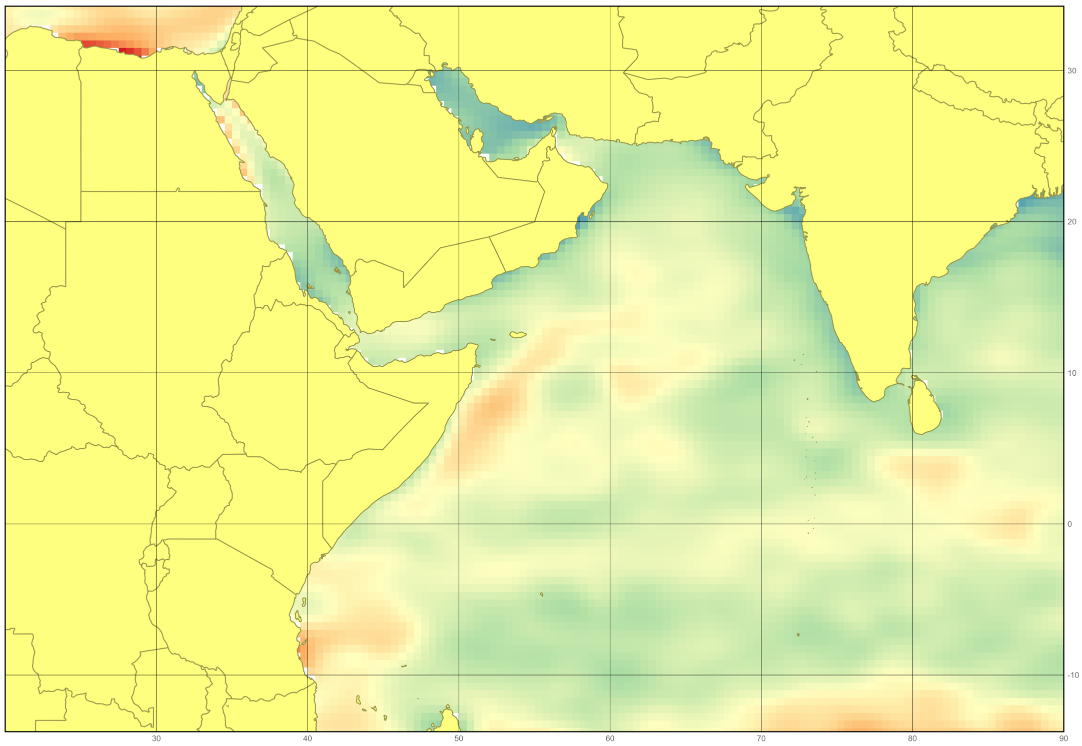


Figure 4.45: Mixed Layer Depth - September to November

4.6.11 Frontal Index

Derived product Thermal fronts mark the boundary between waters of different temperature. They can be productive areas due to mixing of water masses and important for foraging animals of many species, including tunas, whales, seabirds and turtles. We applied a methodology for determining an SST front using edge detection, described in Cayula and Cornillon (1995). Hobday and Hartog (in preparation) extend this method to generate an index of frontal activity for the region of interest. Pixels in individual images are allocated to a front, and then the presence of frontal pixels summed over a period of time. The index presented here is gridded in quarter degree boxes and averaged over an 8-day week. These were averaged for the selected seasons or years as presented herein. The resulting contours are then mapped onto a 0.25 degree grid that measures the frontal density in each of these grid cells.

Cayula J-F, Cornillon P (1995) Multi-Image Edge Detection for SST Images. Journal of Atmospheric and Oceanic Technology 12, 821-829.

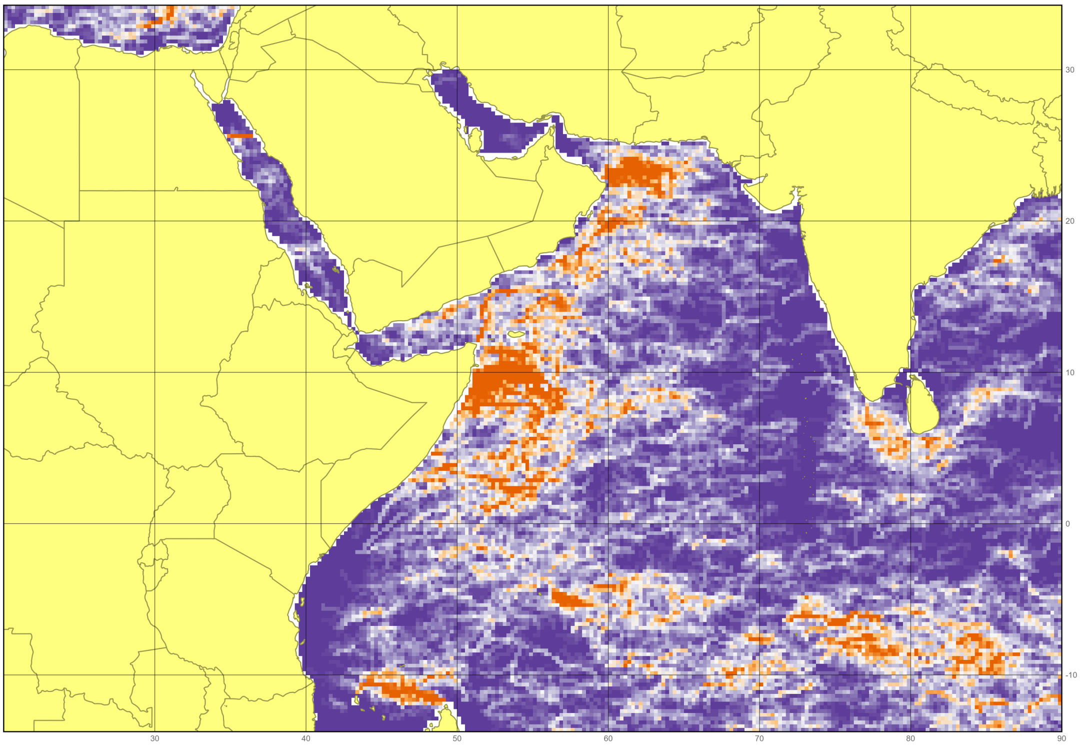


Figure 4.46: Global Frontal Density - December to February

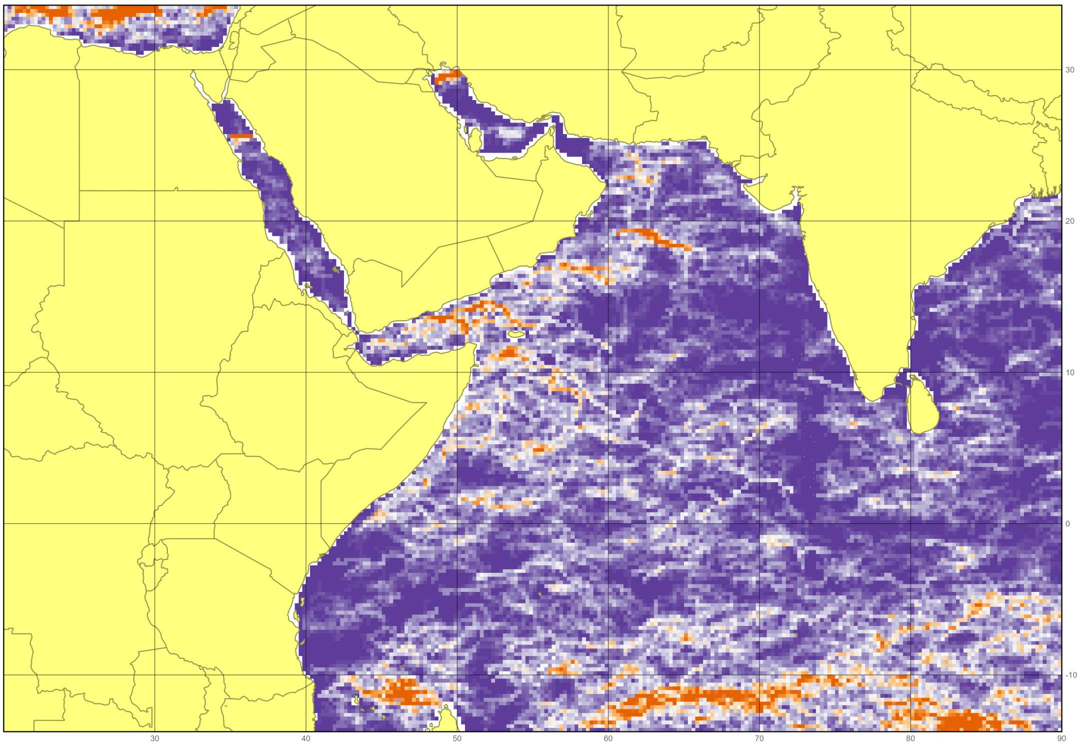


Figure 4.47: Global Frontal Density - March to May

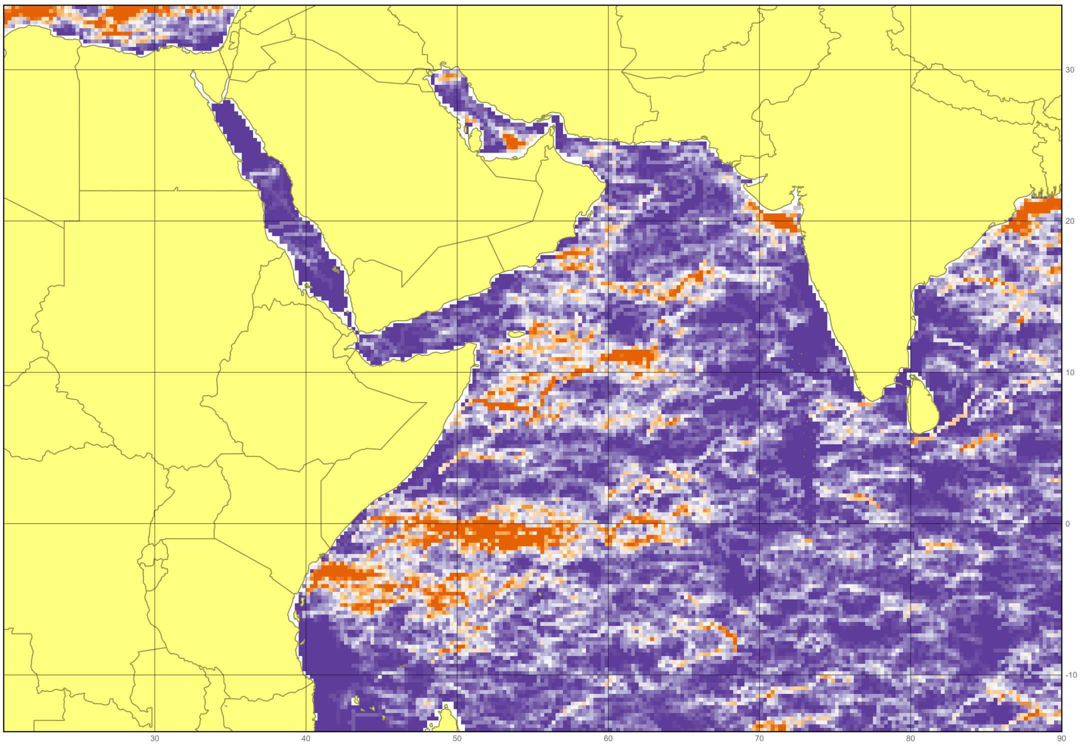


Figure 4.48: Global Frontal Density - June to August

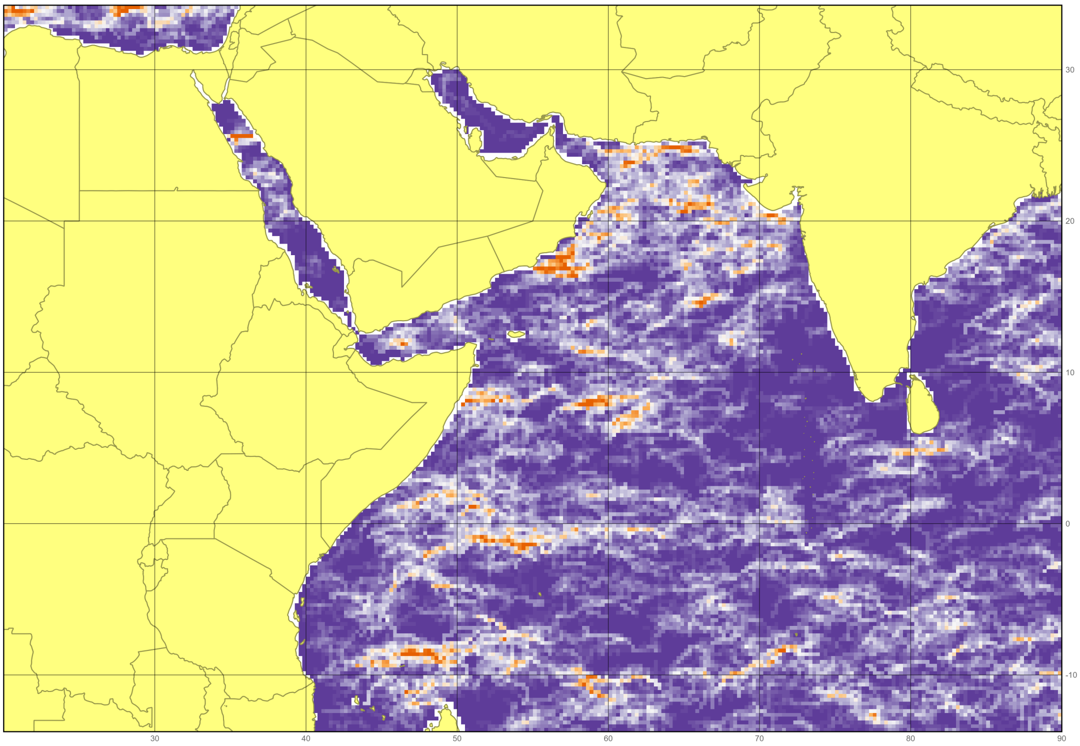


Figure 4.49: Global Frontal Density - September to November

4.6.12 Eddy Kinetic Energy

Locations where shear between water masses is high can generate productivity due to mixing. One measure of this mixing is estimated using Eddy Kinetic Energy (EKE). For example, regions of high tuna abundance occurred in relatively high EKE (Zainuddin et al 2006). EKE was calculated from the velocity maps based on sea surface height. Using the u and v values from the CARS synTS u and v products, EKE is defined as

$$0.5 * (U^2 + V^2)$$

Zainuddin M, Kiyofujia H, Saitohb K, Saitoh S-I (2006) Using multi-sensor satellite remote sensing and catch data to detect ocean hot spots for albacore (Thunnus alalunga) in the northwestern North Pacific. Deep-Sea Research II 53, 419-431.

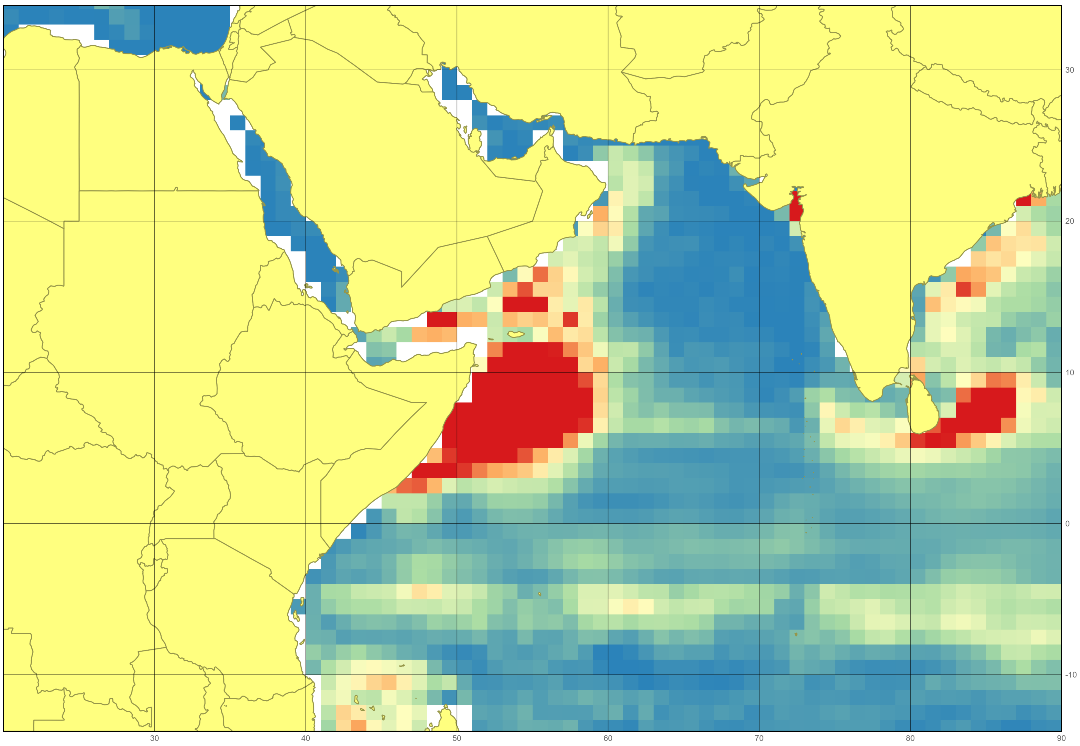


Figure 4.50: Eddy Kinetic Energy - December to February

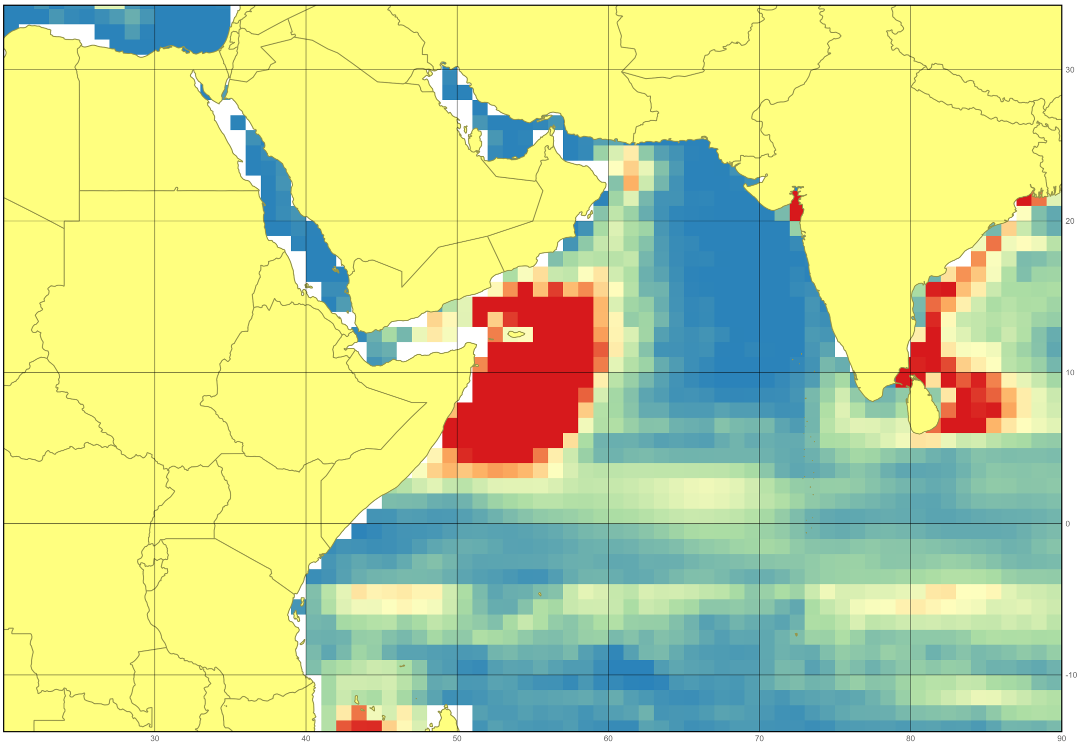


Figure 4.51: Eddy Kinetic Energy - March to May

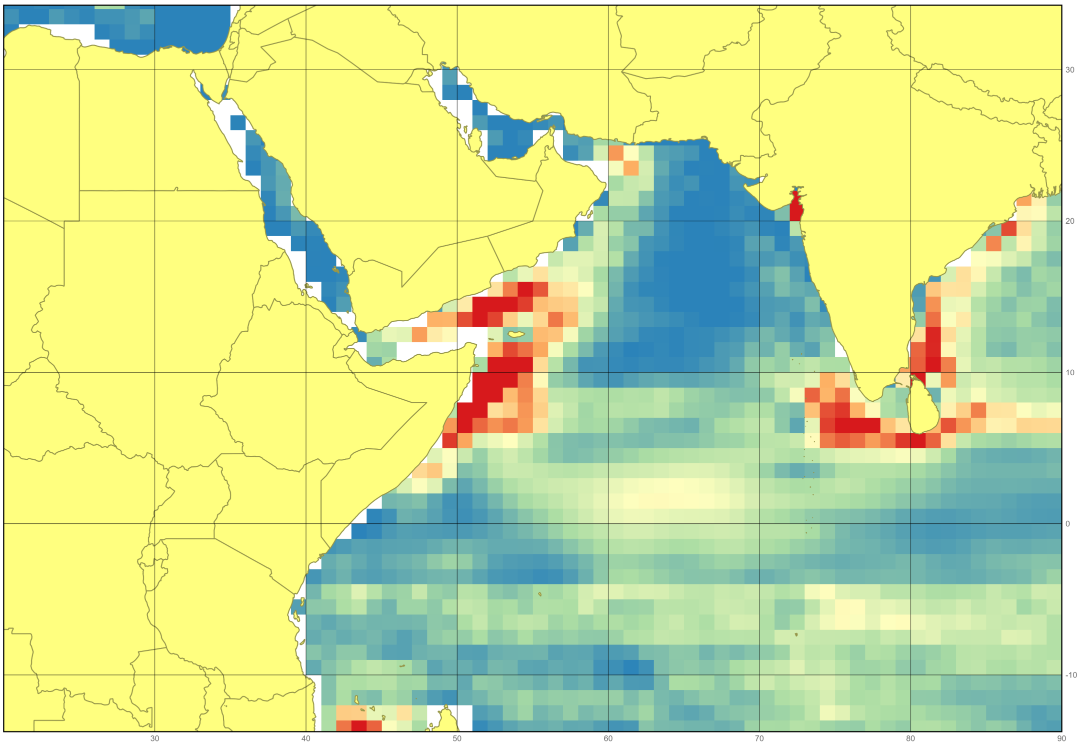


Figure 4.52: Eddy Kinetic Energy - June to August

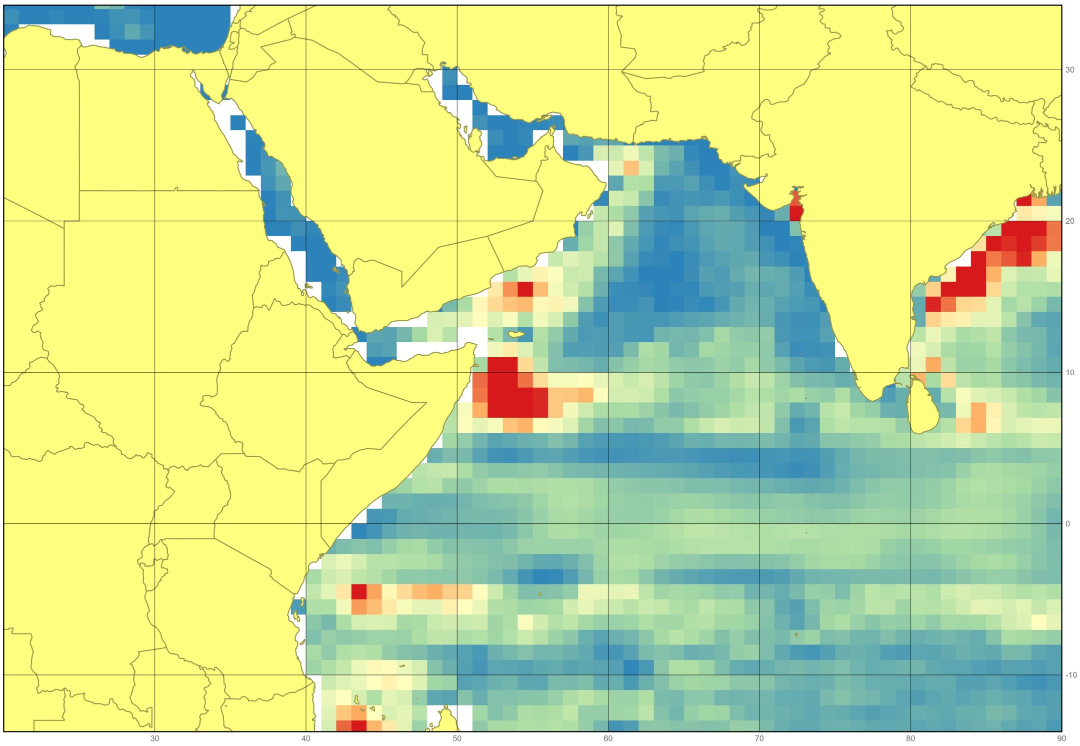


Figure 4.53: Eddy Kinetic Energy - September to November

5 Acknowledgments

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