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Conservation values in Commonwealth waters of the Christmas and Cocos (Keeling) Island remote Australian territories

Wealth from Oceans Flagship

FINAL REPORT
August 2009

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Australian Government
Geoscience Australia

ISBN: 978-1-921605-23-9

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Acknowledgements

The authors thank Louise Bell for the preparation of the report cover and Toni Cannard for formatting the report. Lilis Sadiyah (CSIRO), Craig Proctor (CSIRO) and Rachel Green (Western Australian Fisheries) provided information on fisheries resources in the region. Expert opinion was also provided by Dave Milton (seabirds), Colin Limpus (Turtles) and Curt Jenner (whales and dolphins).

Cover photos: Coral photo by J. Jaycock, Commonwealth of Australia, 2009; Whale shark photo courtesy Department of Environment and Conservation (W.A.).

This publication should be cited as:
Brewer, D.T., Potter, A., Skewes, T.D, Lyne, V., Andersen, J., Davies, C., Taranto, T., Heap, A. D., Murphy, N. E., Rochester, W. A., Fuller, M., Donovan, A. (2009). Conservation values in Commonwealth waters of the Christmas and Cocos (Keeling) Islands remote Australian Territories. Report to Department of Environment and Water Resources. CSIRO, Cleveland. 216 pp.

ISBN: 978-1-921605-23-9

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Table 5-14. Table summarising the assessment of conservation values against four of the NRSMPA criteria for the Cocos Volcanic Field subregion. CI = Christmas Island; CKI – Cocos (Keeling) Islands; POM - particulate organic matter. 201

1. EXECUTIVE SUMMARY

CSIRO Marine and Atmospheric Research, (CMAR) in collaboration with Geoscience Australia (GA), was asked to provide a succinct summary of the available and relevant information describing the conservation values of the marine environment under Commonwealth jurisdiction surrounding Christmas Island and the Cocos (Keeling) Islands. The conservation values were identified using a systems approach and with reference to ecological processes, habitats and biodiversity. In order to assist in developing the National Representative System of Marine Protected Areas (NRSMPA), key attributes of the conservation values, with respect to the ANZECC NRSMPA identification criteria, are also assessed.

The "systems" approach developed by CMAR, and used during previous projects to characterise the marine domains of the South West, North West and East Marine Planning regions was further developed in this project to identify the conservation values in what is a dynamic and unique environment under Australia's external territories jurisdiction. The remoteness of the region and general lack of research outside of the local island scale have made this a challenging project to undertake. However, guided by the systematic approach, excellent national and international data sources and expert knowledge, we were able to provide a comprehensive appraisal of the conservation values within the context of current information and knowledge.

Overall, we found that the environment of both Christmas and Cocos EEZs are highly unique with many potential deep ocean ecological systems that we have very little understanding of. Even locally, the flora and fauna below diving depths around the islands are poorly understood. Despite these limitations, the systematic approach using available information and knowledge from other deep ocean environments suggests that many new ecological systems remain to be discovered in the EEZs of both islands. Some key results of the work are summarised below.

Systems and regional understanding

The area of study is located in the north eastern Indian Ocean, in a region bounded by the Ninetyeast and Broken ridges (to the west and south respectively), the Sunda Trench to the north and the Australian continental margin to the east. The oceanic crust ranges from Jurassic to Cretaceous in age, and the abyssal plain is interrupted by a large volcanic province of seamounts of varying sizes, heights and ages, that stretches over 1,000 km across two deep water basins – the Wharton and Cocos Basins. Though volcanism has ceased in the area, it is still tectonically active with areas close to the Sunda trench experiencing uplift due to the fore-arc bulge and faulting along the ridges and earthquakes are common. Christmas Island is located in a region that is experiencing uplift. The Investigator Ridge to the east of Cocos (Keeling) Islands is a striking, 1,800 km long, N-S fracture zone (the major tectonic feature of the Cocos basin) and is forming a new plate boundary within the Indo-Australian plate. In contrast to Christmas Island, the Cocos (Keeling) atoll has undergone cycles of uplifts and submergence so the development of flora and fauna on the island has been much more dynamic and fractured compared to Christmas Island.

The knowledge that the two island environments had very different paleohistorical developments, led us to believe that despite both islands being located in the same region of the Indian Ocean, their many aspects of their geology and geomorphology were fundamentally different. A systematic study of the eastern Indian Ocean led us to characterise the region into a hierarchy with a number of levels:

Level 1: Areas to the east and west of the Ninetyeast Ridge

Level 2: Areas to the east of the Ninetyeast Ridge split into:

- *A western striation region that includes the Cocos (Keeling) Islands that has an eastern boundary just to the east of the Investigator Ridge.*

- *An eastern region that includes Christmas Island*

Level 3: Splits of the Level 2 units into a volcanic province and abyssal plains

The key distinction between the islands occurs at Level 2 due to the differing paleo evolution of the striation region containing the Cocos (Keeling) atoll from the plate subduction and uplift region containing Christmas Island as explained below.

Isolation of the islands from land has resulted in low sedimentation rates that are mainly pelagic in origin. The average sediment thickness in the Wharton Basin is 200 m. Exceptions are areas adjacent to seamounts where sediments gather from erosion and slumping from their slopes. Both basins have a similar sedimentary sequence, lying on a basement of pillow basalts. However, thinner sediment cover in the Wharton Basin results in more rugged topography than that found in the Cocos basin.

The region is influenced mainly by the inflow of oligotrophic, Indo-Pacific (ITF) waters which creates a deeper mixed layer that suppresses the availability of nutrients to surface waters. However, there is high seasonal, biological productivity in the local region due to the presence of strong mid-oceanic currents that spawn chaotic eddies that appear to be driven by baroclinic instabilities. Upwelling of deeper, nutrient-rich, cooler water into the region from the south Java coast also provides seasonally productive water and phytoplankton blooms into the region. These blooms appear to form mid-year and strengthen through spring before shutting down in summer due the onset of the NW monsoon which brings warm water from the NW into the region. This is reversed in autumn as the SE trades strengthen and drive the Indo-Pacific Throughflow into the region, and eventually strengthening to the point where the drivers of high productivity cycle through the region again.

The Christmas Island territory receives a stronger influence of the mechanisms described above and has a strong connection with the shallow water communities of the Indo-west Pacific. The Cocos (Keeling) Islands territory is almost 1000 kms further to the west and receives the tail end of these productivity blooms in most years (depending on the strength of the drivers). The Cocos (Keeling) Islands territory also appears to be more closely related to Indian Ocean communities than Indo-west Pacific, and more so than any other region in the AEEZ.

Both of these two external territories have a unique geographic isolation. However, there appears to be an unusual lack of endemism on the Cocos (Keeling) Islands and surrounding shallow reefs due to its recent emergence and colonisation some 4000 years ago in conjunction with periodic, catastrophic events, including tropical cyclones that have substantially impacted the viability of fauna. Christmas Island on the other hand is an uplifted limestone island that is still being uplifted so that its biota has existed for a longer and more stable period of time.

The shallow reef communities of the Cocos (Keeling) atoll provide habitat for two endemic coral species and the Cocos pygmy angelfish. Seven other coral species have not been recorded elsewhere in the eastern Indian Ocean.

The shallow marine habitats surrounding Christmas Island support a similar number of marine species compared to the Cocos (Keeling) atoll. However, Christmas Island has far less available habitat area and diversity. It is known to supports four species of endemics fish and two near endemics. Fifty of the 607 fish species are not found in other Australian waters, 28 are found in extraordinary abundance and 8 are hybrid species. There are also endemic molluscs and echinoderms a range of endemic land-based species including crabs, seabirds and mammals.

Although there appear to be a range of unique habitats in the deeper waters of the Christmas and Cocos (Keeling) Islands territories, little information is known about the species composition, endemism and connectivity of the deeper habitats.

Wharton Basin subregion

This subregion comprises mainly abyssal plain with physically isolated seamounts and covering an area of approximately 145,500 km^2 (20% of the combined Christmas & Cocos EEZs). The subregion has some of the deepest areas of all the subregions, and 90% of the area is in water depths >4,000 m. Sediments are in general fine grained, ranging from sand to mud dominated. Volcanic rock types occur across most of the subregion. 21% of the seamounts in the AEEZ are found in this subregion.

The subregion has high pelagic productivity flowing from upwelling along the south Java coast and medium-term, seasonal, cold core eddies. It supports a relatively high abundance of pelagic fish, appears to correspond with the western end of the Southern Blue Fin Tuna spawning area and may be an important feeding area for the larvae of this stock as well as migrating whale sharks and other pelagic species. The deep seamounts in the region are not common in other subregions in the area or in the northern or western marine regions of the AEEZ. Other unique habitats include the deep hole and valleys and abyssal plain environments which will also benefit from the high pelagic productivity (via falling particulate organic matter), potentially leading to relatively rich and unique deep water communities within the AEEZ.

Central Ridge subregion

The Central Ridge subregion is the shallowest of the subregions, though still has large areas of abyssal plain and covering an area of approximately 69,220 km^2 (9% of the combined Christmas & Cocos EEZs), Most (80%) of this subregion is in depths >4,000 m. The seamounts comprise 12% of all seamounts in the AEEZ, one of which Christmas Island is the surface expression. These share a connectivity of shallower habitats not found in other subregions. Although the region contains 12% of the seamounts in the AEEZ, the rarity of shallow seamounts in the AEEZ make this subregion even more unique in geological and ecological terms. Sediment ranges from mud to gravel and is highly correlated with water depth. Rock types are most commonly volcanic with some carbonate and sedimentary rocks present. Christmas Island itself is comprised of a series of interbedded carbonates and basaltic volcanics.

The proximity to upwelling along the south Java coast and eddies spun off interactions between the shallow seamounts and currents in the subregion result in seasonally high productivity in the pelagic and deeper waters within this subregion. This is demonstrated by known seasonal influxes of large pelagic fish and whale shark migrations. The seamount communities in this subregion are likely to support a rich and diverse fauna due to their shallow position and proximity to relatively high primary and secondary production. These dynamics will also have correlated downstream effects on deeper slope, basin and abyssal plain communities. The subregion also supports a range of endemics (described above), provides nesting habitat for internationally significant seabirds (including the endemic Abbotts Booby and Christmas Island Frigatebird) and green turtles and habitat for other listed species including pipefish, cetaceans, other turtles, seabirds and possibly sea snakes.

Cocos Basin subregion

The geomorphology of the Cocos Basin subregion is almost entirely abyssal plain, covering an area of 62,480 km^2 (8% of the combined Christmas & Cocos EEZs), with 90% of the area is in depths >4,000 m. The sediments are dominated by mud, with lesser amounts of sand and minor gravel. Rock types are mainly volcanic, with carbonates restricted to seamount slopes. Manganese nodules and crusts were detected on abyssal plain between volcanic topography, though not on the seafloor in the northern part of the subregion.

This subregion also benefits from the relatively high seasonal productivity in this external territory. However, it is dominated by abyssal plain and most of the benefit will be seen in seasonal abundances in the pelagic food web and a detrital food web in the benthic environment. The small number of deep seamounts in the subregion may also benefit by supporting relatively high abundances of suspension feeders at these depths. Little is known about any of the marine communities in this subregion, although a range of listed species, including whales, dolphin, seabirds and turtles, are expected to use the pelagic waters.

East Cocos Abyssal Plain subregion

The East Cocos Abyssal Plain subregion has abyssal plain, basin and four seamounts features (the western end of the Vening-Meinesz chain). It spans an area of approximately 93,780 km^2 (13% of the combined Christmas & Cocos EEZs), with >80% of the area is in depths >4,000 m, and <1% occurring in depths <2,000 m. Sediments are dominated by mud with minor amounts of sand. Erosion and deposition rates are likely to be lower here than at the Christmas Island end of the chain. The seamounts have abundant carbonate deposits on them.

Very little is known about the ecological communities within this subregion. The region is dominated by oligotrophic waters although sporadic seasonal primary and secondary productivity flows into the region in years where the regional productivity drivers are relatively strong. The seamounts are relatively shallow and consequently may support diverse benthic and demersal communities. Abyssal plain and basin environments are poorly understood. Listed species do not appear to be critically dependent on the subregion, although little is known about these interactions.

Investigator Ridge subregion

The main features of this subregion are the Investigator Ridge (which extends the length of the subregion) and associated trenches on either side, which are features not found elsewhere in the two EEZs. This represents 15.5% and 7.5% of the total area of ridge and trench features respectively, found in the AEEZ. The subregion has an area of approximately 61,000 km^2 (8% of the combined Christmas & Cocos EEZs), with >90% of the area in water >4,000 m. Sediment varies from mud to gravel, with variability based on location. Rock type is variable along the ridge, with volcanic, metamorphic and sedimentary rock types.

Little is known about this subregion although is appears to have a range of unique features including the extensive, unbroken ridge rising from deep water (~5,000 m) and extending into shallower depths varying up to about 2,500 m. This ridge is likely to provide a range of hard substrate habitats on its surface and slopes. The combination of characteristics are likely to support a diverse range of benthic and associated demersal community types that appear to be largely unimpacted by anthropogenic activity. The deep troughs on either side of the ridge also provide habitat for unique community types given their association with and influence of the ridge and coarse sediments transferring from it.

Cocos Volcanic Field subregion

The Cocos Volcanic Field subregion covers approximately 167,100 km^2 (22% of the combined Christmas & Cocos EEZs) and has >85% of its area in waters >4,000 m. It contains abyssal plain and a cluster of seamounts which tend to be larger and more elongate than the ones in the Christmas Island EEZ. They comprise 26% of the total area of seamounts in the Christmas and

Cocos EEZs, one of which the Cocos (Keeling) Islands. The nearly emergent (17 m BSL) Muirfield seamount and the Cocos (Keeling) Islands are coral atolls dating from the Pleistocene. Rock type on the seamounts of the subregion is mainly volcanic and sediment type ranges from gravel dominated to homogenous mud.

The shallow seamounts provide unique areas of highly diverse reef and other shallow water communities, representing the only extensive shallow reef features for about 1000 km. In an Australian context they are unique when compared to other shallow reef systems in Australia's western regions. The Cocos (Keeling) Islands are an internationally recognised seabird rookery and is one of the major seabird breeding grounds in the Indian Ocean. Seabirds occur in large numbers on North Keeling Island, in particular, with about 24 bird species currently found on the island, and 15 of these breeding in Pulu Keeling National Park. It houses the world's largest breeding population of the endemic red foot booby (*Sula sula*). It also has the second largest lesser frigate bird (*Fregata ariel*) nesting population in Australia. The island habitats also appear to be an important staging point for a range of migratory birds.

Little is also known about the other environments within this subregion, but like other subregions described above, their unique geographic location and subsequent influence of biophysical drivers, in conjunction with their own unique combination of geomorphic features, sediment characteristics and connectivity to other habitats indicates that unique ecological communities are probable in most depth zones, warranting further investigation.

West Cocos Abyssal Plain subregion

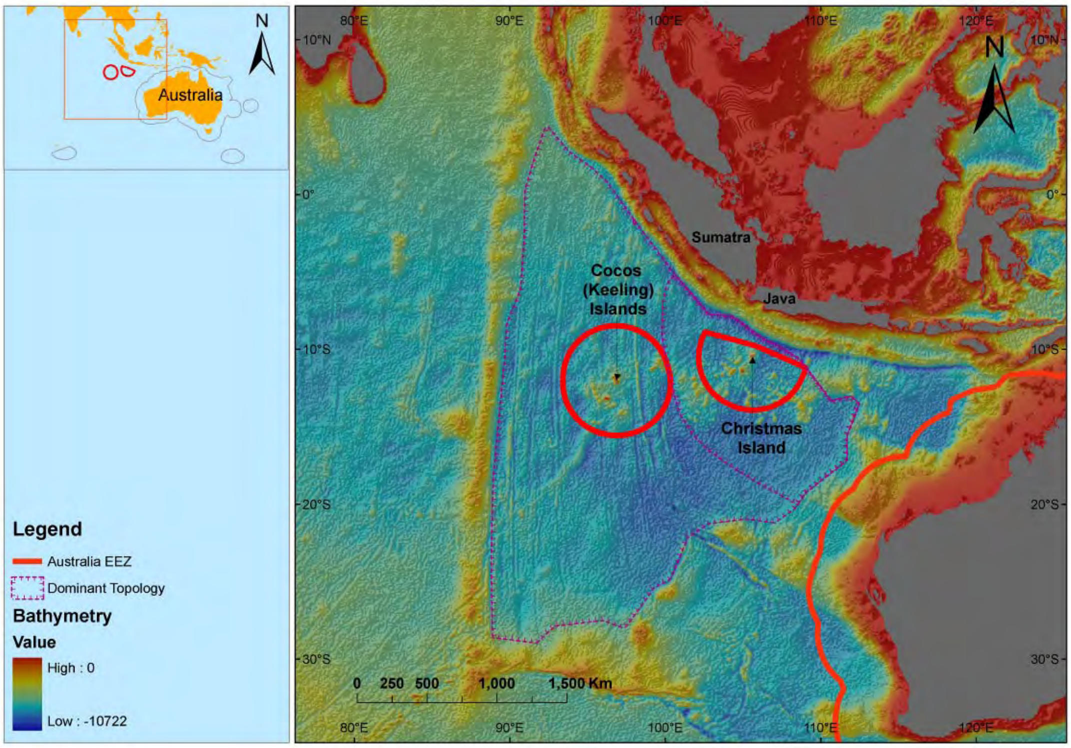
The West Cocos Abyssal Plain subregion is approximately 145,250 km^2, consists of abyssal plain and numerous basins and is the only subregion without some kind of high relief feature. It has no water shallower than 4,000 m, although only 1% in water deeper than 6,000 m. Though these basins represent 62% of the total area of basins in the combined EEZs, they are only a minor portion of the basins within the AEEZ (5.4%). Sediment across the region is homogenous, dominated by mud with lesser amounts of sand.

The subregion is relatively remote and largely undisturbed. The surface waters of the subregion are mostly oligotrophic, with sporadic interannual variability in productivity during autumn and due to seasonal upwelling forced by the local climate and oceanographic conditions. The large expanses of abyssal plain are likely to have sparse, but potentially unique community types associated with them. There are a range of species that are listed that may either use the East Cocos Abyssal Plain subregion as a foraging ground or other habitat. However, there has been little scientific study of species such as whales, dolphins, seabirds and turtles in the subregion so the importance of this subregion for these species is largely unknown.

Information gaps and monitoring

These two external territories contain a range of unique features and systems. However, they are relatively poorly understood with the possible exception of the island and atoll terrestrial and shallow reef habitats. Very little is known about the pelagic midwater and benthic communities, including their community composition, larval distribution and connectivity and interdependencies between communities at different depths. Trophic relationships (such as specialised feeding of Abbot's Booby bird on flying fish), feeding ranges and the links between biophysical drivers of higher productivity, trophic cascading and seasonal and temporal dynamics in these processes are generally poorly known. Very little is also known about key habitats and spawning aggregations other than for Southern Bluefin Tuna, which has been the focus of an international fishery, and the Islands terrestrial environments.

The threats to the habitats and associated species occur largely from climate change (at all scales), human habitation (island scale) and industry (fishing, mining etc). Greater understanding of the communities that exist in these regions and monitoring programs for the most sensitive and vulnerable communities will help the formulation of effective management and adaptation strategies to guard against the loss of the unique habitats and species found in these two external Australian territories.



2. BACKGROUND

The Department of the Environment, Water, Heritage and the Arts intends to make recommendations to the Minister for the Environment, Heritage and the Arts about areas within Commonwealth waters surrounding Christmas Island and the Cocos (Keeling) Islands that are suitable for inclusion in Australia's National Representative System of Marine Protected Areas (NRSMPA). The Commonwealth is currently developing Marine Bioregional Plans, including a system of Marine Protected Areas (MPAs) for all Commonwealth waters. Commonwealth waters have been divided into 5 marine regions: the South-east, South-west, North-west, North and East.

CSIRO Marine and Atmospheric Research, in collaboration with Geoscience Australia, was asked to provide DEWHA with advice and data on the conservation values of the marine environment under Commonwealth jurisdiction surrounding Christmas Island and the Cocos (Keeling) Islands, including their ecological processes, habitats and biodiversity with reference to the ANZECC NRSMPA identification criteria.

For the purposes of Marine Bioregional Planning conservation values are defined as those elements of the marine environment that are either specifically protected under the *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act) or the *Historic Shipwrecks Act* 1976, or have been identified as key ecological features. Key ecological features are defined as features of the marine environment which meet one or more of the following criteria:

- a species, group of species or a community with a regionally important ecological role (e.g. a predator or a prey species that affects a large biomass or number of other marine species); or
- a species, group of species or a community that is nationally or regionally important for biodiversity; or
- an area or habitat that is nationally or regionally important for:
  a) enhanced or high biological productivity (such as predictable upwellings),
  b) aggregations of marine life (such as feeding, resting, breeding or nursery areas),
  c) biodiversity and endemism; or
- a unique seafloor feature with known or presumed ecological properties of regional significance.

In order to identify Key Ecological Features we will identify systems and subregions around Christmas and Cocos (Keeling) Islands via the "systems" approach. The report will comprehensively explain and discuss each system and subregion in context of its ecological processes, habitats and biodiversity.

2.1 Objective of the Project

To provide a succinct summary of the available and relevant information about the marine environment under Commonwealth jurisdiction surrounding Christmas and Cocos (Keeling) Island territories, their ecological processes, physical environments (i.e. oceanography, geomorphology, substrate type, geological history, etc), habitats and biodiversity, especially those relevant to the ANZECC NRSMPA identification criteria.

3. METHODS

3.1 Description and justification of approach for assessing conservation values

Our approach was based on identifying the conservation values and the key ecological questions that need to be addressed in order to assist DEWHA with subsequent use of the information in their planning exercises. For the purposes of this project we used the definition of conservation values developed for the Marine Bioregional Planning listed in the previous section.

To address conservation values at range of relevant scales we systematically compiled information to describe the systems and subregions within which Christmas and Cocos (Keeling) Islands were contained. Each system and its subsystems were then assessed to determine their key species, functional groups habitats and ecological processes and potential conservation values.

The attributes of the identified conservation values were then qualitatively discussed against the NRSMPA to determine how those values may relate to each of the criteria, in order to provide some guidance as the relevance of the criteria for each conservation value. We also identified, along with DEWHA project staff, a number of likely questions that may be asked against each NRSMPA criteria, as outlined in Table 3-1.

Taking all these elements into consideration (species, group of species, areas, habitats ecological attributes, resilience), the various scales involved, and the range of likely questions that may be asked, the approach we adopted was an extension of the "systems" approach used successfully in the Bioregional Marine Planning project in the North West of Australia (Brewer *et al.*, 2007a) and Eastern Australia (Brewer *et al*., 2007b). The first task in applying the approach is to systematically articulate the composition and functional relationships within a range of nested systems constructed from bioregional units (see for example IMCRA Version 4). The schematic below shows how systems and subsystems can be defined in terms of drivers, outputs and self-similar nesting of systems comprised of functional groups, habitats and the flow of processes that support provision of ecological services (Figure 3-1).

In order to identify Key ecological features we will identify systems and subregions around Christmas and Cocos (Keeling) Islands via the "systems" approach. The report will comprehensively explain and discuss each system and subregion in context of its ecological processes, habitats and biodiversity. In particular, these features can be categorised as follows:

- protected species (i.e. listed under the EPBC Act as either threatened, migratory, cetacean or listed marine species);
- protected places (i.e. listed natural, indigenous and historic heritage places under the EPBC Act and shipwrecks under the Historic Shipwrecks Act) and;
- key ecological features, which are features of the marine environment which meet one or more of the following criteria:
    - a species, group of species or a community with a regionally important ecological role (e.g. a predator or a prey species that interacts significantly with a large biomass or number of other marine species);
    - a species, group of species or a community that is nationally or regionally important for biodiversity;

- o an area or habitat that is nationally or regionally important (this is further defined – see last page of the contract)
- o a unique seafloor feature with known or presumed ecological properties of regional significance

At a generic level, we define a system as follows.

- A region with a unique set of drivers that control the environment of the system, its spatial makeup and variation at the larger timescales: for example, tectonic upheaval or subsidence of islands, volcanic formation of seamounts, ocean currents, tidal, seasons, interannual and climatic. Drivers may provide, and alter, the input of biotic and abiotic elements that affect the makeup and productivity of the system and the services it provides. Drivers may also disturb and redistribute elements of the system.

- The system provides services to humankind and other systems, and it may use services provided by other systems. Within the system, there is a self-similar collection of subregions which also respond to a set of local drivers and in turn interact with other subregions. Subregions may be responsible for elements of services provided by the regional system and they may also preferentially, or otherwise, use the services provided by neighbour systems. At the subregion level, drivers and services are internalised in the sense that these exchanges occur between the subregions and the environment surrounding them within the system. Thus each subregion has a local set of drivers and services including exchanges with neighbouring subregions (Figure 3-1). Within each subregion there is a collection of trophic elements (denoted by “T” in Figure 3-1) which may comprise functional groups or biota that are of importance to the functioning of the subregion and/or to the services it provides. The trophic elements interact with a set of habitats (denoted by “H” in Figure 3-1).

- Part of the exchange, or linkage, between subregions may be from a dependence of a set of trophic elements on habitats in more than one subregion (denoted for example by the red dashed line in Figure 3-1 that crosses subregions 1 and 2). Features within subregions may comprise important trophic elements (denoted by “t” within the larger “T” trophic groups in Figure 3-1), which in turn are associated with one or more important sub-habitats (denoted by “s” within “H”) that are part of the subregion suite of habitats.

- The issue of linkage between habitats and trophic elements is highlighted in Figure 3-1 as dashed lines which show the types of interactions that are possible. An important aim of the subregion descriptions is to identify and characterise these linkages along with the associated conservation values.

In applying this approach in this project, the unique aspects of the geological, oceanographic and biological setting were taken into account in identifying a number of scales, and associated systems, containing conservation values within the Christmas and Cocos (Keeling) Islands territories.

Using the hierarchical approach, we identified a nesting of systems within which the EEZs of Christmas Island and Cocos (Keeling) Islands are contained. Key spatial units within this hierarchy are summarised in Table 3-2. These units provide the structural framework within which functional processes and environments operate to affect the status of conservation assets.

Cocos (Keeling) lagoon

Table 3-1. Categorisation of the NRSMPA criteria, and some key questions that may be asked against each, in relation to potential conservation values identified in this project.

Criteria	Scale, Level	Attribute	Key Questions
Naturalness	Island/Local	Human Values Ecological health Human impact	▪ Has any area or part of the subregion not been subjected to human induced change ▪ Is any of the subregion currently protected in reserves
Biogeographic importance	Various	Biogeographic Representation	▪ Does the subregion include important biogeographic qualities
International and national importance	International National	Biogeography	▪ Are any of the ecosystems and/or features in the sub-system of international or national importance
Representativeness	Regional-Local	Ecological composition	▪ What is the range and extent of ecosystems and/or features represented in this subregion
Comprehensiveness	Regional-Island	Ecological composition and functions	▪ What percentage of species, geomorphic features and/or habitats located in this subregion are represented here in comparison to other subregions and in comparison to the AEEZ
Ecological Importance	Regional-Island	Ecological function/services	▪ Does the subregion contain examples of benthic/demersal biological features (e.g. habitats, communities, subregional ecosystems) which may be of high biodiversity value, species richness and or endemism ▪ Does the subregion contain examples of ecologically important pelagic features which have a consistent and definable spatial distribution ▪ Does the subregion contain habitat (eg nursery or juvenile areas or feeding, breeding, resting or aggregation areas) for threatened and/or migratory species ▪ Does the subregion contain one or more areas which are a biologically functional, self-sustaining ecological unit
Productivity	Regional-Local	Ecological Service Area	▪ How productive is the subregion in terms of ecosystem service delivery in comparison to other subregion around Christmas and Cocos(Keeling) Is. ▪ Do the species, populations or communities of the sub-system have a high natural biological productivity
Uniqueness	International Island	Ecological composition, Biography	▪ Does the subregion contain unique species, populations, communities or ecosystems ▪ Does the subregion contain unique or unusual geographic features
Vulnerability Assessment	Various	Exposure-Sensitivity to Threats	▪ What are the pressures/threats on this unit and how capable is it in maintaining its asset condition (resilience)? ▪ Is management capable of controlling adverse pressures and threats on the unit?

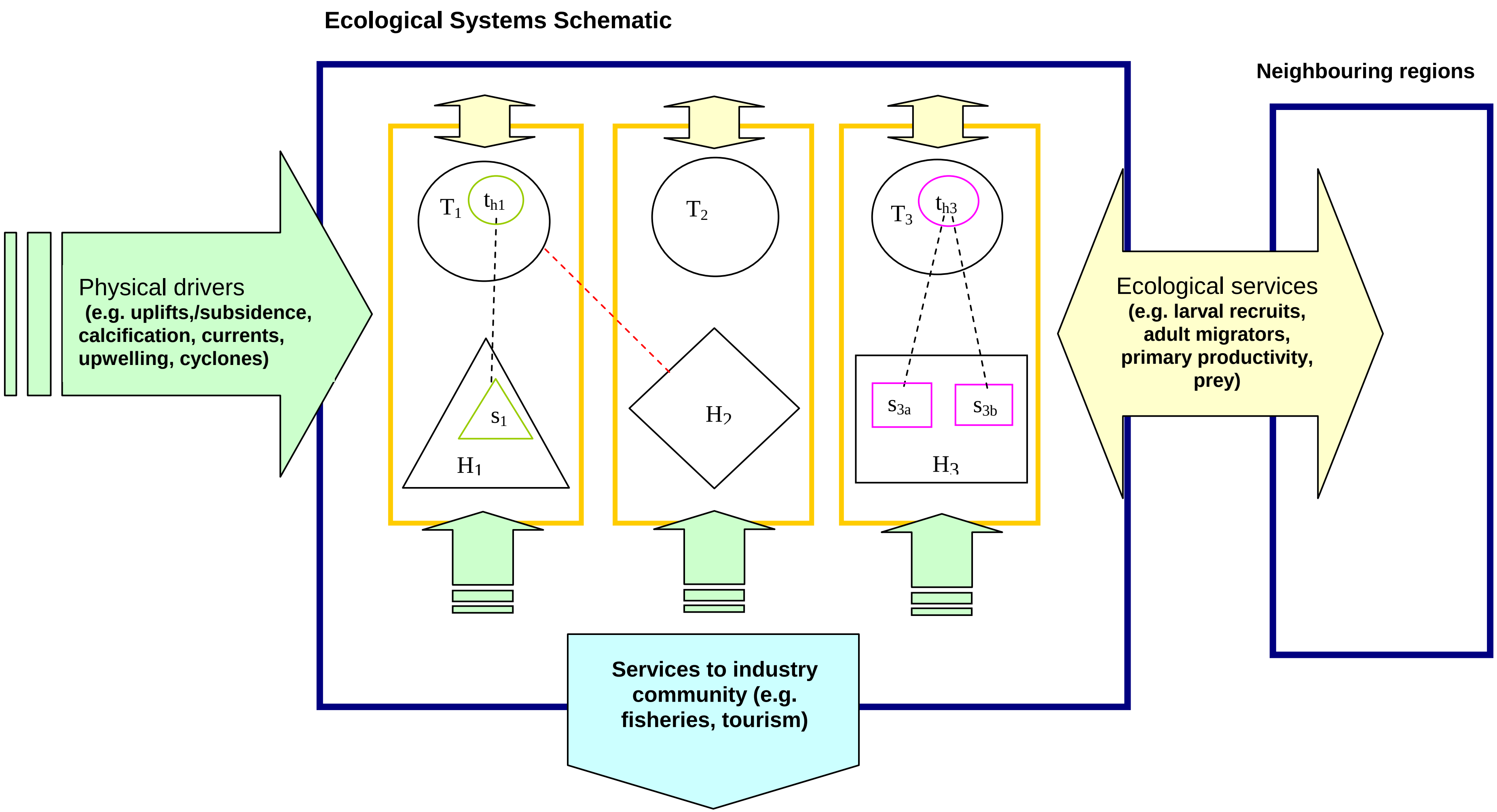


Figure 3-1. Conceptual trophic system model – illustrating the relationship between (i) the region and neighbouring regions and (ii) three compartments, each comprising a major habitat type (H) and associated trophic system (T). Key sub-habitats (s) and their associated trophic systems (t) are also shown. The influence of physical drivers and flow of ecological services is also shown at the regional and subregional level

Experience with bioregionalisation analyses of Australia's coastal and marine regions suggests that the biological composition and structure within the first four levels (down to biomes) cannot be adequately captured by geophysical surrogates alone (see Last *et al*., 2009, *in review*). However, at lower levels, geophysical surrogates may be appropriate. The limited biological information that we were able to collate for this project suggests complex contemporary and historical processes are at play in determining the modern pattern of marine flora and fauna. In addition, human colonisation of the islands over the past centuries has dramatically altered the distribution, and indeed existence, of species and habitats.

Table 3-2. Summary of hierarchical nesting of systems within which Christmas and Cocos (Keeling) Islands territories are contained

Level	Scale, Key Driver	Key Characteristics
1. Ocean Basin	Indian Ocean. Basin circulation, climate, water masses, tectonics, continental drift and basin evolution	Unique basin-scale composition of environments including tectonics, exchanges with other oceans, paleo-evolution of flora and fauna composition
2. Sub-ocean Basin	Portions of the basin that have evolved through formation or breakdown of barriers and environments. Tectonics and ocean circulation	Unique subset of basin environment caused by changes in drivers and/or physical structure of sub-basin. Environmental and evolutionary differentiation of faunal compositions and formation or isolation of unique fauna. Contains a collection of provinces.
3. Province	Units within sub-basins within which distinct fauna have evolved through distinct pathways. Barriers, submergence, emergence, volcanic activity, plate collisions	Unique faunal composition contained within an environment that is differentiated at the sub-basin scale. Speciation aided or hindered by physical processes and moderated by biological adaptive evolutionary processes resulting in a suite of species that adhere to the province unit
4. Biomes	Depth-structured faunal units. Tectonic subsidence and uplift. Circulation, deep water formation and upwelling, mode water formation, subduction of surface mixing, and water mass renewal	Depth structured faunal units that have adapted to and evolved with depth-related biogeophysical processes affecting habitats, speciation and dispersal
5. Geomorphic Type	Distinct geophysical units that act as surrogates for distinct fauna associated with unit. Unit provides differential exposure to environment, exchanges and energy flows	Faunal unit adapted to environment and habitat niches provided by the geomorphic unit and its contained environment
5a. Island Units	Island and sections of island containing unique habitats/environments supporting unique fauna	Habitats that are geomorphic features (e.g., beaches, cliffs, coral coast, rocky shore) and support unique fauna that depend heavily on the unit for its existence
6. Facies	Hard, soft or mixed substrates formed by various degradation and erosive processes with by-products accumulating within certain areas	The composition and texture of facies units provide substrate that serve a variety of purposes for flora and fauna

3.2 Implementation Considerations

The hierarchical systems approach described above was implemented by identifying the broad regional differences in geological structuring processes, oceanographic and climate forcing and species-specific processes that would affect potential conservation values according to the measures discussed above. Key resources and considerations we took into account in implementing included:

- A review of available data maps from a variety of sources described in the following section.

- Expert opinion workshops were held with CSIRO and GA participants to examine the mapped products and collated information to assess the key drivers of the systems at each Level in the hierarchy (e.g. ocean basin evolution, tectonics, oceanography, sediments, geomorphology, productivity/nutrients, climate, habitats, species composition, terrestrial inputs) and how these might influence the identification of conservation values.

- Comparative assessments were made of how systems at the various scales relating to Cocos (Keeling) and Christmas Island territories may differ from other systems at the same Level because of their geologic makeup, physical environment, component species groups and/or habitats;

- Key processes were identified that maintained and/or supported resilience and life history stages of species, their habitats and their contribution to other components of the systems.

- Information provided by DEWHA, the web and literature reviews were reviewed and incorporated as appropriate. Selected GIS layers were provided through the DEWHA project manager.

Exploratory mapping and analyses were first conducted to gain an understanding of the makeup of the region at each of the scales, the processes operating at those scales and the adequacy of the information in helping us make an informed decision on, or at the very least help us identify information gaps on conservation values. The information was then integrated into a systems perspective which was then used to articulate the potential conservation values and their attributes.

In the first instance, we began with the geomorphic units within the EEZ of Christmas Island. From there we expanded out to the basin scale to get an understanding of the paleohistoric and tectonic processes responsible for the differences in the islands and their environments. The inclusion of Cocos (Keeling) has materially added to our insights into the conservation values and their potential importance by providing the contrast required to understand the broader context.

In the following sections a description of the datasets is presented along with key features noted from the exploratory analyses. The descriptions presented here are designed to give a relatively succinct, but accurate depiction of the system components that can be described for the various system levels. Some data may be applicable to a number of systems; for example bathymetry is relevant at the broadest scale, as well as at the scale of the islands, so an integrated assessment of system structure and function is left to a later section. The data descriptions are presented first and then the exploratory analyses.

3.3 Data layers

3.3.1 Physical data

Regional or subregional mean values are originally derived from the CSIRO Atlas of Regional Seas (CARS2000) data series. The 0-2000 m depth values are output from the Australian National Bioregional 2005 project while the Bottom water property values are now incorporated into the CARS2006 dataset. A fully global atlas ("CARS2009") will be available in May or June 2009.

CARS2000 is a set of seasonal maps of temperature, salinity, dissolved oxygen, nitrate, phosphate and silicate, generated using Loess mapping from all available oceanographic data in the region. It covers the region 90-175E, 50-0S, on a 0.5 degree grid, and on 56 standard depth levels. The data was obtained from the World Ocean Atlas 98 and CSIRO Marine and NIWA archives. It was designed to improve on the Levitus WOA98 Atlas, in the Australian region.

The Australian National Bioregional 2005 dataset is interpolated from CARS2000 mean and seasonal fields to 0.1 degree spaced grid, at depths of 0, 150, 500, 1000 and 2000 metres. The Loess filter used to create CARS2000 resolves at each point a mean value and a sinusoid with a one year period (and in some cases a 6 month period sinusoid - the "semi-annual cycle"). The provided "annual amplitude" is simply the magnitude of that annual sinusoid.

Bathymetry is based on the GEBCO 2003 One Minute Grid, a product of the General Bathymetric Chart of the Oceans (GEBCO) Project. GEBCO consists of an international group of experts who work on the development of a range of bathymetric data sets and data products.

Monthly mean Sea Surface Temperature (SST) and Chlorophyll A (ChlA) are derived from the MODIS (MODerate resolution Imaging Spectroradiometer), a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites (Feldman and McClain, 2008). The MODIS satellites view the entire Earth's surface every 1 to 2 days at a nominal 1km resolution. SST has been captured from the Terra platform since 1995, while ChlA has been captured from the Aqua platform since 2002.

Seasonal Primary Production (PP) and Sea Surface Height (SSH) are from the Australian National Bioregional 2005 dataset with original source from the MODIS Aqua satellite (see http://modis.gsfc.nasa.gov/data). No additional processing or quality control was undertaken on this data set. The only changes made were to restrict the geographical and temporal coverage to the region between 90E and 180E, and 10N to 60S; and time range between December 2002 to January 2004. The satellite measures water leaving radiances at a variety of wavelengths, these are converted by a series of algorithms to obtain the ChlA estimate. The algorithms are described in a 50 page document titled Algorithm Theoretical Basis Document Bio-Optical Algorithms - Case 1 Waters. This document is available at http://modis.gsfc.nasa.gov/data/atbd/atbd_mod18.pdf. Parameter accuracy is incorporated in this document. PP is based on ChlA and measured in mg Carbon per square meter with an accuracy of ±30%.

The MODIS Aqua Sea Surface Height (SSH) product provides the measurement of the sea surface height relative to a model of the ellipsoidal Earth (the ellipsoid) at a resolution of 6.2 km along the ground tracks of the satellite. SSH variance can be used with SST to better predict likely cyclone intensity (e.g. see http://www.clivar.org/organization/indian/IOP6_talks/Wednesday/YU-WarmCore-Cyclone.ppt).

3.3.2 Bathymetry

For analyses at the required scale, multibeam bathymetry data collected on the Sonne, S0199 (2 Aug – 22 Sept 2008) and SO200 (Oct 2008 - Jan 2009) in the area of the Christmas and Cocos (Keeling) Islands territories has been incorporated into the existing 250 metre resolution Australian Bathymetry and Topography Grid (2005).

Broader scale analysis was performed on ETOPO2v2G 2-minute Gridded Global Relief Data (U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Geophysical Data Centre, 2006, http://www.ngdc.noaa.gov/mgg/global/etopo2.html).

3.3.3 Geomorphology

Geomorphic province and feature boundaries for the EEZ and all smaller divisions within it were derived from a recent study of the geomorphology of Australia's margin and adjacent deep seafloor (Heap and Harris, 2008). These boundaries were delineated using the 250 m Australian Bathymetry and Topography Grid (2005) and relevant literature. Feature names are based on those endorsed by the International Hydrographic Office (IHO, 2001) and RAN charts. Definitions of features are contained in Table 3-3.

Feature boundaries in the Christmas and Cocos (Keeling) Islands EEZs have been updated to reflect improvements in the bathymetry data for this area and finer scale analysis requirements of this study. Amendments to boundaries of Heap and Harris (2008) are listed below:

- Polygons for land areas (Christmas and Cocos (Keeling) Islands) have been added. Due to paucity of digital bathymetry data for shallow waters surrounding the islands, land polygons were taken from AGSO GIS system documentation prepared for Christmas Island (Porrit, K., Orr, K. & Lucas, L. 2002) and Cocos (Keeling) Islands (Lucas, A. & Porrit, K. 2001)

- Where resolution of data allowed, shelf polygon boundaries have been moved to follow the 200 m isobath surrounding land areas.

- Areas previously classified as 'slope (unassigned)' representing the slope around emergent seamounts in the Christmas and Cocos EEZs, have been reclassified as 'plateaus' so as to be consistent with physically similar areas surrounding non-emergent seamounts. The new class comprising all sloped areas surrounding seamounts has been named 'seamount slope/plateau'.

- Some features have been removed or amended based on improved bathymetry data: A single canyon previously thought to exist off the north of Christmas Island and a ridge to the east of Christmas Island have been shown not to exist, and polygons for these have been removed. The northern and eastern boundary of the seamount/guyot polygon surrounding Christmas Island has been reshaped to become consistent with placement of equivalent boundaries on adjacent topography.

2.3.4 Sedimentology

A total of 84 sediment data points were available in the timeframes of the study. This includes quantitative data generated for this study, and descriptions of sediment characteristics sourced from previous publications. Samples that occur outside the EEZ were included to supplement scarce data for some features to capture the full spectrum of environments.

Quantitative data was generated for 25 samples held at GA and seven samples acquired from Lamont Doherty Earth Observatory (USA). Where adequate amounts existed, these samples were analysed for grainsize and total carbonate (Wt%; µm) and grainsize (vol%; µm). These samples were sourced from four marine surveys conducted between 1963 and 1993 (Table 3-4) and include core, dredge and grab samples. This data has been quality controlled and those samples that failed to meet the minimum metadata standards outlined in Geoscience Australia's *Data Standards, Validation and Release Handbook, 4th Edition (2004)* were excluded from the analysis. Only analyses conducted on dredges, grabs or the top 0.1m of a core and where the gravel, sand and mud fractions totalled 100% ± 1% were included. Core samples that did not include depth measurements were also excluded and duplicates were removed. Ongoing quality control of data may have resulted in slight variations between total samples reported in this document and milestone progress reports. Data generated is now available in MARS and incorporated into GA's sediment data set and derived products.

Qualitative data was compiled for 52 locations. Data was accessed through the National Geophysical Data Centre, Marine Geology resources and includes interpretations of sediment composition and grainsize. These samples were sourced from 16 surveys conducted between 1898 and 1976 (Table 3-5) and include core, dredge and grab samples. Positional accuracy of spatial information varies between surveys. More detailed metadata and seabed photos, where available, are included.

A consistent regional sediment dataset was achieved by using a simplified Folk classification (Folk, R.L 1954, J. Geol., 62 pp334-359) of quantitative and qualitative data (Table 3-6). Detail of classification was limited by inconsistencies in the information available for qualitative data points.

Low tide at the Cocos (Keeling) Islands.

Table 3-3. List of the 11 marine geomorphic provinces and 21 geomorphic features represented in the area of the Cocos (Keeling) and Christmas Island EEZs. (after Heap and Harris, 2008). Original definitions included in this table are adapted from IHO (2001).

No.	Name	Definition
1	Shelf	Zone adjacent to a continent (or around an island) and extending from the low water line to a depth at which there is usually a marked increase of slope towards oceanic depths.
	Seamount slope	Slope surrounding seamounts from the shelf edge to the point where there is a general reduction in slope.
*	Plateau	Flat or nearly flat area of considerable extent, dropping off abruptly on one or more sides.
4	Abyssal Plain	Extensive, flat, gently sloping or nearly level region at abyssal depths.
6	Deep	In oceanography, an obsolete term which was generally restricted to depths greater than 6,000 m.
	Hole	Local depression, often steep sided, of the sea floor.
	Valley	Relatively shallow, wide depression, the bottom of which usually has a continuous gradient. This term is generally not used for features that have canyon-like characteristics for a significant portion of their extent.
7	Trench	Long narrow, characteristically very deep and asymmetrical depression of the sea floor, with relatively steep sides.
	Trough	Long depression of the sea floor characteristically flat bottomed and steep sided and normally shallower than a trench.
8	Basin	Depression, characteristically in the deep sea floor, more or less equidimensional in plan and of variable extent.
11	Knoll	Relatively small isolated elevation of a rounded shape.
	Abyssal Hills	Tract, on occasion extensive, of low (100-500 m) elevations on the deep sea floor.
	Hill	Small isolated elevation.
	Mountains	Large and complex grouping of ridges and seamounts.
	Peak	Prominent elevation either pointed or of a very limited extent across the summit.
13	Seamount	Large isolated elevation, greater than 1000 m in relief above the sea floor, characteristically of conical form.
	Guyot	Seamount having a comparatively smooth flat top.
14	Pinnacle	High tower or spire-shaped pillar of rock or coral, alone or cresting a summit. It may extend above the surface of the water. It may or may not be a hazard to surface navigation.
16	Saddle	Broad pass, resembling in shape a riding saddle, in a ridge or between contiguous seamounts.
18	Escarpment	Elongated and comparatively steep slope separating or gently sloping areas.
20	Terrace	Relatively flat horizontal or gently inclined surface, sometimes long and narrow, which is bounded by a steeper ascending slope on one side and by a steeper descending slope on the opposite side.

* Amalgamation of slope(2) and plateau(15) features of Heap and Harris (2008).

Table 3-4. Samples analysed for this study

Survey name	Vessel	Year	Sample types	No. of samples
Lamont Doherty				
VM19	Vema	1963	Piston cores	2
VM24	Vema	1967	Piston cores	4
VM33	Vema	1976	Gravity core	1
Geoscience Australia				
GA 107	Rig Seismic	1993	Piston & gravity cores, dredge	25

Comparison at regional scales with Global Sediment Types

Global_Oceans_GIS\Data\shape\Global_Sediment_Types.shp

Data Source: Digitised by GA based on the figure produced by Davies, TA. & Gorsline D.S. (1976) Oceanic sediments and sedimentary processes. In: Riley, J.P, Chester, R. editors. Chemical Oceanography. Orlando, Florida: Academic Press

3.3.4 Rock type

Data were available describing rock types collected from the seabed in the Christmas and Cocos (Keeling) Islands territories. This information is useful in interpreting likely composition and extent of hard substrate and gravel.

To collate a comprehensive file containing all this data was not within the scope of this task. However, a total of 95 sample points that had spatial and descriptive data available in appropriate format were coded and converted into an ArcGIS shapefile. Properties selected for coding were presence of volcanic rock, carbonate and manganese. Data coverage was achieved in all subregions, although targeted sampling results in high data densities on seamounts and relatively poor coverage of other geomorphic features.

Table 3-5. Samples with sediment descriptions accessed through international databases

Survey	Vessel	Year	Sample types	No. of samples
Vityaz 35	Vityaz	1962	Gravity cores, dredges	5
Vityaz 31	Vityaz	1959-1960	Gravity cores, grabs	5
RC 14	Robert Conrad	1971	Piston cores	3
unknown	Magnet	1907-1910	grabs	14
Vema 19	Vema	1963	cores	1
Vema 24	Vema	1967	cores	3
Vema 28	Vema	1971	cores	3
Vema 33	Vema	1976	cores	1
Vema 34	Vema		cores	2
Monsoon Expedition	RV Argo	1960-1961	Gravity cores	3
Deep Sea Drilling Project, Leg 22	Glomar Challenger	1972	cores	2
The Swedish Deep-sea expedition	SWED	unknown	unknown	3
Antipode Expedition	RV Melville	1971	Gravity core	1
German Naval expedition (unknown)	Planet	1910	Gravity cores	3
Soviet Antarctic expedition, 2nd cruise of the D/E ‘OB’	D/E ‘OB’	1956-1958	unknown	1
German Deep-sea Expedition	Valdiva	1898-1899	unknown	2

Table 3-6. Simplified Folk classification used for sediment data points. Aggregated classes were created by merging traditional Folk Classes.

Aggregated value	Definition	Original Folk classes
Mud (M)	Mud dominated with some sand and < 1% gravel	Sandy Mud, Mud
Sand (S)	Sand dominated with some mud and < 1% gravel	Muddy Sand, Sand
Gravely Mud (gM)	Mud dominated with gravel >1%, sand may also be present	Gravely Mud, Gravely Sandy Mud,
Gravely Sand (gS)	Sand dominated with gravel >1%, mud may also be present	Gravely Sand, Gravely Muddy Sand
Gravel (G)	Gravel dominated with lesser sand and/or mud	Muddy Gravel,, Sandy Gravel, Gravel

Table 3-7. Surveys included in this file.

Survey name	Vessel	Year	Sample types	No. of samples
GA 107	Rig Seismic	1993	Dredge, Free fall grab	55
SO 199	Sonne	2008	Dredge	40

3.3.5 Seafloor age

Age, spreading rates and spreading asymmetry of the world's ocean crust

Global_Oceans_GIS\Data\grid\fin_age_my2

Data Source: Muller, R. D., M. Sdrolias, C. Gaina, and W. R. Roest (2008), Age, spreading rates, and spreading asymmetry of the world's ocean crust, Geochem. Geophys. Geosyst., 9, Q04006, doi:10.1029/2007GC001743.

http://www.ngdc.noaa.gov/mgg/image/crustalimages.html

3.3.6 Sediment thickness

Global Sediment Thickness

Global_Oceans_GIS\Data\grid\sedthick_null

Data Source: Divins, D.L., NGDC Total Sediment Thickness of the World's Oceans & Marginal Seas.

http://www.ngdc.noaa.gov/mgg/sedthick/sedthick.html

3.3.7 Seafloor temperature

Global Sea Floor Temperature

Global_Oceans_GIS\Data\grid\temp_null

Data Source: Locarnini, R. A., A. V. Mishonov, J. I. Antonov, T. P. Boyer, and H. E. Garcia, 2006. World Ocean Atlas 2005, Volume 1: Temperature. S. Levitus, Ed. NOAA Atlas NESDIS 61, U.S. Government Printing Office, Washington, D.C., 182 pp. (Data from each depth level merged to produce a pseudo depth grid of temperature).

http://mersea.jrc.ec.europa.eu/products.jsp

3.3.8 Primary productivity

Global Ocean Surface Primary Productivity

Global_Oceans_GIS\Data\grid\pp_null

Data Source: MERSEA (Marine Environment and Security for the

European Area) (2006). Monthly Averaged primary production for the global oceans derived from SeaWiFS data from September 1997 to December 2004.

http://mersea.jrc.ec.europa.eu/products.jsp

3.3.9 Calculation of statistics

All statistics were calculated in ArcGIS with further analysis completed in Microsoft Excel. Areas were calculated in Asia South, Albers Equal Area Conic Projection.

Bathymetry

Bathymetric ranges were calculated using Spatial Analyst (Zonal Statistics).

Histograms were generated by conversion of raster to polygons and calculation of polygon areas.

Oceanography and water masses

Water mass characterisations were based on the pelagic regionalisation work of Lyne and Hayes (2005) using their Level 1b units which were available at a resolution of 0.1 degrees. Fifty-six depth layers were available at the following depths: 0, 10, 20, 30, 40, 50, 60, 70, 75, 80, 90, 100, 110, 125, 150, 175, 200, 225, 250, 275, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 800, 850, 900, 950, 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1750, 2000, 2250, 2500, 2750, 3000, 3250, 3500, 3750, 4000, 4250, 4500, 4750, 5000 and 5500.

Geomorphology

Areas for geomorphic features within the EEZ were calculated in ArcGIS, X-Tools Pro, based on the amended geomorphic features of Heap and Harris (2008). Areas for larger topographic features were estimated by delineating generalised boundaries for these features based on descriptions in literature. Global geomorphology dataset of Agapova *et. al.* (1979) was not used as classification, it was deemed too coarse to be relevant at the scale of this study.

Sedimentology/rock type

Water depths for sediment and rock sample points were interpreted by spatial intersection with the amended 2005 Australian Bathymetry and Topography Grid. These may vary slightly from water depths quoted in survey reports and databases.

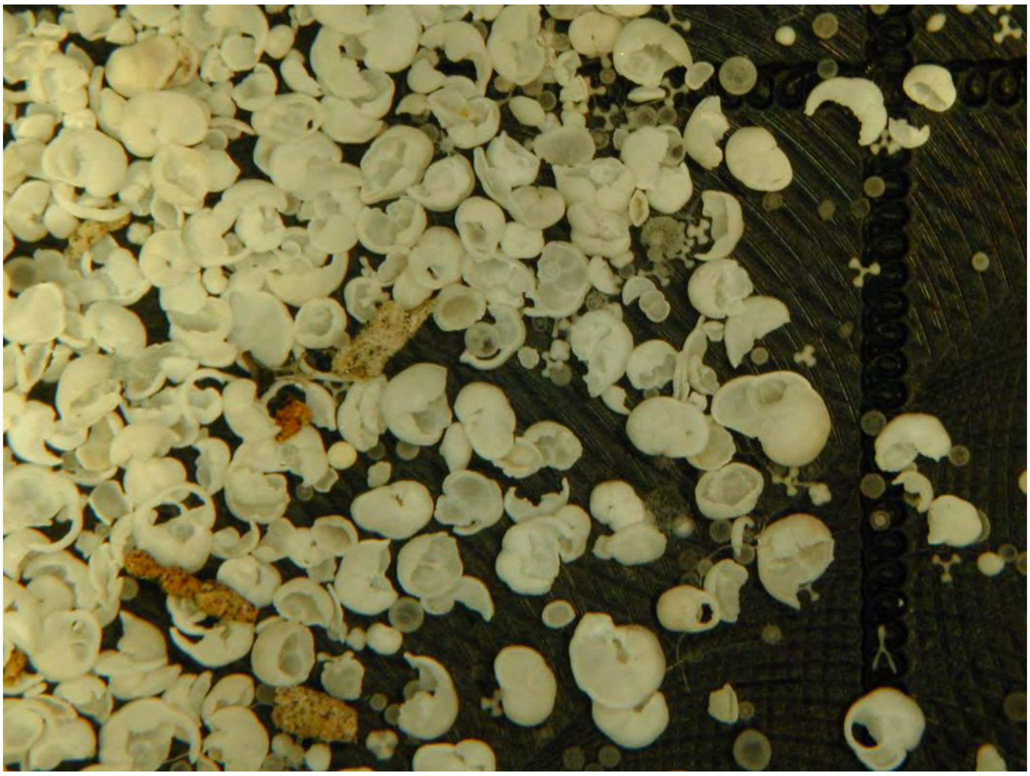


Figure 3-2. Photo of sand fraction from Sonne 199 station 53 taken on abyssal plain SW of Christmas Island showing foraminifera tests and radiolarian skeletons.

4. REGIONAL AND SYSTEMS UNDERSTANDING

Conceptual descriptions of each of the system levels were used to help describe the characteristic structural and functional features in each system, and thus provide context and relevance for the conservation values. The system descriptions included:

- the main environments and other 'important habitats' in each system;
- the main physical drivers affecting the structure and processes;
- examples of the species and functional groups within each system;
- the main services exported from and imported into each system; and
- an indication of the level of certainty we have in each of the components.

4.1 Ocean Basin Context

4.1.1 Oceanography and Climate

Amongst the oceans of the world, the Indian Ocean is unique in having a closed northern boundary apart from leakage between the western Pacific and the eastern Indian Oceans occurring via the so-called Indo-Pacific Through Flow (denoted as ITF). The southern extent is undefined, as it is in intimate contact with waters and currents of the Southern Ocean which sweep well north into the Indian Ocean and materially affects its circulation and water properties. Being closed in the north, active air-sea exchanges take place causing a characteristic series of currents and monsoonal weather patterns to develop. Active exchange with the Southern Ocean also takes place via boundary currents that flow pole-ward on both sides of the ocean: the Agulhas Current in the west and the Leeuwin Current in the east (Figure 4-1).

Christmas and Cocos (Keeling) Islands territories are located in the eastern Indian Ocean, in the path of the South Equatorial Current that carries the ITF waters into the Indian Ocean. Seasonal currents for the Indian Ocean are described in Figure 4-2, with the exception of the winter SE Monsoon and summer NW monsoon winds patterns seen south of the equator, which are described in Figure 4-3. Christmas and Cocos (Keeling) Islands are the only islands situated in deep water and in the pathway of this current. The nearest shallow water habitats in the AEEZ intersecting this current are the Ashmore and Scott Reefs, located on the NW continental slope.

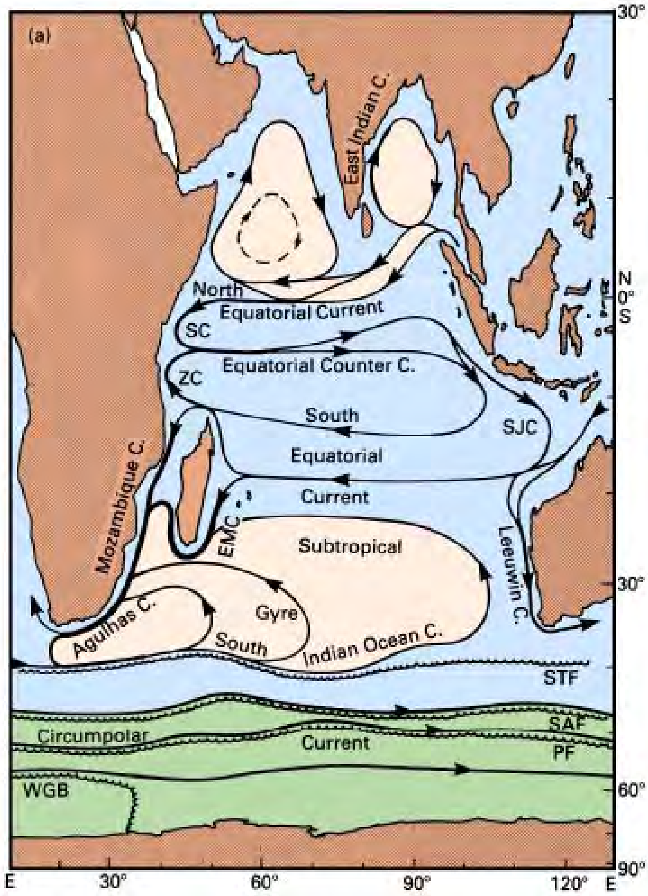


Figure 4-1. Tomczak and Godfrey's (2005) depiction of the surface currents in the Indian Ocean during the Northeast Monsoon (March-April) (after Tomczak and Godfrey, 2005).

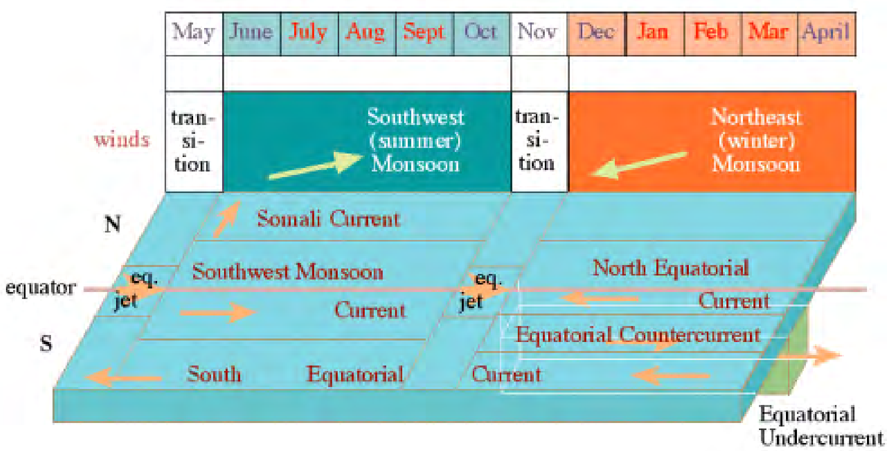
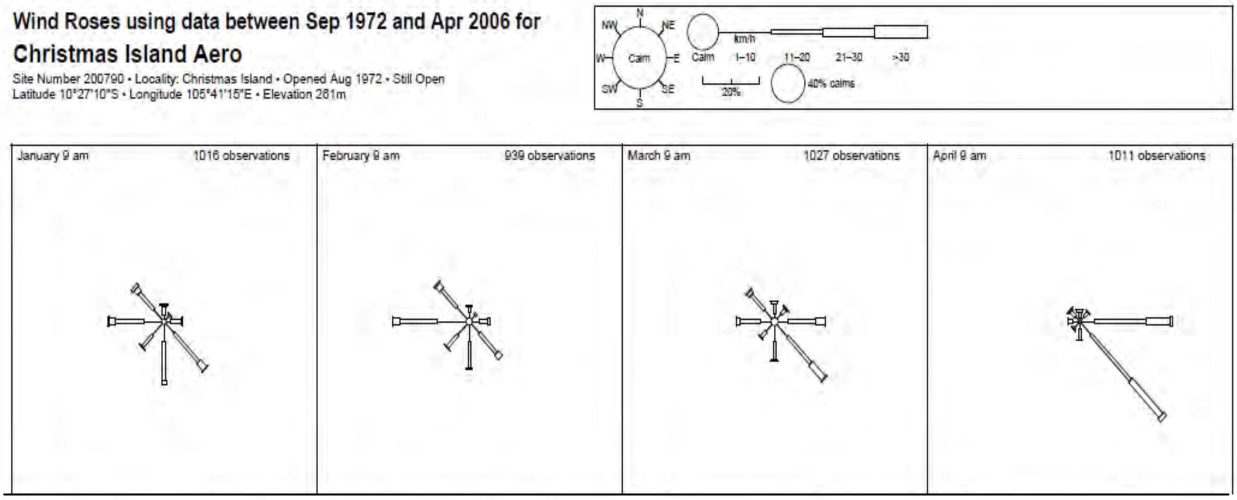
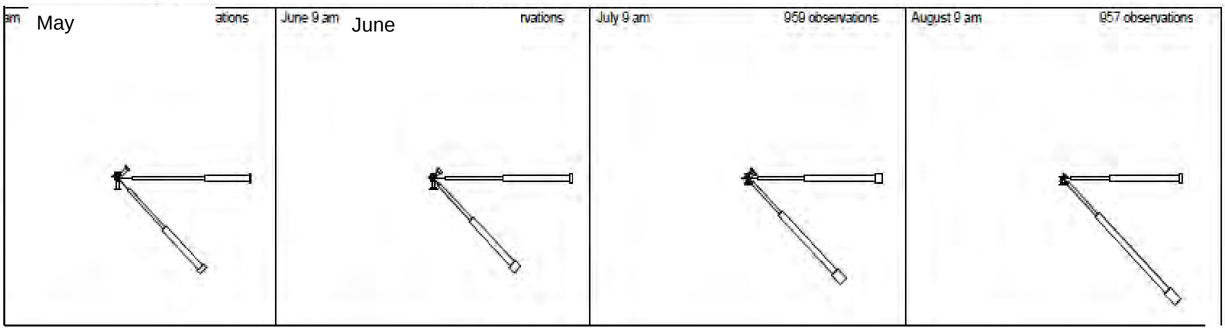


Figure 4-2. Tomczak and Godfrey's (2005) depiction of the monsoon system in the Indian Ocean. The top part indicates the wind cycle for the northern hemisphere, the lower part shows the major currents that develop in response to the wind for both hemispheres (after Tomczak and Godfrey, 2005). Southern hemisphere wind patterns are depicted in Figure 4-3.

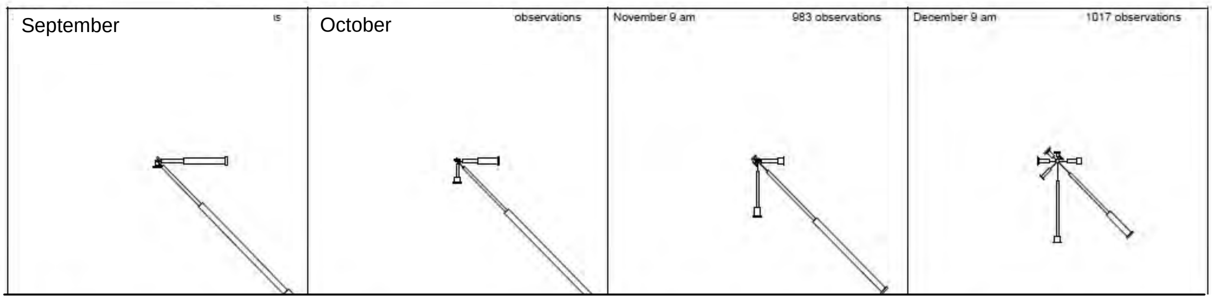
Figure 4-3. Monthly wind vectors for the Christmas Island region as measured by on the Island between 1972 and 2006.



January to April



May to August



September to December

Other drivers of the Indian Ocean condition include waves and currents, seafloor venting processes and the inflow of freshwater and other runoff constituents from the continents. The deep waters of the southern Indian Ocean enter from the south and from the dense, high-salinity, evaporative waters from the marginal seas of the Red Sea and Persian Gulf (Fieux *et al*., 2005). The South Equatorial Current originates in the western Pacific and has a generally westward flow, which is dispersed by New Guinea and north-eastern Australia (Wilson & Allen, 1987). Part of this flow becomes the East Australian Current and part flows around the northern side of New Guinea and between the eastern islands of Indonesia and the Timor Sea to become the ITF. These waters determine the composition of the Indian Ocean component of the South Equatorial Current which is a major circulation feature during the south-east monsoon season. During the north-west monsoon, the South Equatorial Current loses strength and retreats south, while the Equatorial Counter-current (locally the Java Current) enters from the west. Just south of Java it is drawn into the South Equatorial Current, which flows in the opposite direction. Some upwelling at the interface between the two current systems has been reported and is of some importance to the productivity of this part of the ocean and has implications, for example, in the distribution of pelagic fish and seabirds. Thus, at the sub-basin scale of the eastern Indian Ocean, the monsoonal nature of the currents and associated upwelling and mixing may be key determinant processes affecting these species and drifting eggs and larvae that may interact with habitats in the Christmas and Cocos (Keeling) Islands territories.

At the sub-basin scale, the current field in the eastern Indian Ocean is depicted in Figure 4-4. The South Equatorial Current (part of the ITF) is clearly the main current system affecting the Christmas and Cocos (Keeling) Islands territories, bringing species with larval drift stage preferentially from east of the islands, possibly as far away as Western Pacific. Eddies and currents spun off the South Java Current may also provide a pathway for species from Sumatra and Java to reach the islands.

Water Mass Characteristics

Water mass types across a zonal (across longitude at a particular latitude) are shown in Figure 4-5 for the whole water column and for the top 1000 m in Figure 4-6. Key features include:

- Marked differences between the Pacific and the Indian Ocean (at this zonal section) are evident right through the water column;
- Some water masses are shared between the oceans but in different proportions;
- The waters of the ITF dominate the upper 1000 m of the Indian Ocean.
- At depths beyond 1500 m, the water masses are similar between the two sites.
- Differences between the location of the Christmas and Cocos (Keeling) Islands territories comprise the following:
    - A subsurface layer centred at about 400 m water depth, occurs in the Cocos Island region but not at Christmas Island.
    - A mid-water Indian Pacific layer, centred at about 1200 m water depth occurs in the Christmas Island region but barely reaches across to the Cocos Island territory.

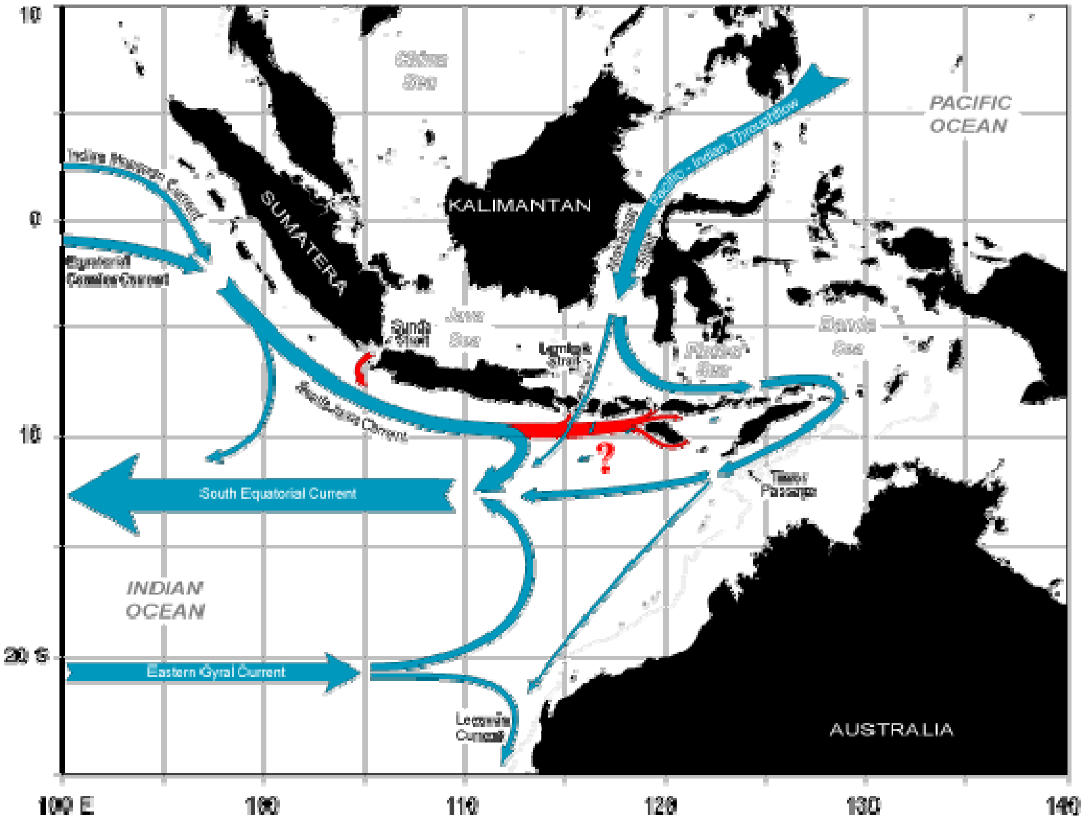


Figure 4-4. Schematic of the current system associated with the Indonesian Throughflow (see the article by Theresa K. Chereskin: http://tryfan.ucsd.edu/woce_ioe/woce_ioe.htm).

These features suggest that in water depths >1500 m Christmas and Cocos (Keeling) Islands territories share similar water mass environments. At shallower depths, water masses of the ITF strongly affect the Christmas Island territory and affect Cocos (Keeling) Islands territory down to depths of about 200 m. At water depths between 200 m and 1500 m, the Cocos (Keeling) Islands territory appears to be more influenced by waters from the west.

Water mass types across a meridional (across latitude at a particular longitude) for the whole water column are shown in Figure 4-7 and for the top 1000 m in Figure 4-8. Key features include:

- Both Christmas and Cocos (Keeling) Islands territories appear to be in the core of the South Equatorial Current with markedly different and complex layering of water masses on either side down to about 1500 m. The Antarctic Intermediate Water and the West Australian Deep Water represent transition layers marking significant differences; in water masses on either side (upper and lower depths) of this depth zone.
- Down to about the 400 m water depth, there is a juxtaposition of near-surface water masses suggesting a complex mixing of waters in the major current systems reaching down to this depth.
- This suggests that water mass differences across latitude between Christmas and Cocos (Keeling) Islands territories are relatively weak by comparison the variation with longitude – implying that ecological differences may be dominantly influenced by longitude variations.

- The corollary implication is that there is greater ecological connectedness along the axis of the major current systems which in this region comprise the South Equatorial Current and the South Java Current. A counter current also exists beneath the surface.

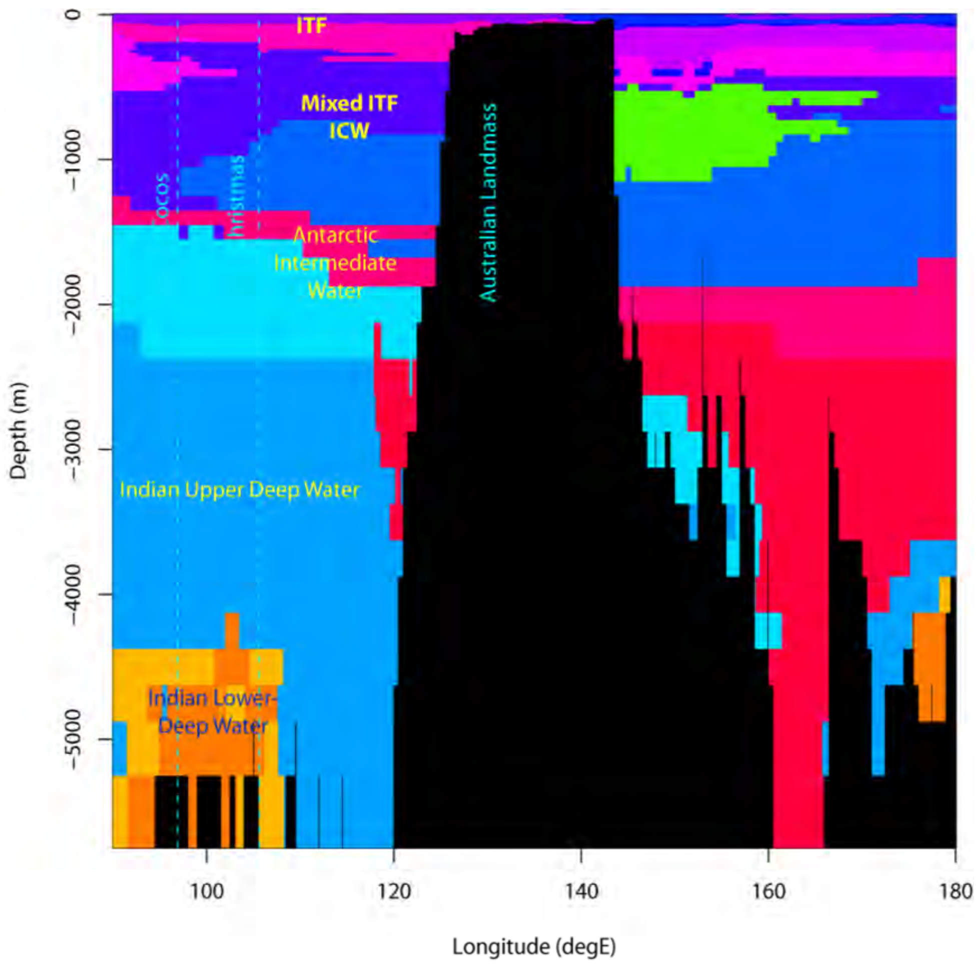


Figure 4-5. Cross-sectional profile of water mass types by longitude and depth, taken at a latitude of 11.3°S (intermediate between the latitudes of Cocos (Keeling) and Christmas Islands). The characterisation of water mass types is from the work of Lyne and Hayes (2005).

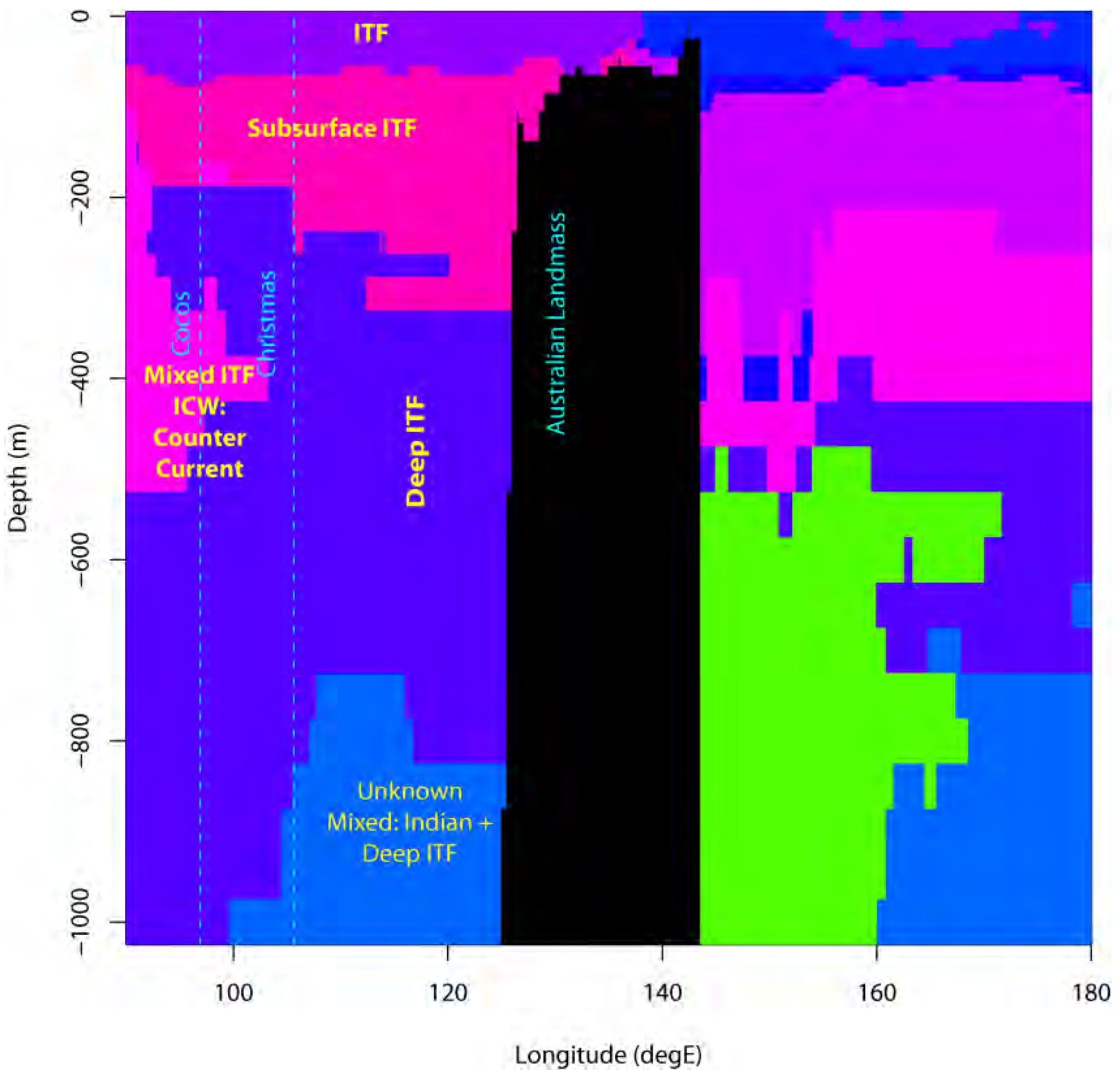


Figure 4-6. Cross-sectional profile of water mass types by longitude and depth down to 1000 m, taken at a latitude of 11.3°S (intermediate between the latitudes of Christmas and Cocos (Keeling) Islands). The characterisation of water mass types is from the work of Lyne and Hayes (2005).

Other key features of relevance from the literature on water masses can be seen in Wijffels (2002) are described below. This additional information includes figures duplicated in Appendix D, Figure a) and Figure b).

1. There is still uncertainty about the dynamics and naming of water masses because of the complexity of monsoonal currents, mixing and subduction processes. In brief, sources of waters include those from the Indo Pacific Throughflow, waters from the Red/Adriatic Sea, the high salinity Indian Central Water Mass and deep waters from the Southern Ocean (denoted here at the Lower and Upper Indian Deep Water). Mixing between these water masses within the Indian Ocean basin also forms intermediate water mass layers.

2. The surface waters are dominated by the flow of Indo-Pacific Throughflow (ITF) waters which flow as the South Equatorial Current during the south-east monsoon. Both Cocos (Keeling) and Christmas Islands are in the path of these waters. Further south, the waters of the Indian Central Water Mass dominates but active mixing and subduction occurs in the intermediate zone between these water masses and their current systems.

3. Seamounts and abyssal bathymetric features in the deep water (below about 2500 m), appear to have an impact on water properties at shallower depths, as indicated by some examples:

   a. While we recognise irregularities in contouring and note that data may cause artefacts, in the trio of the tallest seamounts between about 11-14°S in the IR6-9.95 the southern-most (tallest) seamount appears to have mixed waters along its flanks as well as an apparent uplift in the isoclines at about 2000 m which may be due to the formation of Taylor columns.

   b. In the I10-11.95, there appears to be clear uplift of isoclines up to the massive seamount structure located between 10-12°S which peaks at about the location of the seamount. Isoclines on both sides of the peak are uplifted by 1000 m or more.

   c. Perturbations in the isoclines noted above appear to reach up to at least 500 m and there are noticeable differences in the water column salinity anomaly structure to either side of the seamount.

   d. Likewise, the other massive seamount in that transect, centred at about 20°S, has very marked differences in water column anomaly to either side up to about 500 m.

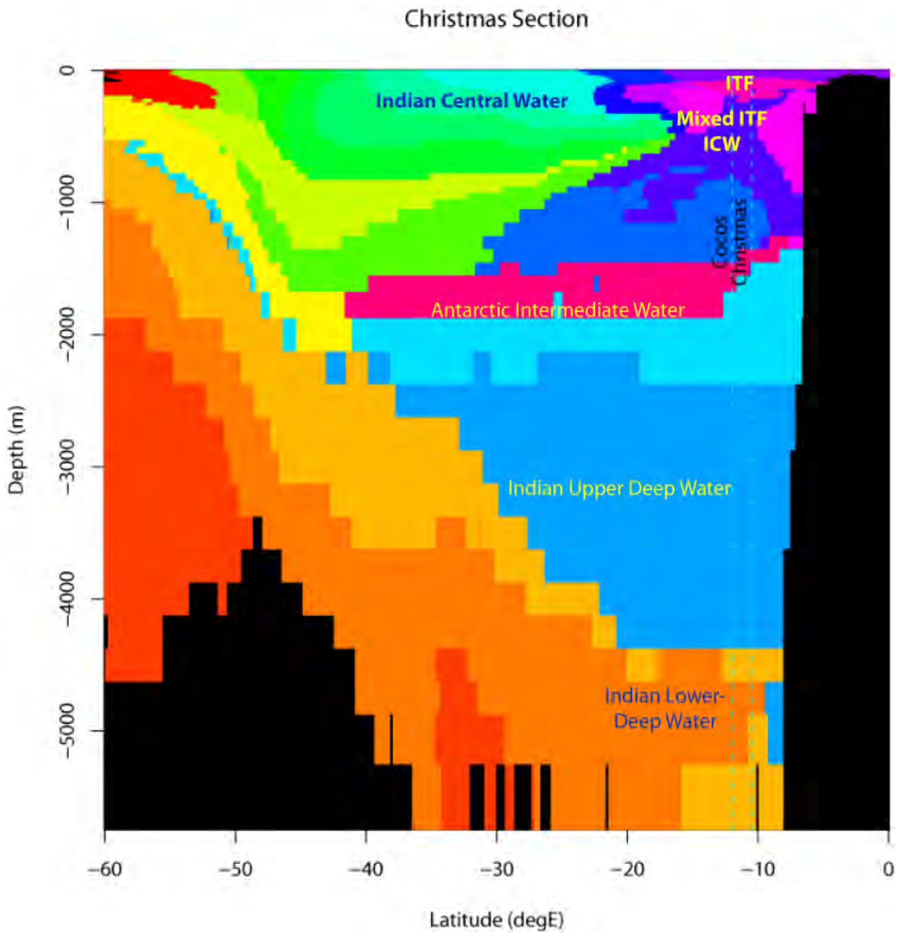


Figure 4-7. Cross-sectional profile of water mass types by latitude and depth, taken at a longitude of Christmas Island (105.6°E). The characterisation of water mass types is from the work of Lyne and Hayes (2005).

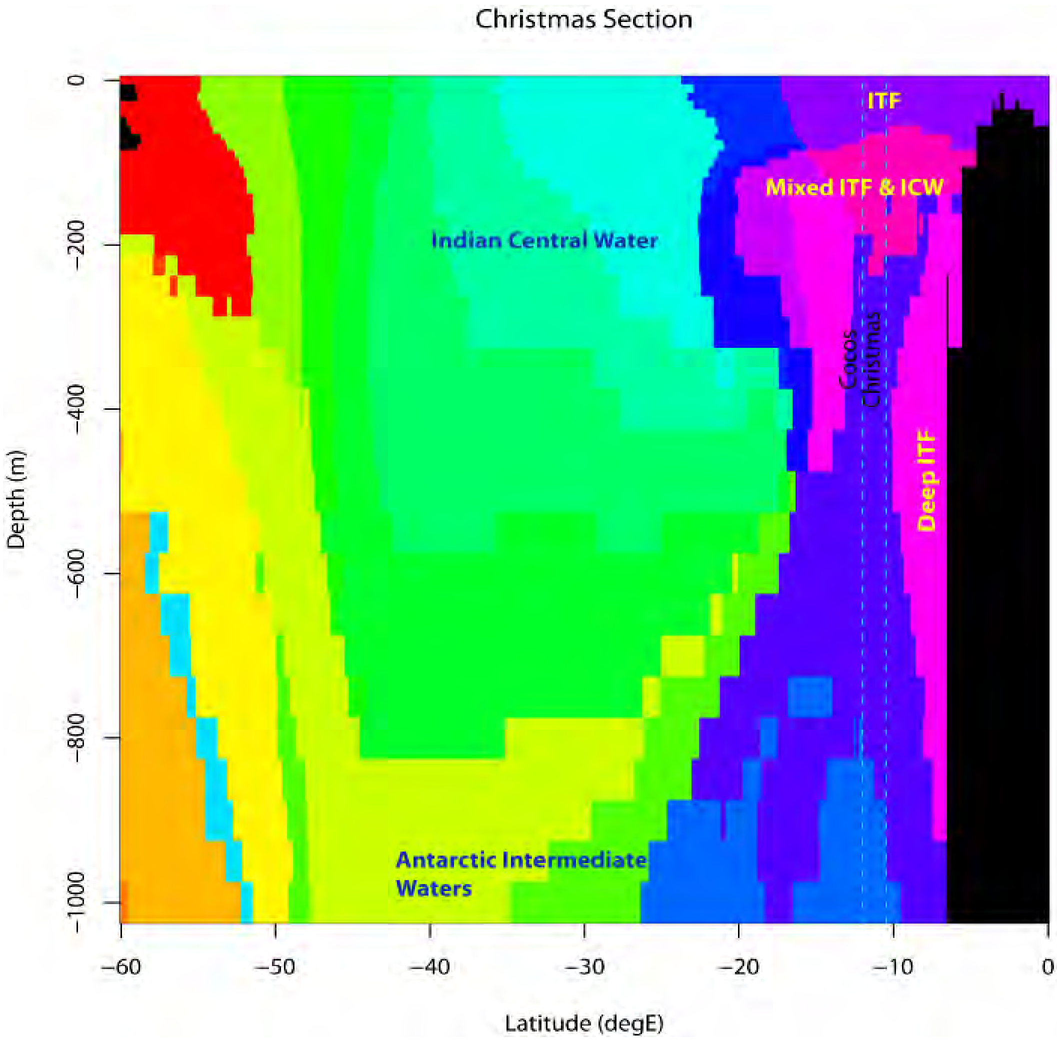


Figure 4-8. Cross-sectional profile of water mass types by latitude and depth down to 1000 m, taken at a longitude of Christmas Island (105.6^{o}E). The characterisation of water mass types is from the work of Lyne and Hayes (2005).

4.1.2 Geological Setting

Crustal age in the NE Indian Ocean is not well constrained and evolutionary history of the region remains poorly understood. Data collected in recent years refutes earlier theories of origin and age of many of the large scale seabed features in the region. A full discussion of the existing theories is beyond the scope of this report. However, it is hoped that new data collected on scientific surveys during 2008-9 will result in a more comprehensive picture of the region's development.

The present day NE Indian Ocean is bounded to the west by the Ninetyeast Ridge, to the east by the Australian Continental margin and to the south by Broken Ridge. This area comprises two large deepwater central ocean basins, the Wharton and Cocos. These basins occur on the N-NE moving Indo Australian plate, beyond zones affected by seafloor spreading (Pushcharovsky, 2007). These basins were segregated from the Western Indian Ocean during the late Cretaceous and Cenozoic by development of the Ninetyeast Ridge, a north-south trending aseismic volcanic ridge that extends ~5,000 km between 10°N and 30ºS along the 90ºE meridian (Heezen and Tharp, 1965). It is defined by 4,000 and 3,000 m isobaths, with relief of around 2500 m, locally coming within 1km of the ocean surface (Udintsov, 1963) and continues to develop through faulting, particularly in the south.

To the east of the Ninetyeast Ridge, the Wharton and Cocos Basins cover a total area of approximately 5,050,000 km^2 and have over time contained a diverse range of geodynamic settings resulting in complex tectonic trends evident on the present seabed (Pushcharovsky, 2007). The basins' history have included significant lateral and vertical movement of the crust (kilometres in magnitude), dominated by subsidence (Pushcharovsky, 2007). Both basins have a similar underlying structure and contain a broadly similar sequence of sediments that become deeper-water up section. Sediments overlie a basement of pillow basalts (Veevers, 1973). Sediment cover in the Wharton Basin is thinner resulting in rugged seabed topography. This contrasts to more subdued topography in the Cocos Basin.

The sedimentary sequence indicates that over time sediment sources have varied, with basaltic volcanics dominating from pre-late to mid Miocene (REF), followed by a shift to more complex inputs including Indonesian silicic volcanics, sediments from Ganges-Brahma River, aeolian sediments from the western Australian margin, pelagic siliceous material settling from the water column in the equatorial productivity zone, and continuing but less significant basaltic volcanics locally (Pimm 1973). Sedimentation rates are generally low and, except in areas adjacent to seamounts and ridges, sediments are dominantly of pelagic origin (Pimm 1973; Royer, Peirce & Weissel 1991). Surficial sediments in the NE Indian Ocean show a pattern of increased carbonate content and decreasing silica content with increasing water depth (Williams 1992, Appendix A).

The Cocos basin (Figure 4-9) is bounded by the Ninetyeast ridge in the west, the Sunda Trench in the northeast, and delineated by isobath patterns in the south (Pushcharovsky, 2007). Its 1,950,300 km area comprises dominantly flat abyssal plain occurring at water depths around 5,500 km. In the north of the basin, relief is generally limited to low abyssal hills that rise above sediment sheet and minor depressions. North-south oriented broad ridges, with little or no sediment cover and sediment-filled valleys cover significant areas in the central-south of the basin. In the south of the basin, complex faulting has resulted in formation of a series of north-northeast trending ridges and troughs (Luyendyk & Rennick 1977). Similar features occur in the adjacent Central Indian Basin to the west, indicating that the basins were likely joined until the development of the Ninetyeast Ridge (Pushcharovsky 2007).

The most significant tectonic feature in the basin is the Investigator Ridge, a north-south striking fracture zone 1,800 km in length that represents development of a new plate boundary between the eastern and western parts of the Indo Australian Plate (IFM-GEOMAR 2009). A west facing scarp of varying elevation (~600 - 2,800 m) extends most of the length of the fracture zone comprising complex volcanic and tectonic topography and a wide range of rock types including lavas, sheeted dykes, mafic and felsic intrusives, layered cumulates, and serpintinites. The ridge top may be capped locally with pelagic sediments up to 800 m thick (Ewing *et al*. 1969). Large scale earthquakes in this area, faulting of sediments, and the development of north-south oriented topographic features including ravines and seamounts on and adjacent to the ridge indicate present reactivation of older seafloor fractures linked to Australia's movement to the northwest.

The Cocos basin has experienced subsidence since the Cenozoic and sections through basin fill indicate a sequence of basaltic pillow lavas overlain by a Paleocene - Present sedimentary sequence becoming more deepwater up section. Surficial sediment is mainly turbidites (these are present mainly in the west where sediment is transported down the eastern flank of the Ninetyeast Ridge) and biogenic ooze, similar to that found on the Argo Abyssal plain off Australia's NW margin (IFM-GEOMAR 2009; Pimm 1973).

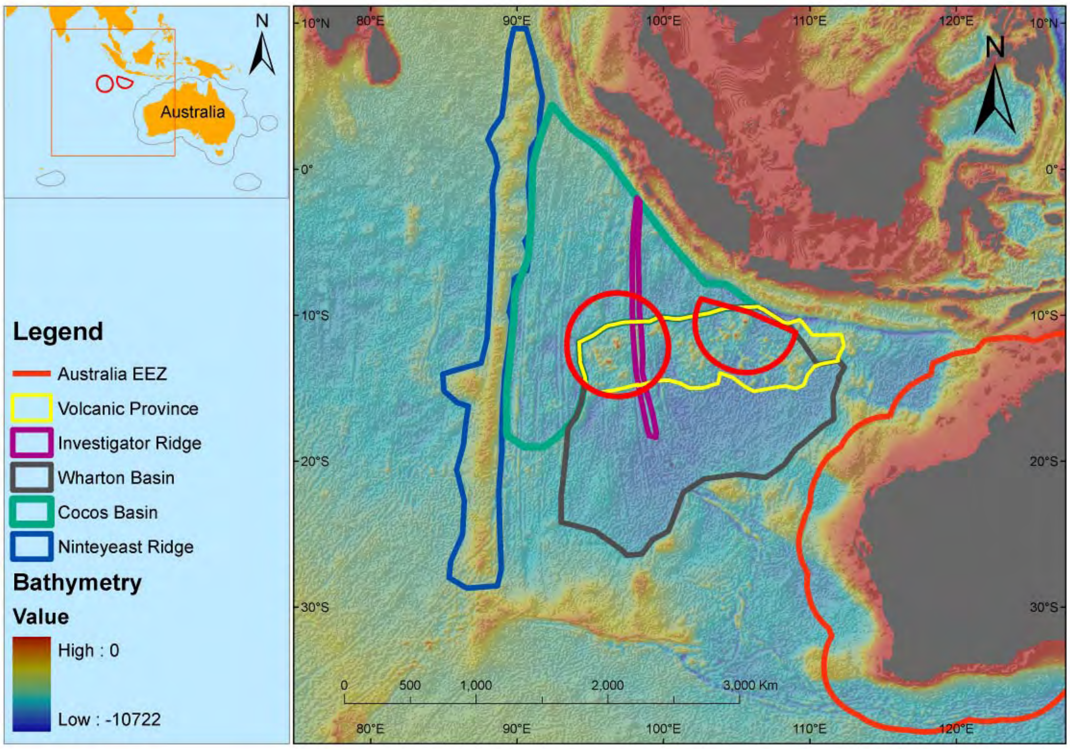


Figure 4-9. Major physiographic features of the NE Indian Ocean and intersection of these with the Christmas and Cocos (Keeling) Islands territories

The Wharton Basin is bounded by the Zenith Rise to the east and by Broken Ridge to the south (Pushcharovsky, 2007). Its 2,471,400 km^2 area is dominated by abyssal plain with volcanic edifices becoming more abundant to the north. The basin is divided into north and south areas by a huge submarine volcanic province. The south of the basin comprises the deepest part of the Indian Ocean and on average is deeper than the north. The main deep of the basin (water depth 6,786m) occurs in the south east, and is separated from the western deep (6,477m) by the southern extension of the Investigator Ridge (Naini 1973).

Basement of the Wharton Basin has undulating topography with depths filled dominantly with calcareous turbidites, to average basin floor level. Abyssal plain in the main basin consists of series of local highs with no significant sediment cover and depressions filled with sediment. Changes in elevation rarely exceed 200 m. Areas between deeps are generally rugged, the shallow basement draped with discontinuous and ponded sediments (Ewing et. al. 1969; Pimm 1973).

Average thickness of sediment cover across the entire basin is approximately 200 m (Pushcharovsky, 2007). Sediment cover in the southwest does not exceed 200 m, but thickness increases northward toward the Sunda Trench (where cover exceeds 500 m) and east toward the Australian continental margin (cover 200-500 m). Surficial sediments are dominated by deep sea clays and siliceous sediments, with clays dominating in the south and siliceous components in the north (global GIS).

The current sedimentation rate in the basin is very low (Opdyke and Glass 1969). Low terrigenous sediment input, particularly in the south (DSDP site 212), is due to isolation from major regional sediment sources such as the Bengal Fan by the Ninteyeast Ridge, and is further indicated by widespread occurrence of manganese nodules. Surficial sediments where present, are generally soft and muddy and locally have been shown to support abundant benthic fauna (Naini 1973).

The volcanic province is a chain of seamounts trending broadly east-west along latitude 12ºS. It covers approximately 1,000,000 km^2 of the northern Wharton Basin and comprises the Vening Meinesz chain, the Golden Bo’sun Bird chain, the Flying Fish chain, the Karma and Bartlett seamounts, Muirfield seamount, Scherbakov seamount the Raitt, Cocos and Christmas Rises and numerous unnamed large and small volcanic cones. The mechanism for formation of these seamounts remains uncertain, although the chemistry of volcanic rocks from the area suggests typical intraplate volcanism. Earliest volcanism at the Christmas Island end of the province was in the Campanian, with seamounts building through eruption of basalt and trachyte lavas to near sea surface level, and in some cases emergence, 34-40 million years ago (Ma). This was followed by a period (late Cretaceous) of subsidence during which shallow water limestones developed in the photic zone on eroded guyot platforms. These were overlain by bathyal sediments deposited in deeper water during the Eocene as seamounts subsided further. A second period of volcanism occurred from 3-5 Ma. This is evidenced in present topography with volcanic cones formed on eroded guyot platforms, and frequent uneroded seamounts (Exon *et al*. 1993; IFM-GEOMAR 2009).

Cementation and other alteration of sediments and development of manganese and phosphate-rich crusts and deposition of pelagic oozes and sands occurred later in deeper water (Exon *et al* 1993). Frequency of these crusts indicate that current sedimentation on seamounts is minimal. Multibeam data collected over the Christmas rise indicate that the summit and southern side of the rise is sharp crested and devoid of sediment. Ridge and valley topography occurs on the flanks and valleys are infilled with sediment (Veevers 1973). At water depths >3,500 m, surficial sediments are dominantly siliceous oozes except where carbonate sediments have slumped off shallower areas of seamount flanks.

At the Cocos (Keeling) Islands end of the province, abyssal hills to the east of the Cocos Rise are devoid of sediments. The southeast flank of the rise and seamounts adjacent to the south of the rise have continuous sediment cover. Elsewhere the rise is rugged with sediment accumulating only in narrow valleys on the summit. Topography becomes more rugged to the NW, with the NW flank consisting of numerous seamounts and ridges (IFM-GEOMAR 2009).

The relative age of seamounts along the length of the volcanic province remains uncertain. The depth of guyot-type seamount platforms suggest that these features have different ages and non-uniform subsidence rates (IFM-GEOMAR 2009). In general, seamounts at the Cocos (Keeling) end of the province have been subsiding at a rate of 100 m/m.y. (Woodroffe & Veeh et. al. 1991). This is much faster than those around Christmas Island which have been subject to strong uplift likely resulting from bending of the plate in the adjacent Java Trench (Woodroffe 1988). Systematic sampling of seamounts on SO199 cruise (August-September 2008) and analysis and dating of volcanics is likely to offer insight into the timing of development and origin of features in this province.

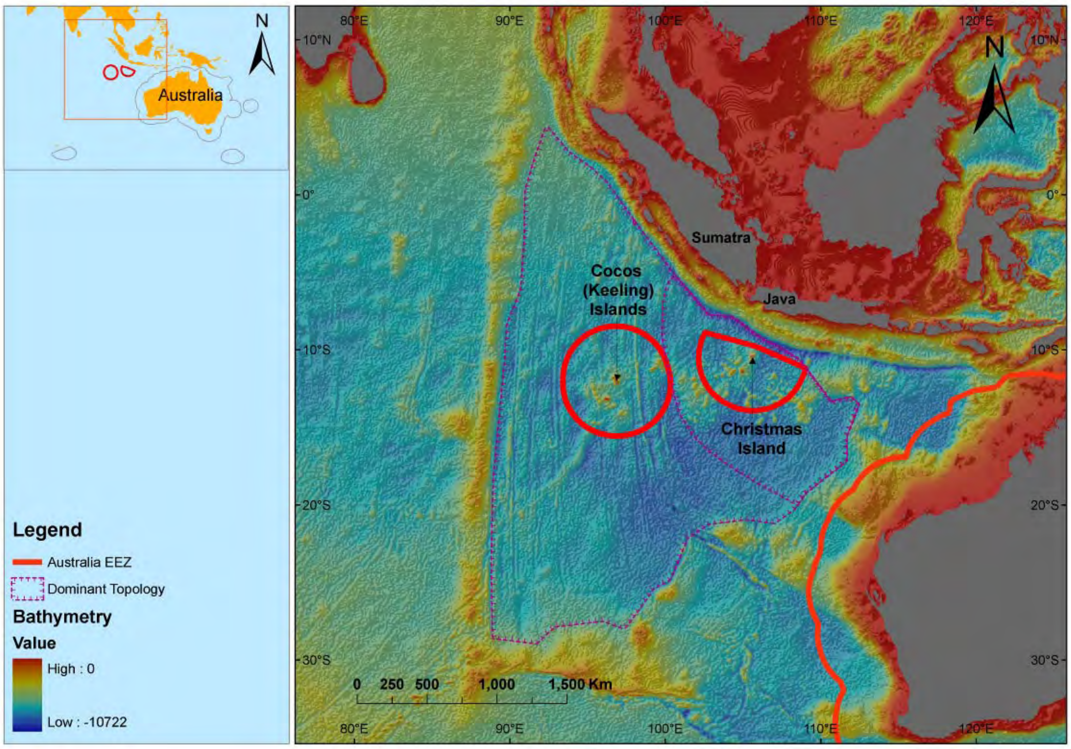


Figure 4-10. Division of Indian Ocean (Level 1 and 2) based on tectonic origin and current physiography.

4.1.3 Paleo processes in island formation

A number of studies of the atolls of Cocos (Keeling) have been assimilated by Woodroffe *et al.* (1994) to show phases in the interaction of the atolls with sea level variation. The present day depth structure of the islands and its evolution is shown in Figure 4-11. The model suggests that a number of depth strata down to about 130 m may be affected through the late Quartenary development of the islands in relation to sea level. With respect to Christmas Island, while geological uplift and subsidence processes are different to those at Cocos, the overlay of the sea level influence would also suggest that habitats may be depth structured by these evolutionary processes.

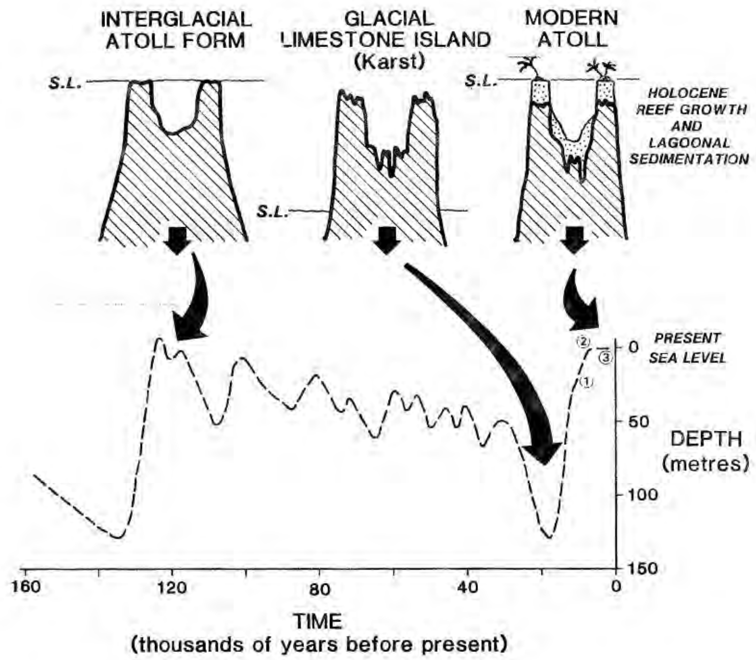


Figure 4-11. A suggested model of the late Quaternary development of the Cocos (Keeling) Islands. Figure from Woodroffe, McLean and Wallensky (1994)

4.1.4 Biological Setting

Regional productivity

Biological productivity in the region is driven by three key processes: 1) the inflow of Indo-Pacific waters which brings with it oligotrophic (nutrient-depleted) waters that create a deeper mixed layer that suppresses the availability of nutrients to surface waters, and 2) the presence of a strong mid-oceanic current system which spawns chaotic eddies that appear to be driven primarily by baroclinic instabilities associated, for example, with the South Equatorial Current (Feng and Wijffels, 2002), and 3) upwelling of deeper, nutrient-rich cool water adjacent to the Java coast due to Ekman pumping of surface waters driven by seasonal SE monsoonal winds. This brings these deeper waters to the surface, producing phytoplankton blooms. The length scale of the variability is of the order of 100-150 km propagating westward at phase speeds of 15–19 cm/s and at timescales of 40 and 80 days.

The overlay of the main currents with sea-surface height anomaly (Figure 4-12) shows a strong association between the South Equatorial Current and the anomaly field which has its greatest variability in September centred near Christmas Island.

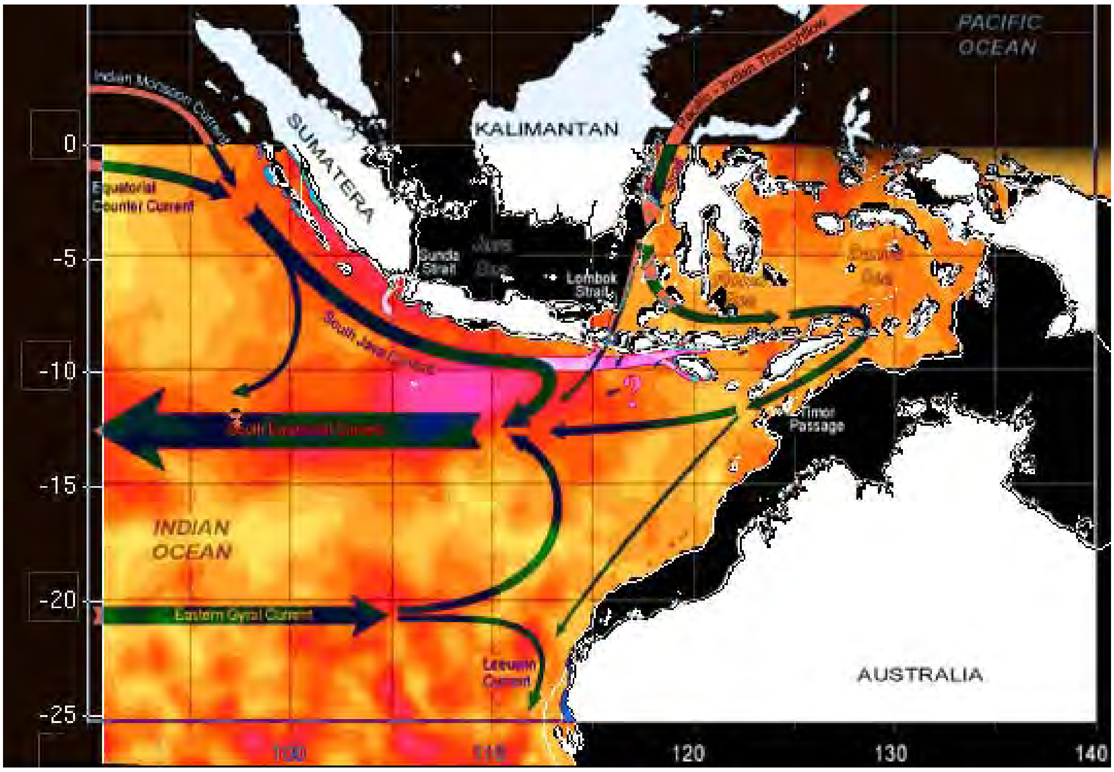


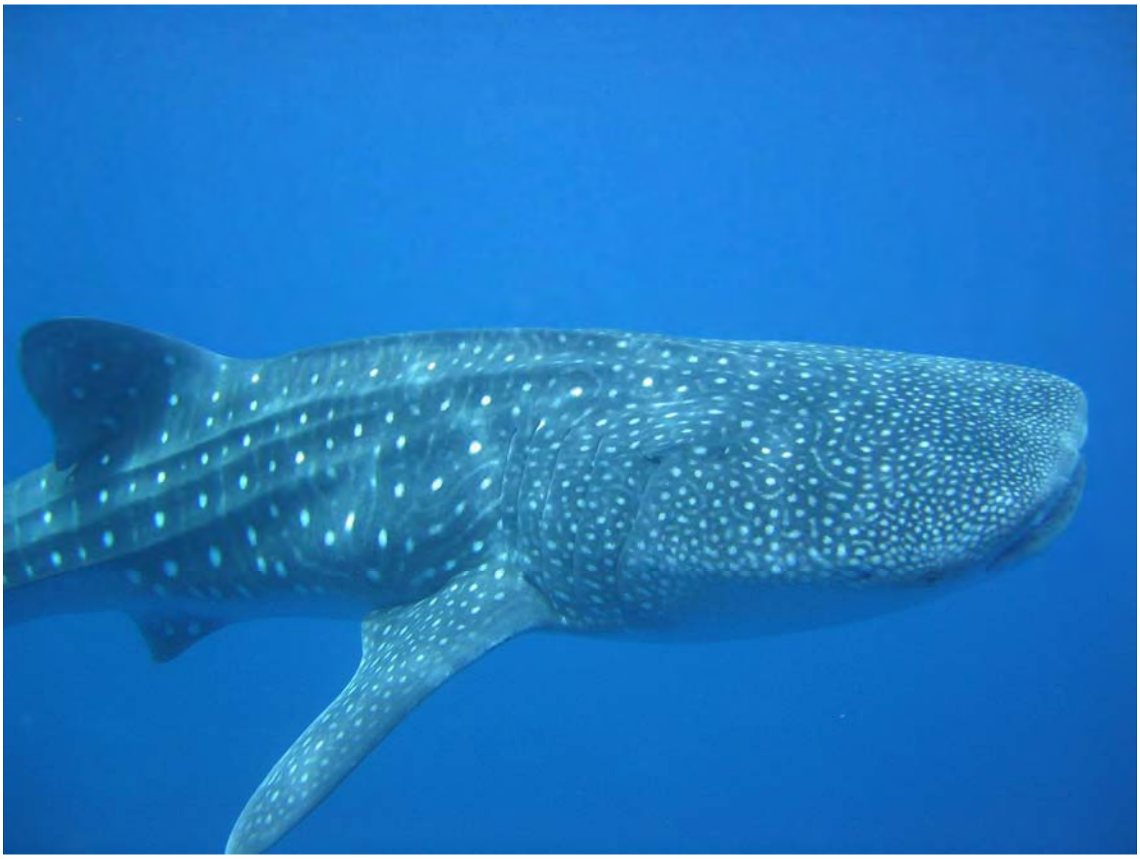
Figure 4-12. A montage overlay which attempts to depict the correspondence between the currents in the eastern Indian Ocean (see above) with the altimeter sea-surface height anomaly for the month of September (image from the work of Hayes *et al* (2005)). Pink represents high variance in sea-surface height and light orange, low variance.

The pattern of catches from the Western Tuna and Billfish Fishery overlaid onto a monthly ChlA image for July-August (Figure 4-13) shows that catches in the Cocos (Keeling) Islands territory are most likely associated with the enhanced productivity in the northern half. In the Christmas Island territory, the fishery is more centred along an east-south-east axis which is more in line with the main field of sea-surface height anomaly (see Figure 4-12). Possible explanations for this include subsurface enhancements in productivity that are not apparent in the surface ChlA maps, or visual predators avoiding high ChlA areas (they are not plankton feeders) in preference to areas which have recently experienced high ChlA and have developed over a period of time to allow the secondary and tertiary communities to evolve. One observation in support of the second hypothesis is that there appears to be denser catches in the northern half of Cocos. A possible mechanism for this is an evolving trophic system that matures as it advects into the Cocos (Keeling) Islands territory.

Variations in the seasonal surface signature of ChlA are shown in the following images (Figure 4-14, Figure 4-15, Figure 4-16) taken from the Aqua satellite images on the Giovanni site (http://reason.gsfc.nasa.gov/Giovanni/). Key features to note include:

- the highest levels of ChlA through the region occur in Jul-Aug with frequent outbursts of elongated ChlA plumes reaching well offshore from Java (explained in more detail in 4.1.4). Christmas Island is in the path of these plumes, while Cocos (Keeling) appears to be less affected.
- moderate ChlA concentrations persist through Sep-Oct and as cloud cover increases, ChlA levels drop to low values by Nov-Dec.

- southern hemisphere summer ChlA at the surface is lower due to a combination of lower nutrients at the surface and a deep overlying surface water mass layer due to the ITF.
- by May-June, bloom conditions are underway again, starting in the Java-Sumatra coastal regions and expanding out over time. This period coincides with a maximum in the eastward transport of the South Java Current (SJC) which flows along the Java shelf-break and slope (Wijffels *et al*. 1994).
- the characteristic "wedge" structure of the ChlA field (narrowing to the north east) suggests that the high Chla concentrations at the surface are primarily driven by the energetics of the near-coastal current systems. In particular the South Java Current which is fed by waters from the southern coast of Sumatra and leakage around the islands of Java. Further offshore there appears to be large energetic eddies that may arise from the interaction of the opposing currents of the SJC and the South Equatorial Current. The presence of these currents materially affects the productivity of the waters around Cocos (Keeling) and Christmas Islands.



The relatively productive waters of the Christmas Island territory and thought to be an important juvenile habitat for whale sharks.

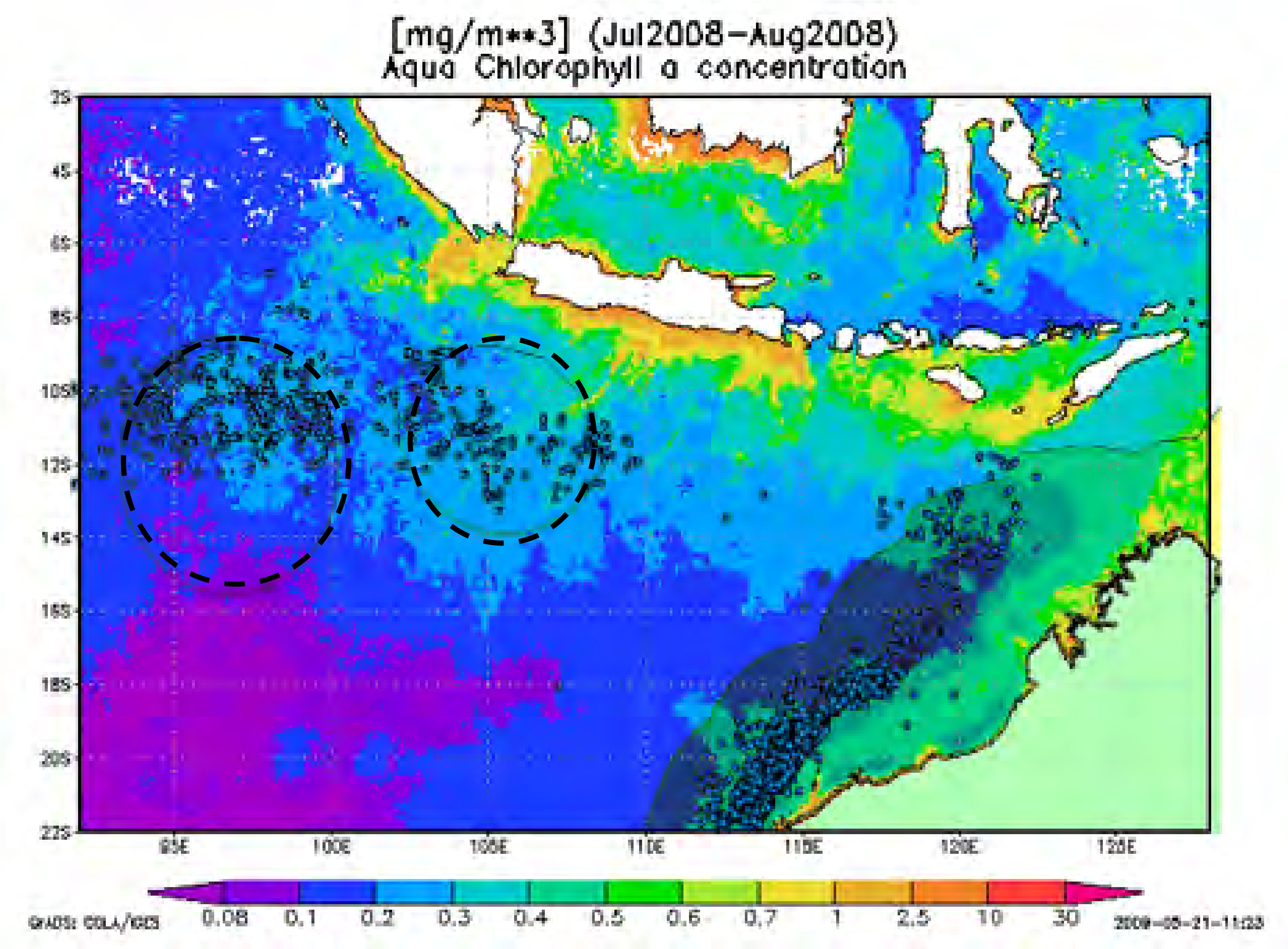
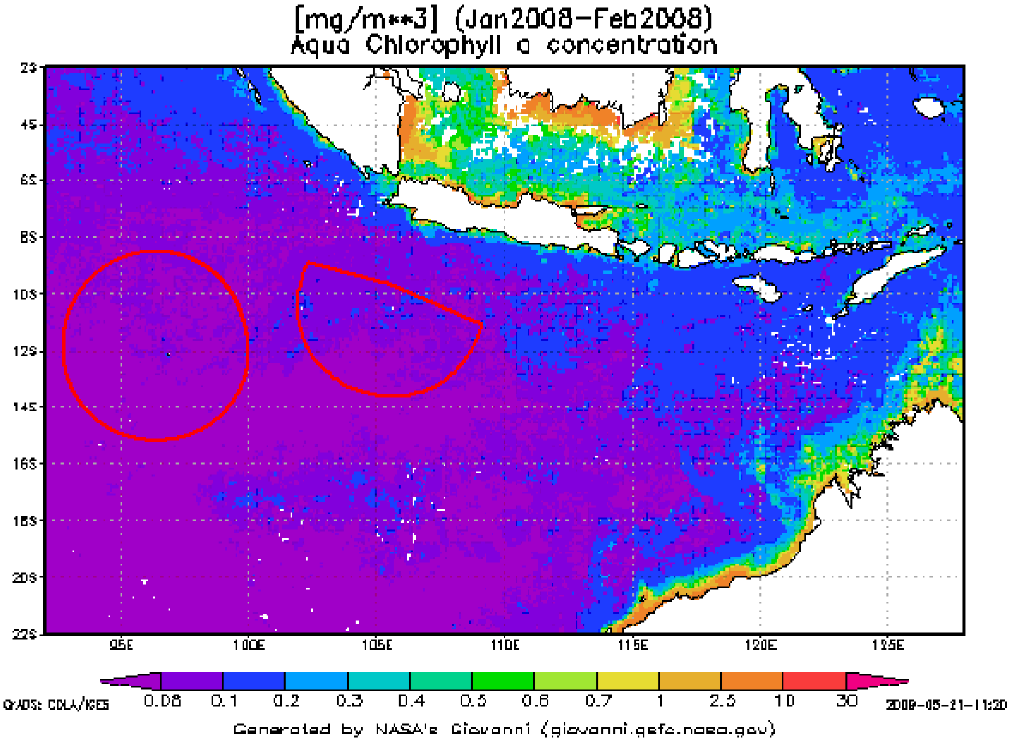


Figure 4-13. Overlay of the ChlA distribution from July-August 2008 and catches from the AFMA database for the Western Tuna and Billfish Fishery for Japanese longliners (all records from 1987-1997). Approximate territorial boundaries are shown as dashed lines.



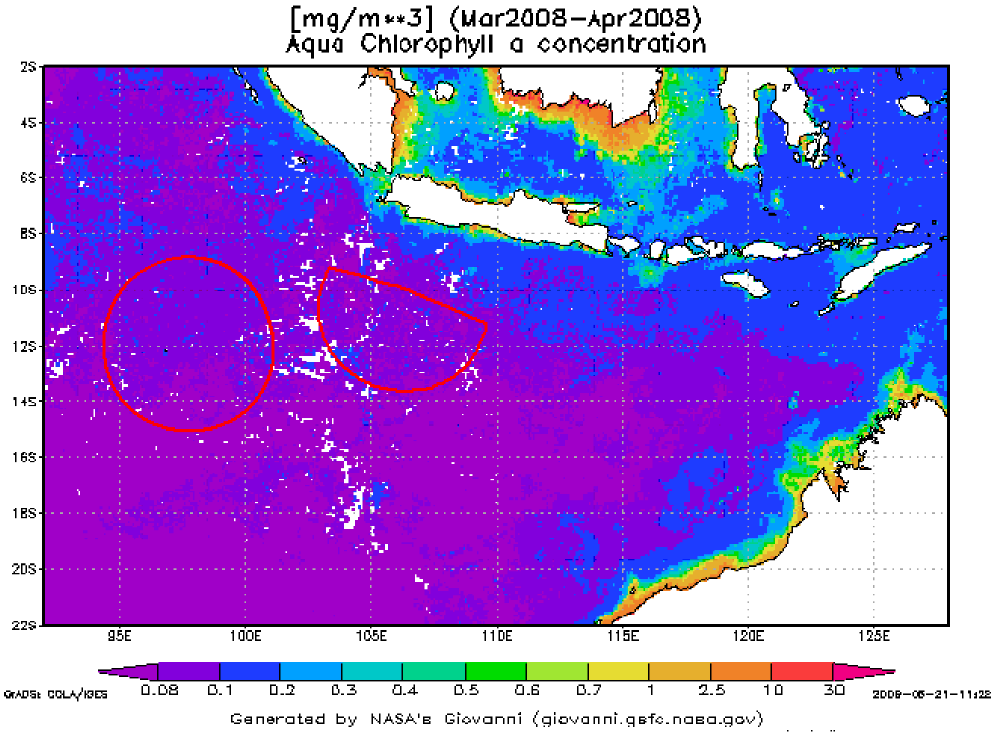
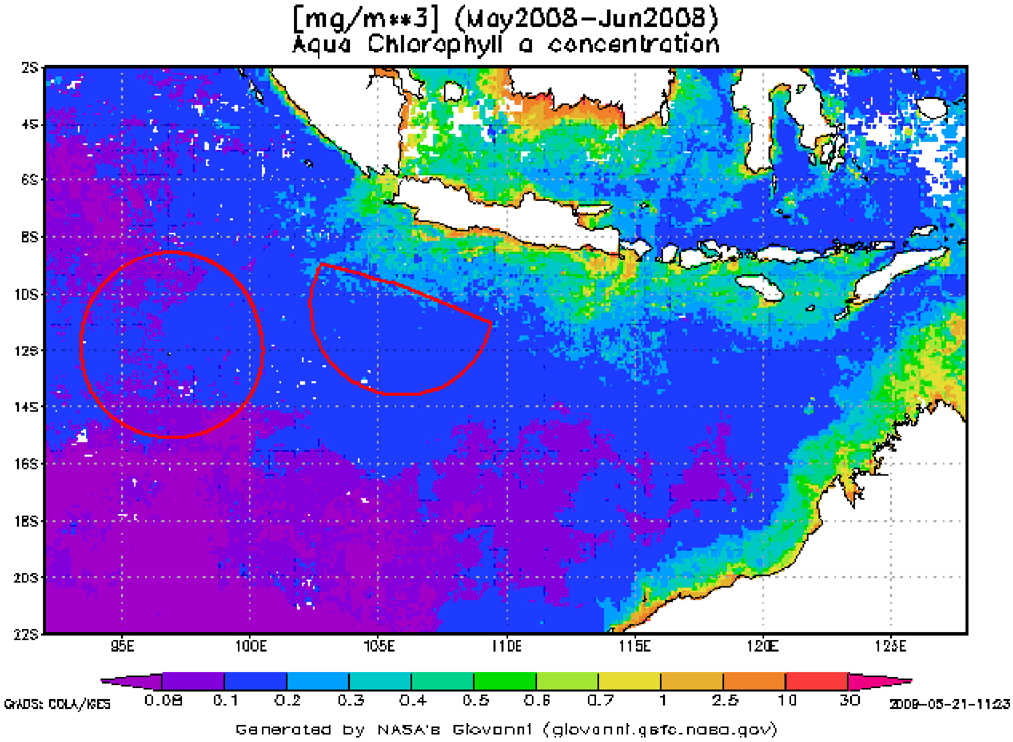


Figure 4-14. Bi-Monthly Ocean Colour sequences for 2008 from the Aqua satellite sensor for January-February and March-April. (MODIS Terra Nightime Sea Surface Temperature and MODIS Aqua ChlA climatology data downloaded from Ocean Colour Web (http://oceancolor.gsfc.nasa.gov/cgi/l3) February 2008).



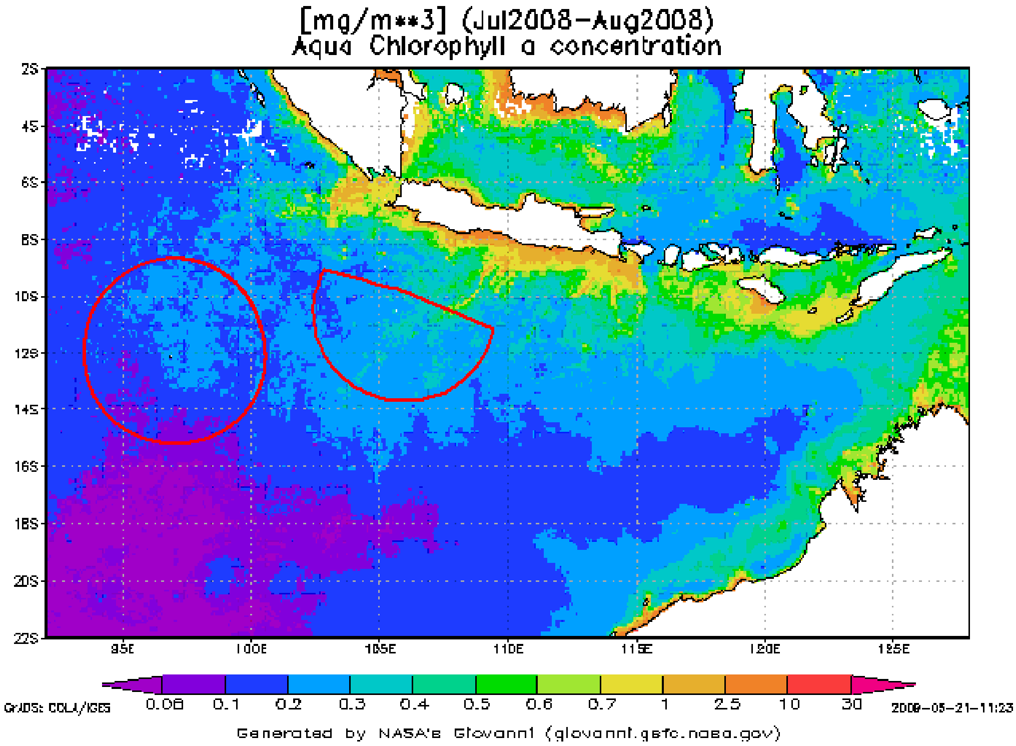


Figure 4-15. Bi-Monthly Ocean Colour sequences for 2008 from the Aqua satellite sensor for May-June and July-August. (MODIS Terra Nightime Sea Surface Temperature and MODIS Aqua ChlA climatology data downloaded from Ocean Colour Web (http://oceancolor.gsfc.nasa.gov/cgi/l3) February 2008).

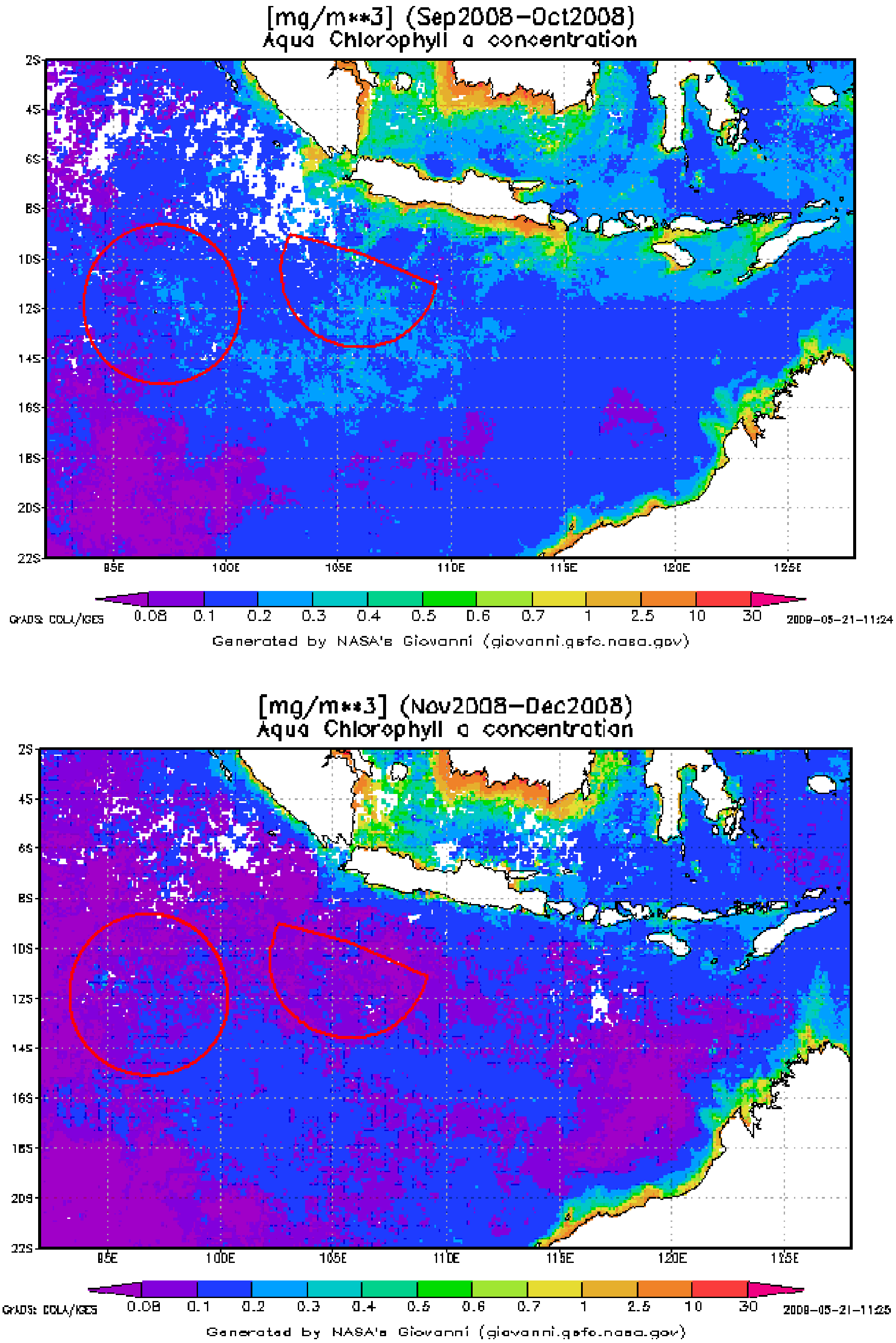


Figure 4-16. Bi-Monthly Ocean Colour sequences for 2008 from the Aqua satellite sensor for September-October and November-December. (MODIS Terra Nightime Sea Surface Temperature and MODIS Aqua ChlA climatology data downloaded from Ocean Colour Web (http://oceancolor.gsfc.nasa.gov/cgi/l3) February 2008).

Endemism, species richness and connectivity

According to Woodroffe and Berry (1994):

"There is almost no endemism in the Cocos biota. The Buff-banded Rail, Rallus philippensis andrewsi, is considered an endemic subspecies, restricted to North Keeling, and the rat on Direction Island, Rattus rattus Keelingensis, has been accorded subspecies status, and was considered by Wallace (1902) to be an example of rapid divergence; it can be traced back to the Mauritius which was wrecked in 1825. The angelfish Centropyge joculator is recorded only from Christmas and the Cocos (Keeling) Islands. The Cocos subspecies of Pandanus tectorius, which is only localised in occurrence, is also considered endemic"

The lack of endemism at the Cocos (Keeling) Islands is thought to be due to oscillation in the sea levels and the emergence of the islands only some 4000 years ago implying that all terrestrial and near-surface biota would have had to colonise the reefs since its emergence. Woodroffe and Berry (1994) note that the Cocos (Keeling) Islands have in the past been subjected to periodic and catastrophic events including tropical cyclones that have substantially impacted the viability of fauna. Christmas Island on the other hand is an uplifted limestone island that is still being uplifted so its biota has existed for a longer time and more stable environment.

Comparative number of species of flora and fauna (Table 4-1) show that the Cocos (Keeling) Islands has fewer species of plants and native birds which could be partly due to its reduced size (compared to Christmas) and human pressures. In contrast, marine species are of comparable numbers or occur in greater numbers (e.g. corals and molluscs). These may be restricted at Christmas Island due to availability of suitable substrates and environments.

Table 4-1. Comparative numbers of species of flora and fauna between Cocos (Keeling) Islands and Christmas Island. The last column is the ratio of the number of species at Cocos compared to that in Christmas, expressed as a percentage. Data from Woodroffe and Berry (1994).

GROUP	Cocos Is. (# spp)	Christmas Is. (# spp)	Cocos/CI (ratio as %)
Plants	130	386	34%
Native birds	38	88	43%
Fishes	550	568	97%
Decapod crustaceans	198	204	97%
Echinoderms	88	90	98%
Reef-building coral	99	85	116%
Molluscs	610	490	124%

Table 4-2. Numbers of species of fishes at Cocos (Keeling) Islands categorised by their regional distribution and comparative percentages of numbers at Cocos (Keeling) Islands compared to the numbers in the region (last column). Last row compares numbers from Christmas and Cocos (Keeling) Islands. Data from Allen and Smith-Vaniz (1994).

Distribution	No species.	Percent of total fauna
Widespread or Indo-west Pacific	388	72
West Pacific & Cocos Is.	85	15.9
Indian	31	5.8
Circumtropical Ocean	12	2.3
Uncertain	17	3.2
Total	**533**	**100**
Also known from Christmas Is.	***354***	***66.4***

Allen and Smith-Vaniz (1994) reviewed the fish species of Cocos and found that reef fishes all have a pelagic larval stage lasting several weeks, and the makeup of species comprises distributions according to Table 4-2. The bulk of fish species are widespread or Indo-west Pacific in origin, which points to the significance of the ITF current in delivering larval recruits to the island (Figure 4-17, Figure 4-18). About two thirds of fish species are shared with Christmas Island.

Comparative statistics for the number of species found in fish families are shown in Table 4-3. These show a range from a completely shared family (as in *Microdesmidae*) to those with a high degree of separation (as in *Ophichthidae*). The bulk of the families have species with pelagic egg and/or larval stages as expected. But there are a number of families with benthic egg and larval stages. Pelagic larval stages can be prolonged (weeks to months) while those with benthic or localised eggs and larval stages do not necessarily adhere to one island unit more strongly than the other. Likewise strong separation can occur with families with pelagic larval stages, though there is tendency for those families having localised egg and larval stages to have higher Jaccard indices (more separated). A number of factors could be operating here that are not solely due to egg and larval drift. It may well be that local environmental and human pressures are at play. This is supported by recorded incidences of mass coral death at the Cocos (Keeling) Islands, suggesting that species with restricted eggs and larval stages may be much more vulnerable at that site.

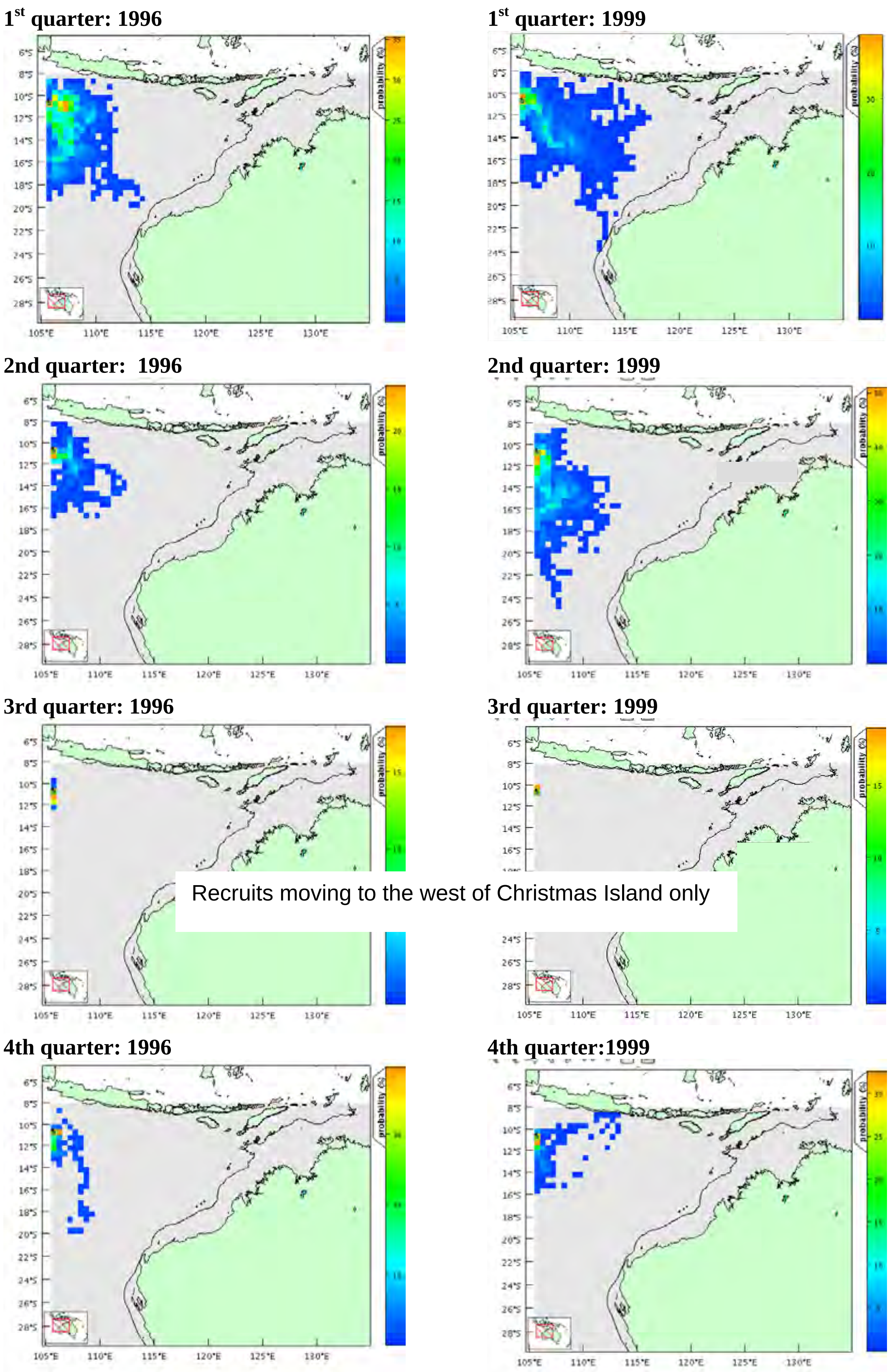


Figure 4-17. Connectivity modelling from ‘Connie’ showing likely areas of **pelagic larval dispersal from Christmas Island** in an 80 day period for four seasonal periods and two selected years (see Condie *et al*. 2005). Only data east of Christmas Island available.

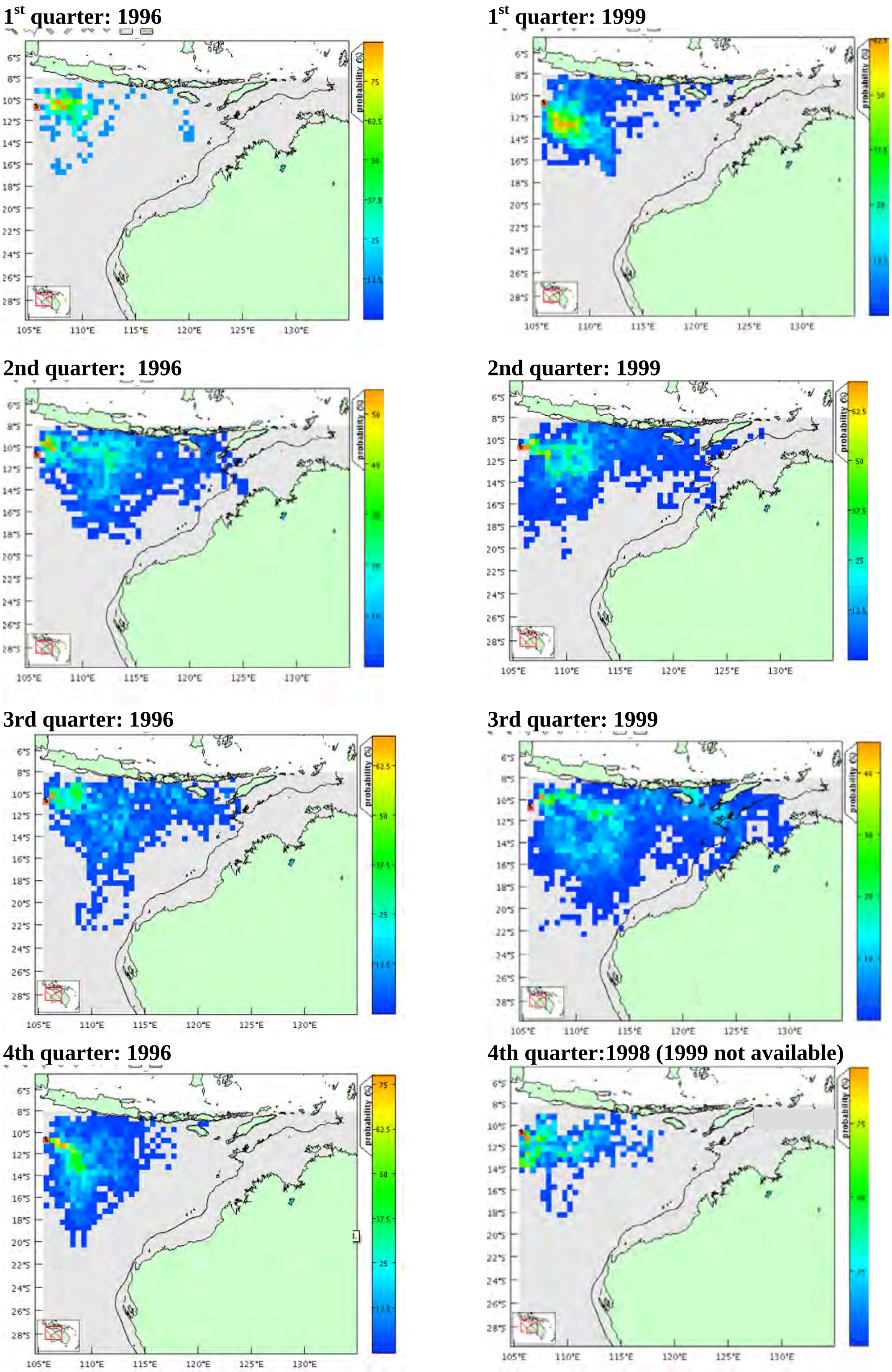


Figure 4-18. Connectivity modelling from ‘Connie’ showing likely areas of **pelagic larval recruitment to Christmas Island** in an 80 day period for four seasonal periods and two selected years (see Condie *et al*. 2005). Only data east of Christmas Island available.

Table 4-3. Comparative assessment of the number of species in fish families found at Cocos (Keeling) Islands (denoted CKI) and Christmas Island (denoted CI) with notes (last column) on eggs and larval stages. The Jaccard index is the sum of species found only at Cocos plus those at Christmas, divided by the total number of species found at the two sites (Cocos (Keeling) Islands only + Christmas Island only + Shared). A Jaccard index of zero (as in the first Family listed) implies that all species are shared, while a Jaccard index of one implies that there are no shared species (species at each island site are unique to that site).

Example Common name	Family	CK	CI	shared	CKI only	CI only	Jaccard index	Notes on eggs/larvae
Wormfish	Microdesmidae	7	7	7	0	0	0.00	benthic eggs/pelagic larvae
Thorntail	Acanthuridae	25	26	24	1	2	0.11	pelagic spawner
Hawkfish	Cirrihitidae	8	7	7	1	0	0.13	pelagic spawner
Goatfish	Mullidae	8	7	7	1	0	0.13	pelagic spawner
Jacks and pompanos	Carangidae	11	13	10	1	2	0.23	pelagic eggs/larvae
Triggerfish	Balistidae	14	12	11	3	1	0.27	demersal eggs
Puffer/trigger fish	Tetraodontidae	6	9	6	0	3	0.33	demersal eggs/pelagic larvae
Damselfish	Pomacentridae	38	44	31	7	11	0.37	demersal eggs
Wrasses	Labridae	54	61	43	11	16	0.39	pelagic spawner, 21-104d larval stage
Butterfly fish	Chaetodontidae	23	27	19	4	8	0.39	pelagic spawner, 2-3 month larval stage
Eels	Muraenidae	24	34	20	4	14	0.47	pelagic spawner, 6-10 month larval stage
Squirrel fish	Holocentridae	20	15	12	8	3	0.48	pelagic larvae out to sea
Scorpion fish	Scorpaenidae	16	19	11	5	8	0.54	eggs in gel, planktonic larvae
Seahorse pipefish	Syngnathidae	6	7	4	2	3	0.56	eggs carried by adults
Snappers	Lutjanidae	8	15	7	1	8	0.56	pelagic eggs/larvae
Parrot fish	Scaridae	20	15	11	9	6	0.58	eggs settle into coral and hatch
Blennies	Blenniidae	21	28	14	7	14	0.60	demersal eggs/pelagic fry
Sea basses/groupers	Serranidae	30	44	19	11	25	0.65	planktonic larvae
Cardinalfish	Apogonidae	30	22	12	20	10	0.71	eggs in mouth
Angelfish	Pomacanthidae	7	12	4	3	8	0.73	pelagic spawner
Bobies	Gobiidae	51	36	18	33	18	0.74	attached eggs
Emperor	Lethrinidae	10	2	2	8	0	0.80	pelagic spawner
Snake eel	Ophichthidae	6	7	2	4	5	0.82	pelagic eggs/larvae
	Total	**530**	**563**	**351**	**176**	**212**	**0.53**	

An indication of the connectivity through the pelagic system in the region is displayed in Figure 4-17 and Figure 4-18. Although these Connie outputs incorporate the region to the east of Christmas Island, we need to infer pelagic transport of eggs, larvae etc to the west. These figures appear to demonstrate the strong seasonal signals described earlier in the wind and current regimes in the area, and highly variable interannual patterns (also seen on plots of other years not displayed here). During the times of strong westward moving currents (ITF and SEC) in the second and third quarters of the year in particular, pelagic eggs and larvae can be transported into the Christmas Island region from as far away as the Timor and Savu seas, East Timor and the NW shelf (assuming an 80 day pelagic larval phase). These habitats in turn have strong connections with many regions in the Indo-west Pacific. During Summer, current patterns suggest that Christmas Island receives water that has streamed from the south-western coast of Sumatra, via the offshore islands.

Recruits and pelagic waters from Christmas Island appear capable of reaching the Java coastline as well as the narrow shelf habitats adjacent to Exmouth Gulf and Ningaloo. During the SE monsoon, although not depicted on the Connie outputs, recruits from Christmas Island are likely to make their way to both the Cocos (Keeling) Islands and to the habitats along the south Sumatra coast.

The patterns of larval dispersal in this region appear to be more complex than the seasonal eastward or westward movement inferred from the general patterns described above. We also know that there are large and sporadic eddies that occur within these currents, at least in part through interaction with the seamounts and islands in the region. There are also potentially strong sub-surface counter currents and other flows that surface currents (depicted in these Connie outputs, see Figure 4-17 and Figure 4-18) may be underestimated or missed.

Fish in the Cocos (Keeling) Islands lagoon.

4.1.5 Assessment of interactions with Threatened, Endangered and Protected species

The Christmas and Cocos (Keeling) Islands territories are home to a wide range of Threatened, Endangered and Protected (TEP) species, including Cetaceans, Seabirds, Turtles, sea snakes, fish and a dugong. There are recorded sightings and behavioural information available for some of these species groups (summarised below). Sources include national and local experts, government and web site reports.

Assessment of teleost fish interactions

A range of pipefish (syngnathidae) have been sighted in both territories (Table 4-4). Six species are known to occur at Christmas Island and eight at the Cocos (Keeling) Islands. This list is biased towards the shallow habitats where data has been collected by divers. There are likely to be more species occurring in these territories than recorded (e.g. in deeper water, on seamounts, slopes etc).

Assessment of elasmobranch interactions

Whale sharks are well known to occur in the Christmas Island territory. There is evidence that the Christmas Island territory is on the migration route for many individuals (Figure 4-19). Whale sharks are thought to use this region to forage (Meekan *et al*., In Press) and as a juvenile habitat (Hobbs *et al*., 2009). Whale sharks are rarely sighted within the Cocos (Keeling) Islands territory.

Although other sharks have been recorded in commercial and recreational fish lists (Appendix C) none are listed under the Act.

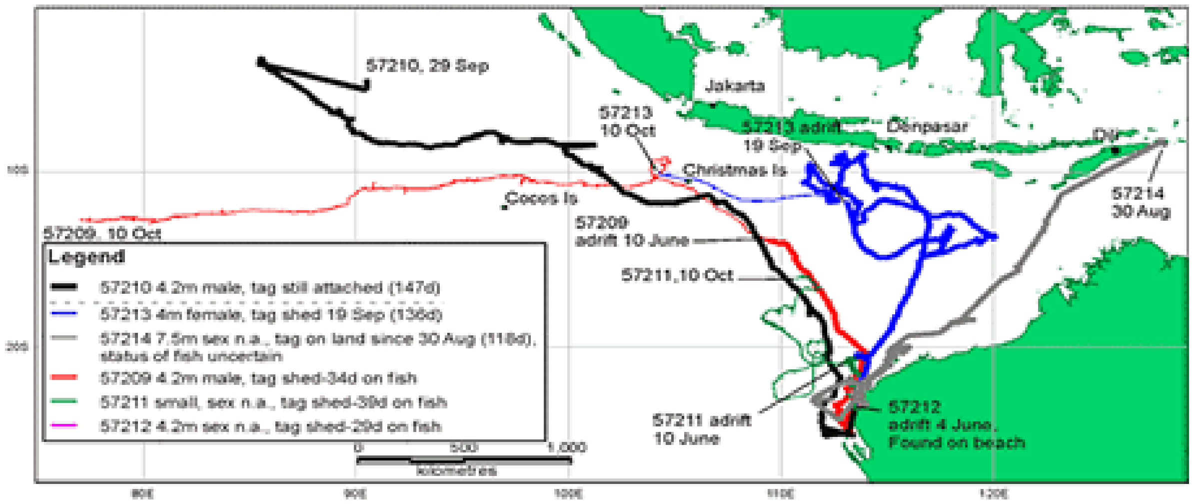


Figure 4-19. Whale shark migration routes showing the Christmas Island territory as a likely key environment for these species (see http://www.cmar.csiro.au/tagging/whale/ningaloo.html).

Table 4-4. Summary of pipefish (Syngnathidae) interactions in the Christmas and Cocos (Keeling) Islands territories. CI – Christmas Island territory; CKI = Cocos (Keeling) Islands territory. Sightings information co-ordinated by Claire Davies, CSIRO.

Common name	**Latin name**	**Sighting location**
Indian blue stripe pipefish	*Doryrhamphus excisus*	Shallow coastal habitat - CKI
Ornate ghost pipefish	*Solenostomus paradoxus*	Shallow coastal reef habitat – CI and CKI
Pacific blue-stripe pipefish	*Doryrhamphus melanopleura*	Shallow coastal habitat - CI
Robust ghost pipefish	*Solenostomus cyanopterus*	Shallow coastal rubble or sand habitat - CI
Schultz's pipefish	*Corythoichthys schultzi*	Shallow coastal habitat - CI
Sculptured pipefish	*Choeroichthys sculptus*	Shallow coastal habitat - CI and CKI
	Cosmocampus banneri	Shallow coastal habitat - CI and CKI
	Dunckerocampus baldwini	Shallow coastal habitat - CI
	Micrognathus brevirostris pygmaeus	Shallow coastal habitat - CI
	Micrognathus brevirostris	Shallow coastal habitat - CKI
	Phoxocampus belcheri	Shallow coastal habitat - CKI

Assessment of sea turtle interactions

Green turtles nest on both Christmas and Cocos (Keeling) Islands, though in low densities on Christmas Island. Up to 100 green turtles nest per year on Cocos (Keeling) Islands, mainly on the north atoll. Green turtles nesting on both Christmas and Cocos (Keeling) Islands are likely to be unique genetic stocks. They also use shallow reef habitats on both islands to forage.

Small numbers of Hawkesbill turtles also nest on Cocos (Keeling) Islands (mainly the north island). However, thousands of individuals forage in the shallow reef environments feeding on encrusting algae and sessile invertebrates.

Loggerhead, Olive-Ridley, and Leatherback turtles also use these two territories, although little is known about their behaviours and activities.

Table 4-5. Summary of likely turtle interactions in the Christmas and Cocos (Keeling) Islands territories. CI – Christmas Island territory; CKI = Cocos (Keeling) Islands territory. Data collated from expert opinion via (i) residents of CI (collated by Claire Davies) and (ii) Colin Limpus (pers. comm.)

Common name	Latin name	Likely behaviours with the Wharton Basin subregion
Green turtle (Vulnerable)	*Chelonia mydas*	• Nesting on Christmas and Cocos (Keeling) Islands – genetically unique stocks • Feeding in Cocos (Keeling) Islands habitats and probably in Christmas Island habitats
Loggerhead turtle (Endangered)	*Caretta caretta*	• Probably foraging in both Christmas and Cocos (Keeling) Islands habitats • Sighted rarely at Christmas Island
Hawksbill turtle (Vulnerable)	*Eretmochelys imbricate*	• Foraging in Cocos (Keeling) Islands habitats and probably in Christmas Island habitats • Maybe limited nesting on Cocos (Keeling) Islands
Olive Ridley turtle (Endangered)	*Lepidochelys olivacea*	• Foraging in Cocos (Keeling) Islands habitats
Leatherback Turtle (Endangered)	*Dermochelys coriacea*	• Foraging in Cocos (Keeling) Islands habitats and probably in Christmas Island habitats

Assessment of sea snake interactions

Little is known about the use of either territorial waters by sea snakes. The limited evidence available suggests that there are no sea snakes in at least the coastal waters of Cocos (Keeling) Islands, and few sea snake sightings in the waters of the Christmas Island territory.

Assessment of seabird interactions

A wide range of seabirds inhabit the territories, including endemics, residents and vagrants. Many species also use the island habitats as breeding sites (Table 4-6). Most of these species use the surrounding waters for foraging, although for most species it is not known how far they roam. Data has been collected for Abbott's booby indicating that their feeding patterns may often relate to the prevailing wind direction and current direction (Figure 4-21).

Assessment of whale, dolphin and dugong interactions

There have been no published surveys of whales and dolphins in the Christmas and Cocos (Keeling) Islands territories. In order to assess the likely interactions of these species we have summarised information from three sources:

- Data collected by Curt Jenner (Centre for Whale Research) from the Scott Reef region
- Data collected from the Komodo World heritage area, and
- Expert opinion from scientists with experience living on or visiting Christmas and Cocos (Keeling) Islands (co-ordinated by Claire Davies)

The information from Scott Reef and Komodo provide an indication of other species that occur in the region. This information may indicate that the sighting data from Christmas and Cocos (Keeling) Islands is an underestimate of the diversity of species that occurs in these two external territories, emphasising the need for a rigorous survey program in the regions.

The whale and dolphin sightings suggest that the external territories contain local populations of three species of dolphin (two in each territory), including feeding and breeding areas - Spinner dolphins and Short-beaked common dolphins in the Christmas Island territorial waters, and Bottlenose dolphins and Short-beaked common dolphins in the Cocos (Keeling) Island territorial waters. However, little is known about precise locations of either activity.

Whales have been sighted in both the Christmas Island (four possible species) and Cocos (Keeling) Islands regions (four species) – Killer whales, Fin whales, Humpback whales, Sei whales in Christmas island territorial waters, and Blue whales, Fin whales, Humpback whales, Sei whales in Cocos (Keeling) Island territorial waters. Most of these sightings require validation and less is known about whale behaviour in these waters.

A single dugong lives in the lagoon at the Cocos (Keeling) Islands, although it appears to be a vagrant surviving in a sub-optimal environment for this species.

Table 4-6. Summary of seabird interactions in the Christmas and Cocos (Keeling) Islands territories. Data collated from expert opinion via (i) residents of CI (collated by Claire Davies) and (ii) from Dr David Milton (CSIRO and Qld Ornithological Soc.).

Common name	**Latin name**	**Interactions within the Christmas and Cocos (Keeling) Islands territories**
Christmas Island frigatebird (Vulnerable)	*Fregata andrewsi*	• Endemic to and breeds on Christmas Island • Nests in low numbers in Pulu Keeling National Park (Cocos (Keeling) Islands) • Forages widely in the seas within the Christmas Island territory (and beyond) • Appears to disperse from around Christmas Island after breeding - seen regularly in Indonesian waters and even into Thailand
Lesser frigatebird	*Fregata ariel*	• Present in both territories, but uncommon on Christmas Island • Breeds on North Keeling Island • Foraging in both territorial waters (and beyond)
Great frigatebird	*Fregata minor*	• Present in both territories • Breeds on Christmas and Cocos (Keeling) Islands • Foraging in both territorial waters (and beyond)
Abbott's booby (Endangered)	*Papasula abbotti*	• Endemic to the Christmas Island region • Breeds on Christmas Island • Forages in territorial waters • More localised than the frigatebirds, with few records of birds dispersing northwards into adjacent countries
Brown booby	*Sula leucogaster*	• Breeds on Christmas and Cocos (Keeling) Islands • Foraging in both territorial waters
Red-footed booby	*Sula sula*	• Breeds on Christmas and Cocos (Keeling) Islands • in territorial waters
Masked booby	*Sula dactylatra*	• Breeds on Cocos (Keeling) Islands • Forages in territorial waters
White-tailed tropicbird	*Phaethon lepturus*	• Breeding on Christmas Island and Cocos (Keeling) Islands • Foraging in territorial waters
Red-tailed tropicbird	*Phaethon rubricauda*	• Breeding on Christmas Island • Foraging in Christmas Island territorial waters
Eastern reef egret	*Egretta sacra*	• Present in Christmas Island

Common name	**Latin name**	**Interactions within the Christmas and Cocos (Keeling) Islands territories**
		• Foraging in Christmas Island territorial waters
Yellow bittern	*Ixobrychus sinensis*	• Vagrant at Christmas Island
Nankeen night heron	*Nycticorax caledonicus*	• Present at Cocos (Keeling) Islands • May be a vagrant at Christmas Island
Common noddy	*Anous stolidus*	• Breeding on Christmas and Cocos (Keeling) Islands • Foraging in both territorial waters
Wedge-tailed shearwater	*Puffinus pacificus*	• Present as vagrants in Christmas and Cocos (Keeling) Islands territories • Foraging and migrating in both territories
Matsudaira's storm-petrel	*Oceanodroma matsudairae*	• Present as vagrants in the both Christmas and Cocos (Keeling) Islands territories • Foraging and migrating in both territories
Round Island Petrel (Critically Endangered)	*Pterodroma arminjoniana* s. str	• Present as vagrant on Cocos (Keeling) Islands
Whimbrel	*Numenius phaeopus*	• Present as vagrants in the both territories • Migrating in the both territories although the region is off the regular migration routes • Lack of suitable feeding habitats means limited foraging possible
Wood sandpiper	*Tringa glareola*	• Present as vagrants in both territories • Migrating in the both territories although the region is off the regular migration routes • Lack of suitable feeding habitats means limited foraging possible
Common sandpiper	*Actitis hypoleucos*	• Present as vagrants at Cocos (Keeling) Islands • Migrating in the both territories although the region is off the regular migration routes • Lack of suitable feeding habitats means limited foraging possible
Common greenshank	*Tringa nebularia*	• Present as vagrants in both territories • Migrating in the both territories although the region is off the regular migration routes • Lack of suitable feeding habitats means limited foraging possible
Marsh sandpiper	*Tringa stagnatilis*	• Present as vagrants at Christmas Island • Migrating in the both territories although the region is off the regular migration routes • Lack of suitable feeding habitats means limited foraging possible
Ruddy turnstone	*Arenaria interpres*	• Present as vagrants at Christmas and Cocos (Keeling) Islands

Common name	Latin name	Interactions within the Christmas and Cocos (Keeling) Islands territories
Red-necked stint	*Calidris ruficollis*	• Present as vagrants at Christmas Island
Common redshank	*Tringa totanus*	• Present as vagrants at Cocos (Keeling) Islands
Oriental pratincole	*Glareola maldivarum*	• Present as vagrants at Christmas Island
White tern	*Gygis alba*	• Present on Cocos (Keeling) Islands • Nesting in Pulu Keeling National Park
Australian pelican	*Pelecanus conspicillatus*	• Present as vagrants in both territories • Foraging and migrating in territorial waters • Birds disperse widely from breeding grounds in Australia and stray into the region at irregular intervals

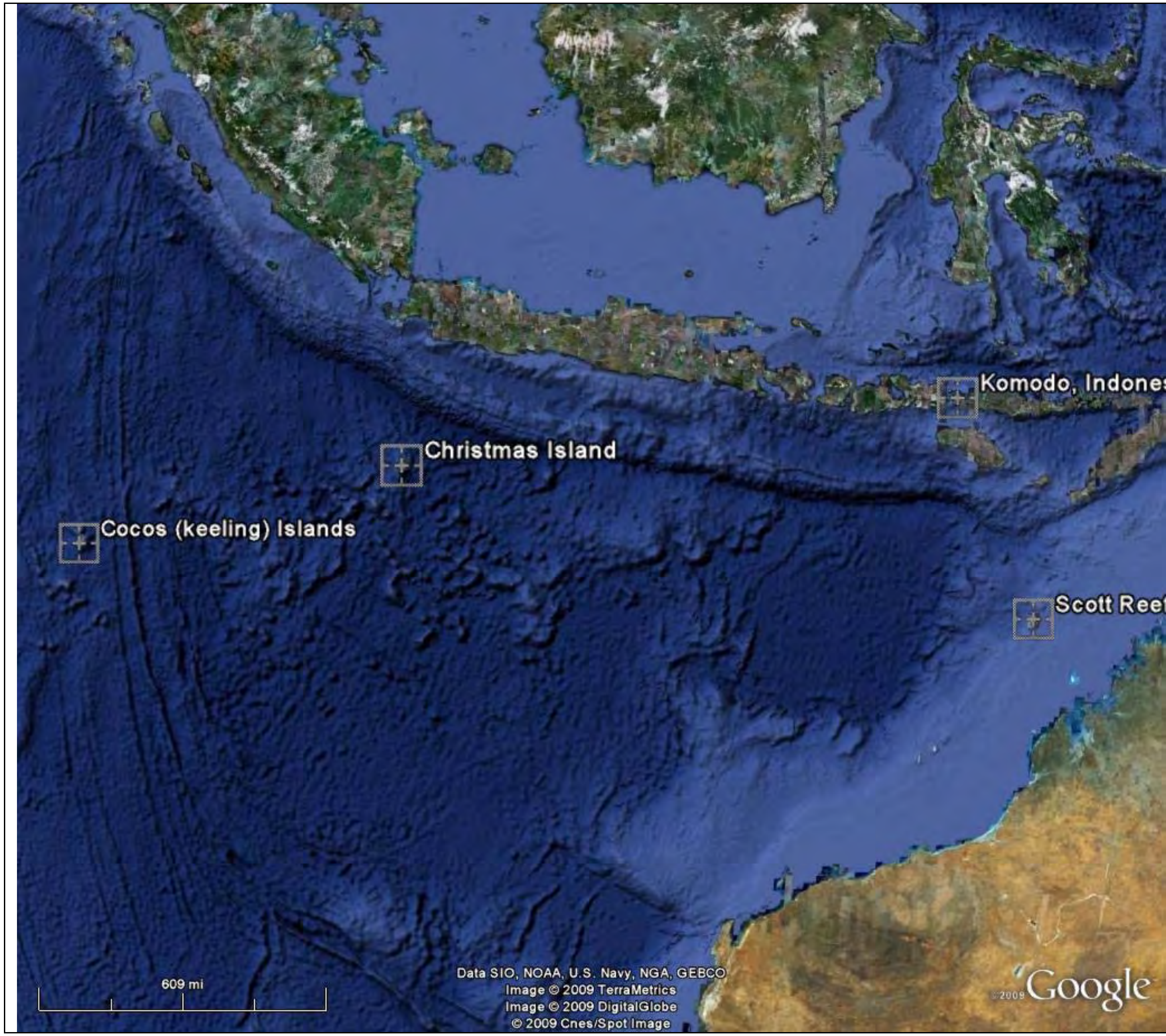


Figure 4-20. Locations of places in the NW Australian/NE Indian Ocean region where cetacean sighting have been used here to help describe the likely cetacean interactions for Christmas and Cocos (Keeling) Islands. The cetacean sightings are summarised in Tables 5.1 and 5.2.

Table 4-7. Data on sightings of cetaceans for locations in the NW Australian/NE Indian Ocean region. Christmas and Cocos (Keeling) Islands data was collated from personal observations of recent residents on Christmas Island (collated by Clair Davies, pers comm.). Scott Reef data was supplied by Kurt Jenner, pers comm., Centre for Whale Research) and Komodo Heritage area data was taken from information from the following web site: www.apex-environmental.com/ListKomodo.html). ? = possible sighting.

Species	**Location sited**			
	Christmas Island	**Cocos (Keeling) Islands**	**Scott Reef**	**Komodo Heritage Area**
Common bottlenose dolphin (*Tursiops truncates)*		√	√	√
Common dolphin (*Delphinus delphis or D. capenis)*				√
Short-beaked common dolphin (*Delphinus delphis)*	√	√	√	
Long-beaked common dolphin (*Delphinus capensis)*			√	
Fraser's dolphin (*Lagenodelphis hosei)*			√	√
Indo-pacific bottlenose dolphin (*Tursiops aduncus)*			√	
Indo-Pacific humpback dolphin (*Sousa chinensis)*				√
Long-snouted spinner dolphin (*Stenella longirostris)*	√	√	√	√
Risso's dolphin (*Grampus griseus)*			√	√
Rough-toothed dolphin (*Steno bredanensis)*				√

Species	**Location sited**			
	Christmas Island	**Cocos (Keeling) Islands**	**Scott Reef**	**Komodo Heritage Area**
Blue whale (*Baleanoptera musculus)*		√		√
Bryde's whale (*Balenoptera edeni)*			√	
Cuvier's beaked whale (*Ziphius cavirostris)*	√			√
Dwarf minke whale (*Balenoptera acutorostrata)*			√	
Dwarf sperm whale (*Kogia sima)*			√	√
False killer whale (*Pseudorca crassidens)*		√	√	√
Fin whale (*Balaenoptera physalus*)	**?**	**?**		
Humpback whale (*Megaptera novaeangliae)*	**1 sighting**	**?**	√	
Melon-headed whale (*Peponocephala electra)*				√
Orca (*Orcinus orca)*	√ **(very infrequent)**			√
Pan-tropical spotted dolphin (*Stenella attenuate)*			√	√
Pilot whale spp. (*Globicephala spp.)*			√	
Pygmy Bryde's whale (*Balaenoptera edeni)*				√

Species	Location sited			
	Christmas Island	Cocos (Keeling) Islands	Scott Reef	Komodo Heritage Area
Pygmy blue whale (*Balaenoptera musculus brevicauda)*			√	
Pygmy killer whale (*Feresa attenuate)*				√
Pygmy sperm whale (*Kogia breviceps)*				√
Sei whale (*Baleanoptera borealis*)		√		√
Short-finned pilot whale (*Globicephalus macrorhynchus)*				√
Sperm whale (*Physeter macrocephalus)*			√	√

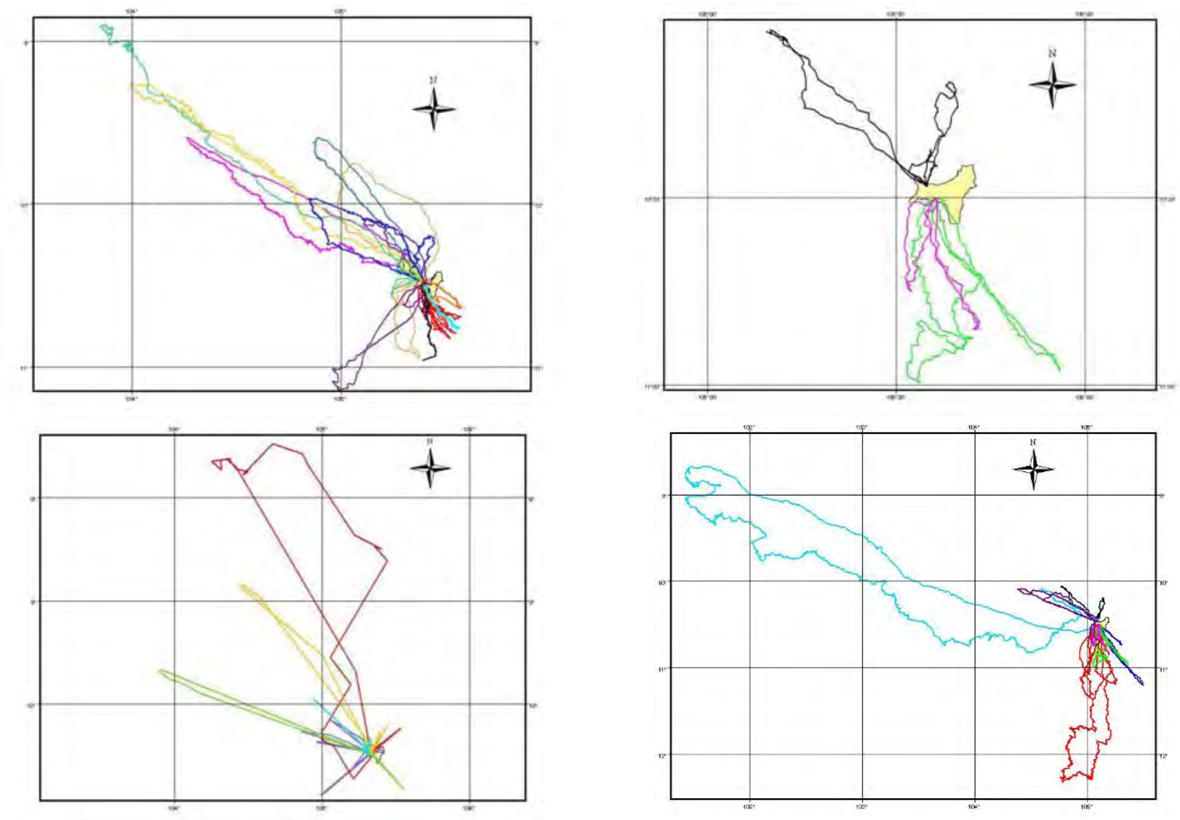


Figure 4-21. Abbotts Booby flights paths to and from Christmas Island, showing patterns that appear to align with the prevailing south-easterly wind direction that dominates this region for most of the year. These flight patterns also demonstrate the dependence of this species on small fish in the pelagic waters within this region. Each colour represents flight paths for separate days.

Table 4-8. Summary of likely cetacean interactions in the Christmas and Cocos (Keeling) Islands territories. CI – Christmas Island territory; CKI = Cocos (Keeling) Islands territory.

Common name	**Latin name**	**Likely behaviours within the Christmas and/or Cocos (Keeling) Island territories**
Blue Whale (Endangered)	*Balaenoptera musculus*	• Possible use of CKI territory – not information on likely behaviour
Bottlenose dolphin	*Tursiops truncates*	• Commonly seen near Cocos (Keeling) Islands • Likely feeding and breeding area
Killer whales	*Orcinus orca*	• Sighted very occasionally at CI • May be migrating through and feeding the region
Fin Whale (Vulnerable)	*Balaenoptera physalus*	• Possible sightings at CI and CKI
Humpback Whale (Vulnerable)	*Megaptera novaeangliae*	• Possible sightings at CI and CKI
Sei Whale (Vulnerable)	*Balaenoptera borealis*	• Possible sightings at CI and CKI
Short-beaked common dolphin	*Delphinus delphis*	• Sighted often at CI on east / south coast • Commonly seen on CKI • Likely feeding and breeding area
Spinner dolphins	*Stenella longirostris*	• Sighted all year at CI • Likely feeding and breeding area

4.2 Christmas and Cocos (Keeling) Islands territories

4.2.1 Geological overview for Christmas and Cocos (Keeling) Islands territories

The Cocos (Keeling) Islands and Christmas Island lie in the Indian Ocean at 12°S, 97°E and 10°30S 105°40E / -10.5, 105.667, respectively and form part of an easterly trending group of seamounts (the Vening Meinesz chain). Christmas Island is the surface expression of an emergent seamount (Barrie 1967) with further sedimentary processes having occurred since emergence. The Cocos (Keeling) Island group consists of low lying coral islands, composed of coral sand and limestone: North Keeling, a single C-shaped atoll, and the South Keeling Island group, the five main islands being West, Horsburg, Direction, Home and South. North and South Keeling are linked by a submarine ridge occurring at approximately 1,000 m water depth (Woodroffe *et al* 1994).

Most of the sea floor area in the AEEZ is abyssal plain, occurring at depths of 5,000-6,000 m. The area contains numerous sea mounts and guyouts, including circular seamounts, elongate ridges, complex combinations of plateaus and seamounts (IFM-GEOMAR 2009), and volcanic ridges.

The seamount volcanism is associated with the reactivation at approximately 80 mya of old transform faults of an extinct spreading centre. There was a second period of volcanism in the Eocene 35-40 my and a third more recent stage (probably confined only to Christmas Island) caused by lithospheric flexure and fault reactivation as the area approached the Java Trench (Borrisova 1994). Seamounts in the Christmas Island area have subsided more slowly than similar seamounts to the west.

The Cocos and Christmas Rises have comparatively small amounts of sediment cover – 100-200 m thick on the Cocos and 100-400 m thick on the Christmas Rise; and is surrounded by crust of lower Tertiary age (60-70 my). In a recent survey (IFM-GEOMAR 2009) it was found that porphyric sheet and pillow lavas dominated the lithological character of the seamounts in the area. Volcaniclastic rocks are also common, some indicating subaerial or shallow water volcanic activity. Evolved lavas and sedimentary rocks (mainly carbonates) are also common.

4.2.2 Composition relative to Regional features

The Christmas and Cocos (Keeling) Islands territories are composed of seabed of the northern Wharton Basin including the volcanic province, the southern Cocos Basin and the Investigator Ridge and associated ridge and ravine topography on the surrounding abyssal plain.

Seabed in the AEEZ represents 23% of the total area of the Wharton Basin, including 60% of the Volcanic province; 9% of the Cocos Basin and most of the area of the Investigator Ridge. This includes almost all large seamounts and all currently emergent seamounts in the Volcanic Province. It also includes the maximum relief area of the Investigator Ridge, where scarp and associated trench features are most developed. Cocos Basin abyssal plain occurring in the AEEZ is typical of the southern area of Cocos Basin, with scarce low relief topography and relatively consistent sediment cover, although areas in proximity to seamounts and ridge features are likely to contain greater sediment thicknesses and coarser clastic sediments that are rare elsewhere in the basin. The area of the Wharton Basin in the AEEZ represents the area of this basin with the highest density of volcanic features, and contrasts strongly with the low relief abyssal plain that dominates most of the basin area. Debris and eroded sediments cover significant areas of the abyssal plain surrounding seamounts in the AEEZ; these sediment types are not recorded elsewhere on the abyssal plain in the Wharton Basin.

Despite having shallower bathymetric profiles than much of the Wharton and Cocos Basin (due to volcanic topography), the Christmas and Cocos (Keeling) Islands territories contain some of the deepest areas of both basins.

4.2.3 Composition relative to AEEZ (general not statistical)

The Christmas and Cocos (Keeling) Islands territories comprise approximately 8.5% of the total area of the AEEZ. Seabed in the Christmas and Cocos Island territories is distinguished from the rest of the AEEZ by differences in location, evolutionary history and current physical processes. These territories sit at higher latitude than most of the AEEZ, making the area more prone to cyclones and resulting in relatively high water temperatures.

The tectonic setting also contrasts to Australia's stable NW margin. The region surrounding Christmas and Cocos (Keeling) Islands is affected by earthquakes along the Java Trench (Borrisova 1994) and ongoing fracturing along the Investigator Ridge, including earthquakes of magnitudes >7. The northern area of Cocos basin has high levels of intraplate seismicity, though seismicity closer to Cocos (Keeling) Islands as more likely related to volcanism (Levchenko 1989). Subsidence rates across the area vary as Christmas Island is experiencing uplift from lithospheric flexure due to its proximity to the Java Trench (Cocos Keeling atolls are on the seafloor which is isolated from this).

The bathymetric profile of seabed in the Christmas and Cocos (Keeling) Islands territories contrasts strongly to most of the AEEZ which is necessarily dominated by shallower, coastal continental platform geomorphology. Seamount and abyssal plain geomorphology in the island territories result in high percentage of the seabed area occurring in very deep water. Shallower seabed occurs mainly on steep rugged slopes or seamount peaks and is fragmented, with shallow areas on individual seamounts to some degree isolated from one another.

Christmas and Cocos (Keeling) Islands occur a significant distance from the continental margin (1,600 km from NW shelf). Although there is some argument over the mechanism for their formation, it is agreed that the islands developed on oceanic crust a significant distance from the Australian Continental Margin and have at no time in their history been in proximity or connection with the landmass.

The Christmas and Cocos (Keeling) Islands territories also experiences significantly lower sediment supply rates than abyssal plain in other areas of the AEEZ. This is due to their isolation from significant regional sediment sources (Australian continent, Bengal Fan). Abyssal plains in the island territories contrasts to seabed adjacent to Australia's continental margin by the absence of significant terrigenous input, with most sediment derived from pelagic sources and some volcanic input from Indonesia.

Hard substrate frequently exposed on and around volcanic edifices in the Christmas and Cocos (Keeling) Islands territories is dominated by basalts. This contrasts in texture to rock types generally found, particularly for shallow waters, in the AEEZ surrounding the Australian Continent.

Cocos pygmy angelfish or yellow headed angelfish **(*Centropyge joculator*)** is endemic to Christmas and Cocos (Keeling) Islands.

The Christmas Island red crab (*Gecarcoidea natalis*) is endemic to Christmas Island.

4.2.4 Quantitative analysis for combined Christmas and Cocos (Keeling) Islands territories

The water depths within the Christmas and Cocos (Keeling) Islands territories range from approximately 0-6,420 m, with more than 80% of the area occurring in water depths >4,000 m. The majority (59%) occurs in water depths of 5,000-6,000 m, though only 1.7% in water depths >6,000 m. Island territories contain 39% of the area for water depths >5,000 m and 93% of water depth >6,000 m in the entire AEEZ.

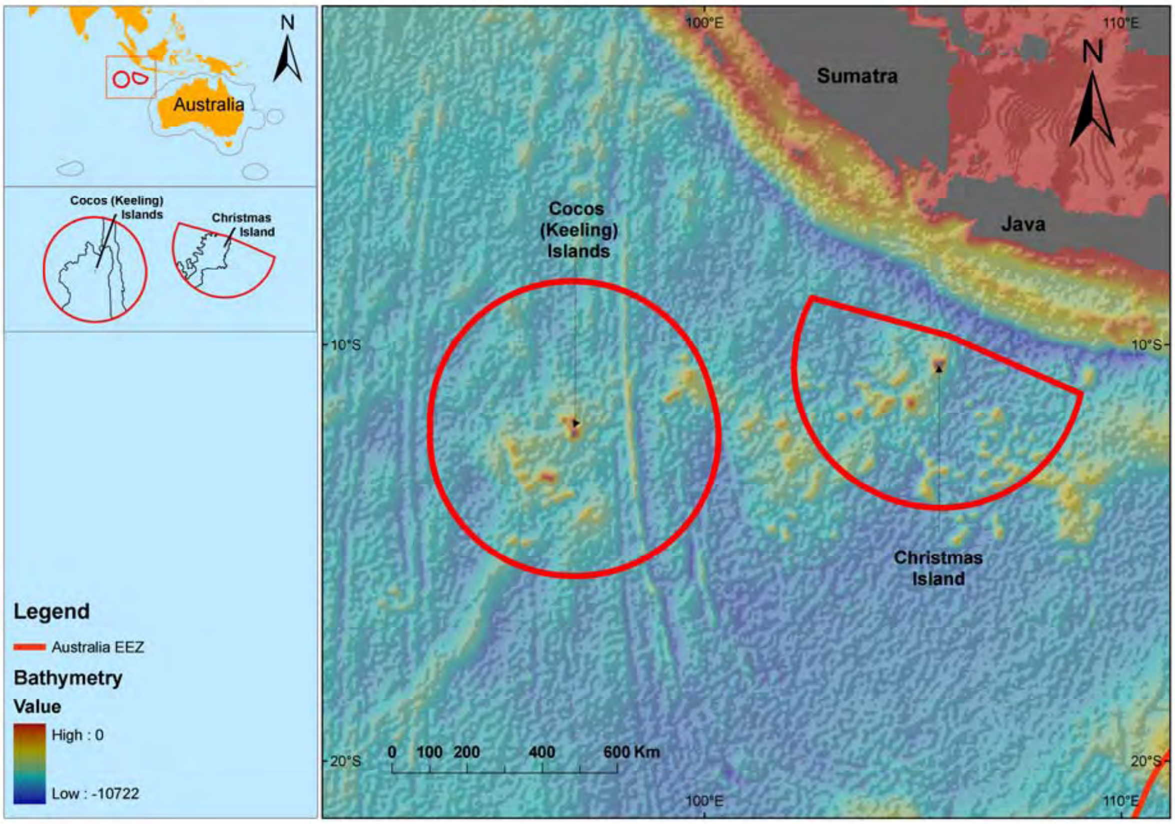


Figure 4-22. Bathymetry of the Christmas and Cocos (Keeling) Islands region

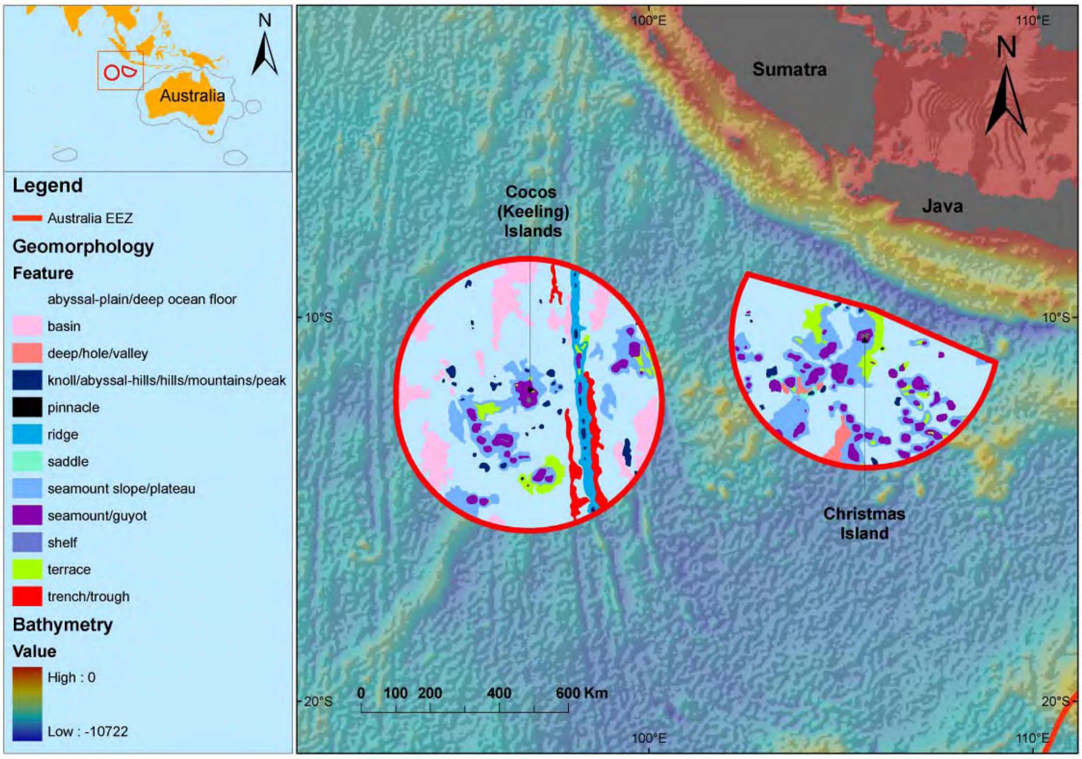


Figure 4-23. Geomorphology of the Christmas and Cocos (Keeling) Islands region

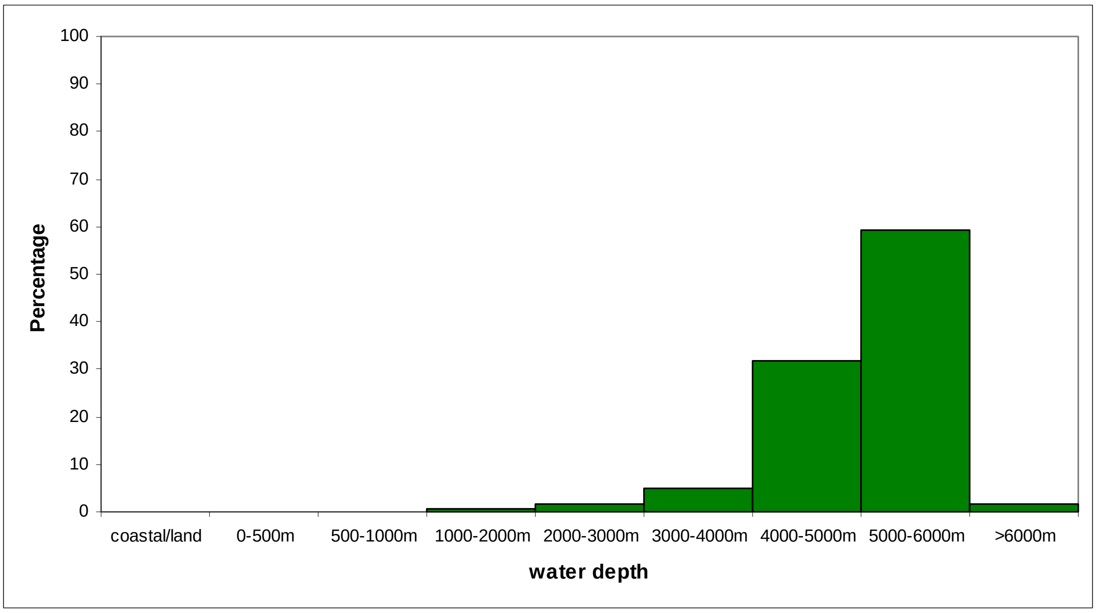


Figure 4-24. Percentage of sea floor area in the combined Christmas and Cocos (Keeling) Islands territories within depth ranges

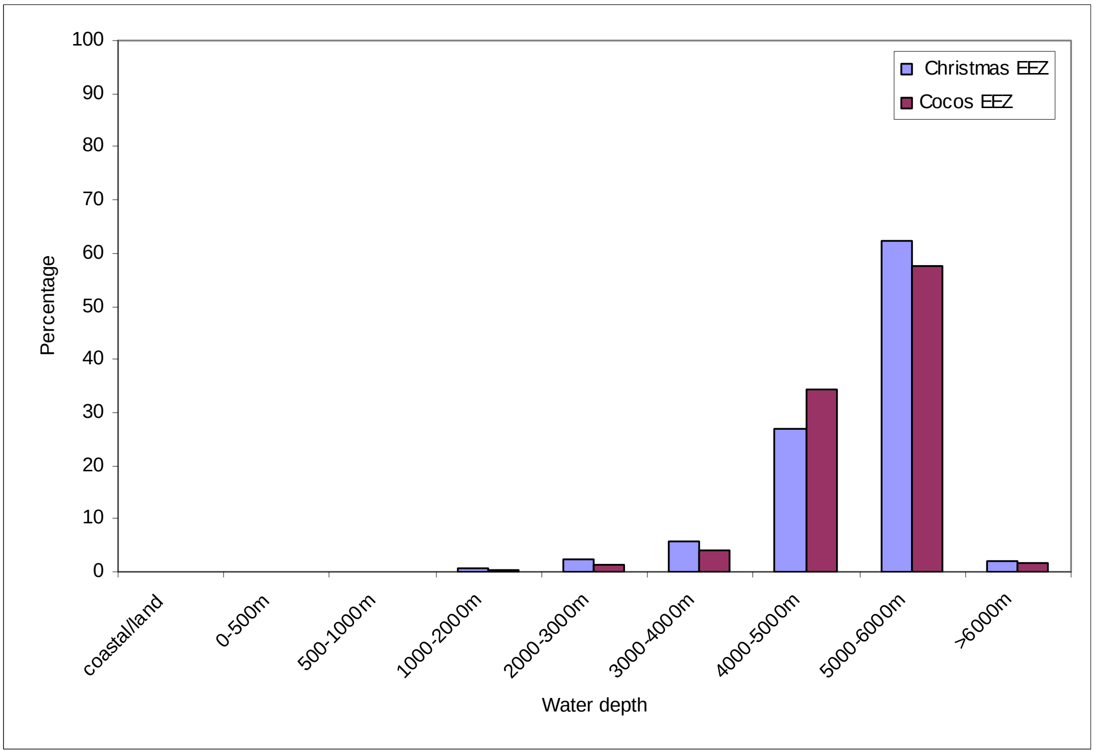


Figure 4-25. Percentage of sea floor area for each territory in depth ranges.

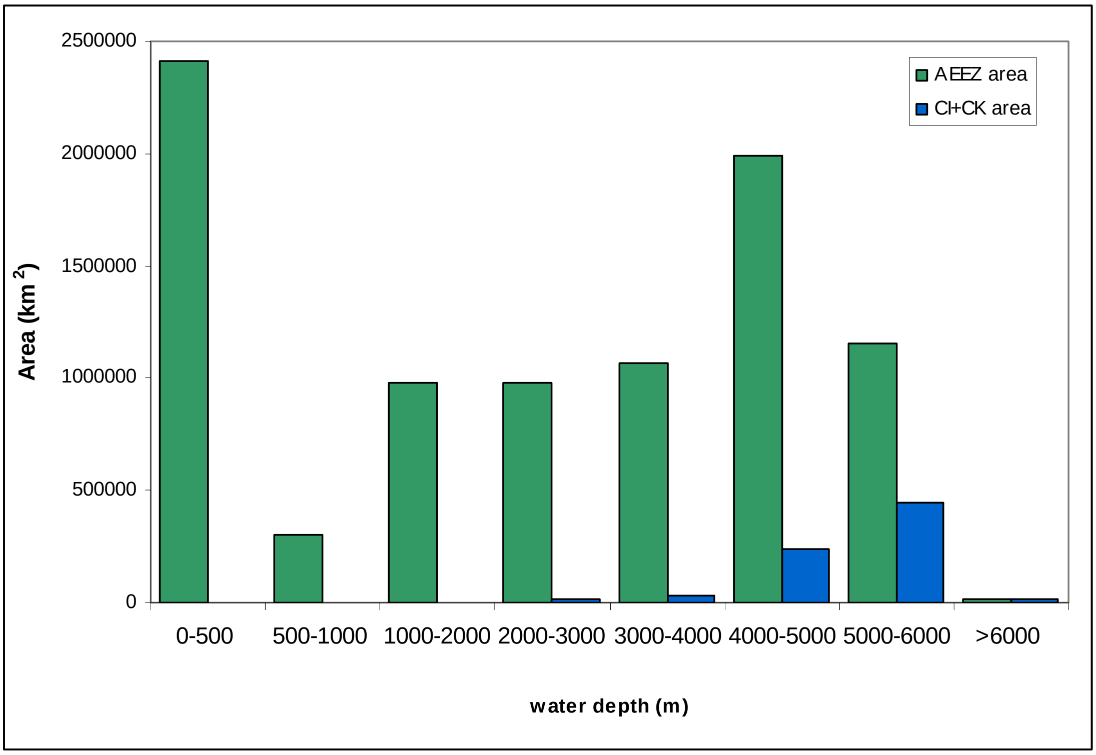


Figure 4-26. Water depth binned at 1,000 m intervals for Christmas and Cocos (Keeling) Islands and total AEEZ.

Table 4-9. Water depths in the Christmas Island (CI) and Cocos (Keeling) Islands (CKI) territory areas compared to water depths in the total AEEZ.

water depth (m)	Area in CI + CKI EEZ (km²)	% of CI + CKI EEZ area	% of AEEZ area	% of total AEEZ area in CI + CKI
0-500	595	0.08	27.1	0.02
500-1000	641	0.09	3.4	0.21
1000-2000	3842	0.52	10.9	0.39
2000-3000	12750	1.71	11.0	1.3
3000-4000	35801	4.81	11.9	3.4
4000-5000	235439	31.6	22.4	11.8
5000-6000	442201	59.4	12.9	38.4
>6000	12834	1.72	0.15	93.2

Deepwater environments in the Christmas and Cocos (Keeling) Islands territories represent ~20% of total abyssal plain area in the AEEZ. Volcanic topography is also rare elsewhere in the AEEZ, particularly off Australia's western margin. Seamounts in the Christmas and Cocos (Keeling) Islands territories represent ~41% of the total area of seamounts in the entire AEEZ, and ridge structures found in the combined Christmas and Cocos (Keeling) Islands territories represent ~16% of the entire area of ridges in the AEEZ. Other significant geomorphic features found in the combined Christmas and Cocos (Keeling) Islands territories are basins and knoll/abyssal-hills/hills/mountains/peaks both representing ~9% of that feature, and trench/troughs ~7% of the AEEZ's total area for those features.

Sediment types

Interpretation of sediment and rock distribution and composition is based on 70 sediment and 95 rock samples from the Christmas and Cocos (Keeling) Islands territories (Figure 4-31). Number of samples and their density determine confidence in interpretation for any feature type. Where features contain <3 samples it is unlikely that data represents the range and frequency of sediment or rock types present across this area and composition/distribution has not been assessed.

Sediment samples provide adequate coverage to assess sedimentology of abyssal plain/deep ocean floor (38 samples, 1 sample per 12,000 km), Seamount/guyots (14 samples, 1 sample per 3,000 km), seamount slope/plateaus (12 samples, 1 sample per 9,000 km) and basins (3 samples, 1 sample per 20,000 km). Rock dredges provide adequate coverage to assess rock types present in abyssal plain/deep ocean floor (42 samples), Seamount/guyots (27 samples), seamount slope/plateaus (18 samples), ridges (5) and saddles (4).

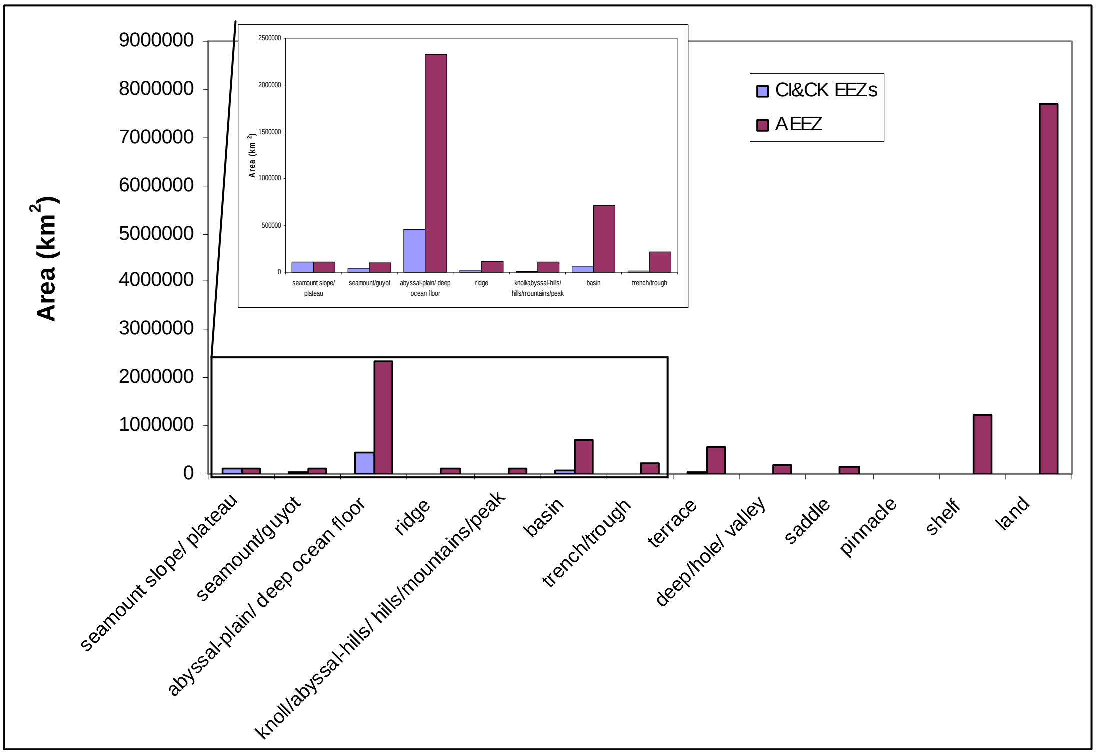


Figure 4-27. Comparison between area covered by geomorphic features in the entire AEEZ and the combined territories of Christmas and Cocos (Keeling) Islands.

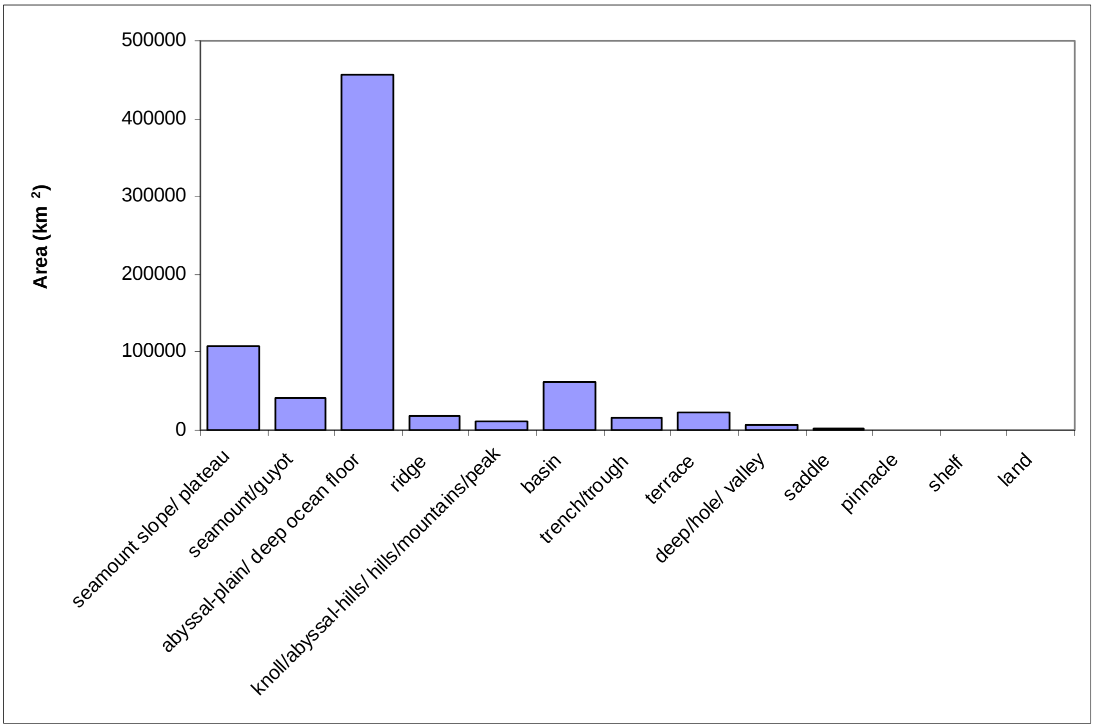


Figure 4-28. Total area covered by geomorphic features within combined Christmas and Cocos (Keeling) Islands territories.

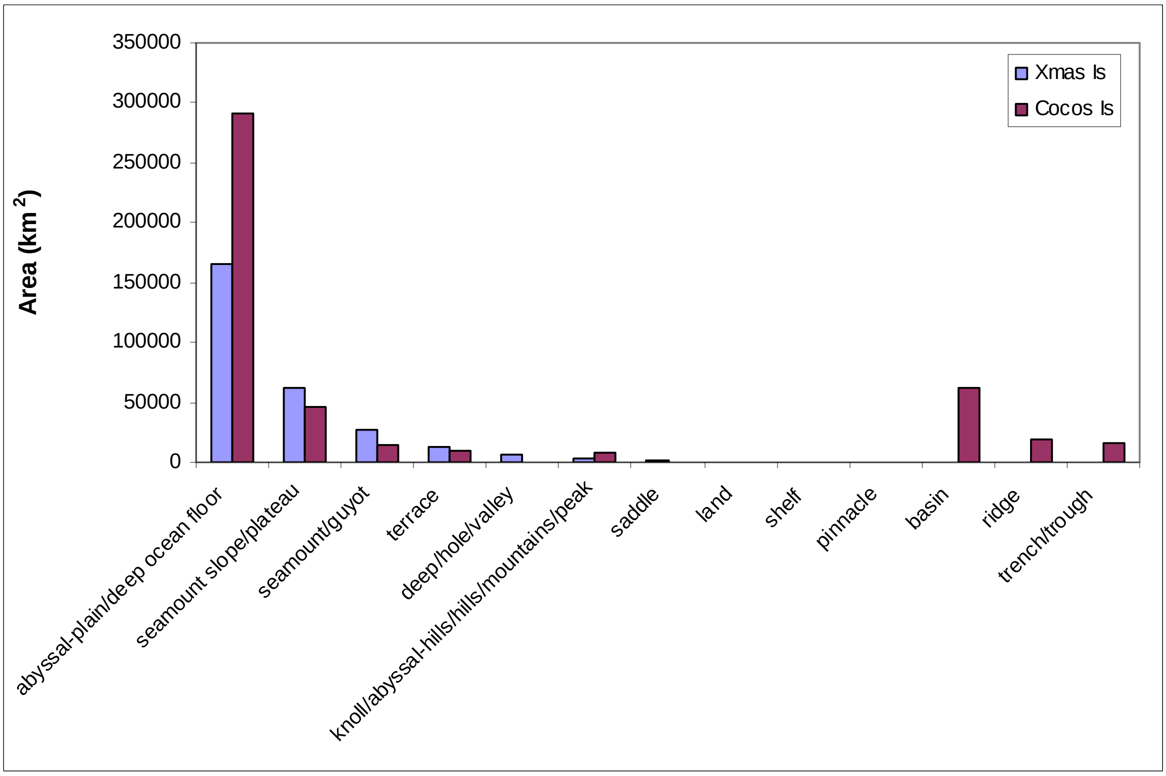


Figure 4-29. Comparison geomorphology of Christmas and Cocos (Keeling) Islands territories.

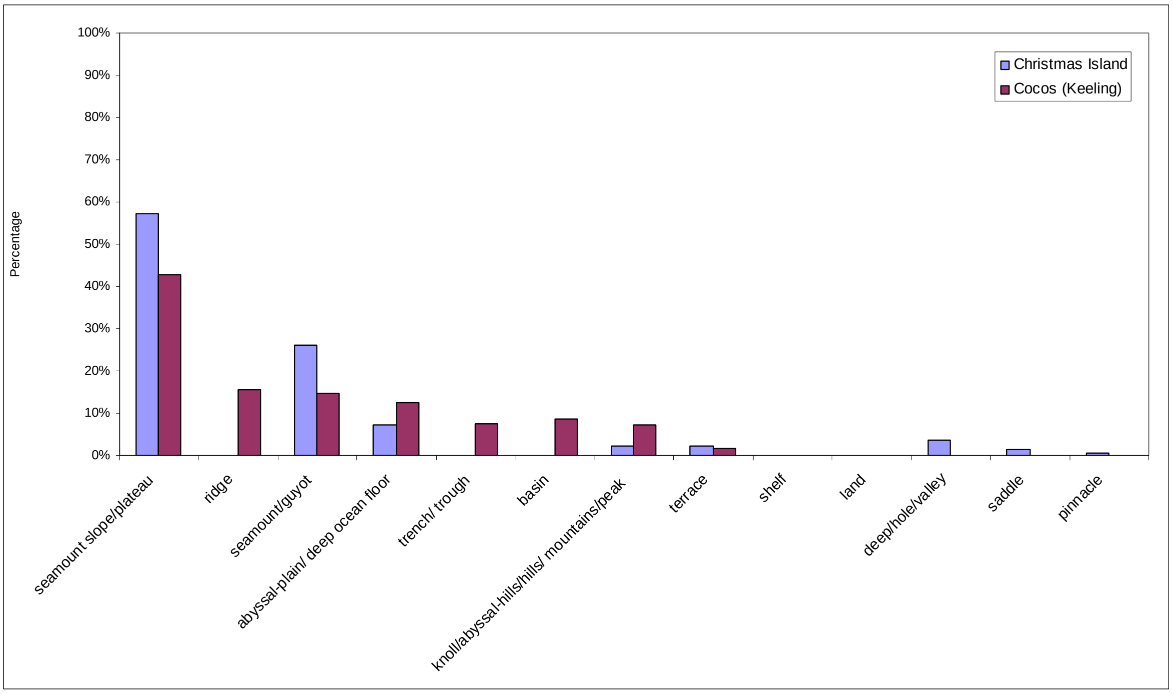


Figure 4-30. Percent of Australia's geomorphic features in Christmas & Cocos (Keeling) Islands territories.

Table 4-10. Number of samples of sediment (70) and rock (95) samples from the Christmas and Cocos (Keeling) Islands territories.

Geomorphic feature	No. sediment samples	% of total sediment samples	No. rock samples	% of total rock samples
Abyssal-plain/deep ocean floor	38	54	39	42
Seamount/guyot	14	20	25	27
Seamount slope/plateau	12	17	17	18
Basin	3	4	0	0
Deep/hole/valley	1	1.5	0	0
Terrace	1	1.5	2	2
Trench/trough	1	1.5	0	0
Knoll/abyssal-hills/hills/mountains/peak	0	0	1	1
Ridge	0	0	5	5
Saddle	0	0	4	4

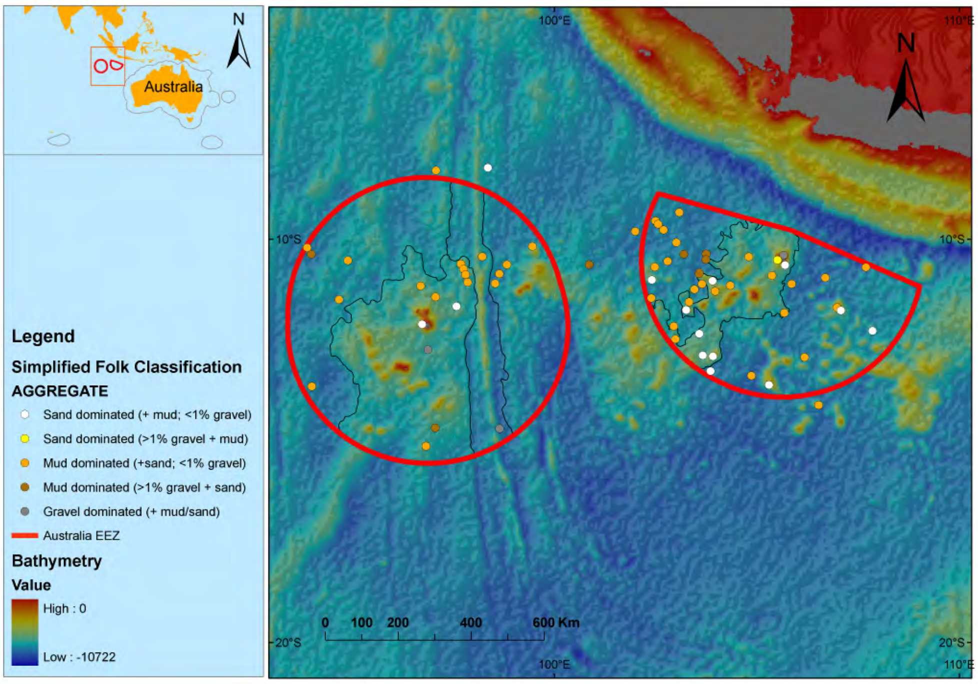


Figure 4-31. Final sediment dataset for the AEEZ in this region (75 points including GA quantitative analyses and descriptions sourced from international databases).

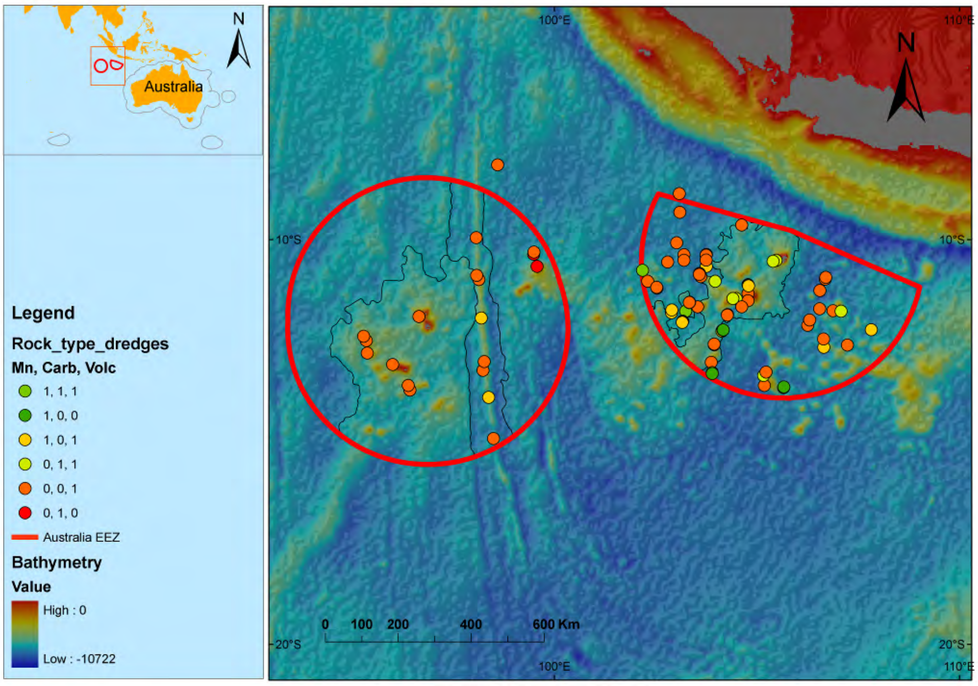


Figure 4-32. Rock dredge sampling sites (95 points) for the Christmas and Cocos (Keeling) Islands territories (descriptions sourced from international databases).

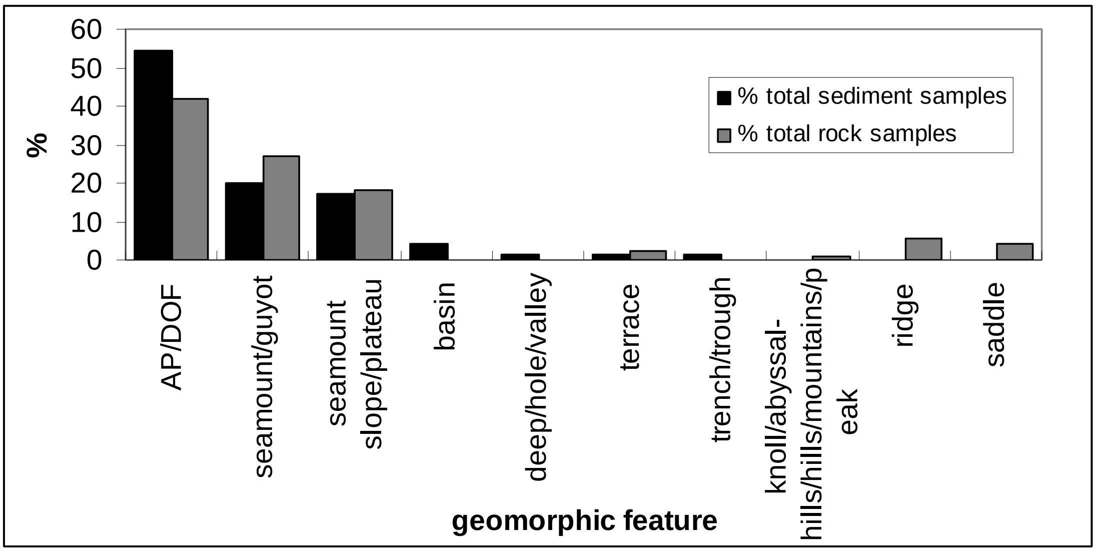


Figure 4-33. Preferential sampling has resulted in uneven distribution of sediment and rock samples across geomorphic features in the Christmas and Cocos (Keeling) Islands territories, with bias toward abyssal plain and seamounts.

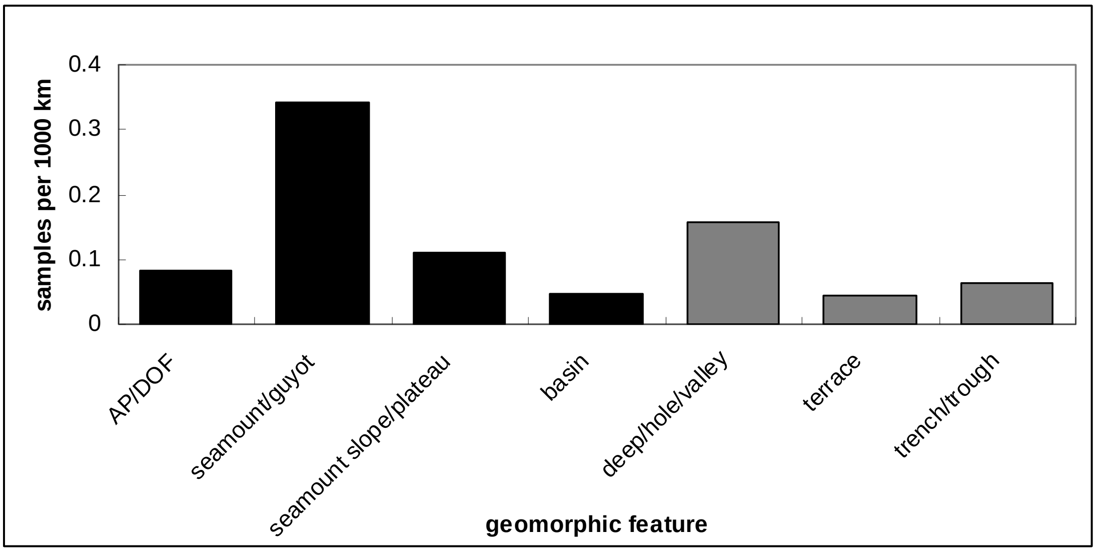


Figure 4-34. Sediment data density in the Christmas and Cocos (Keeling) Islands territories described as samples per 1,000 km for geomorphic features. Grey bars indicate that this area contains inadequate data to interpret sedimentology (<3 samples).

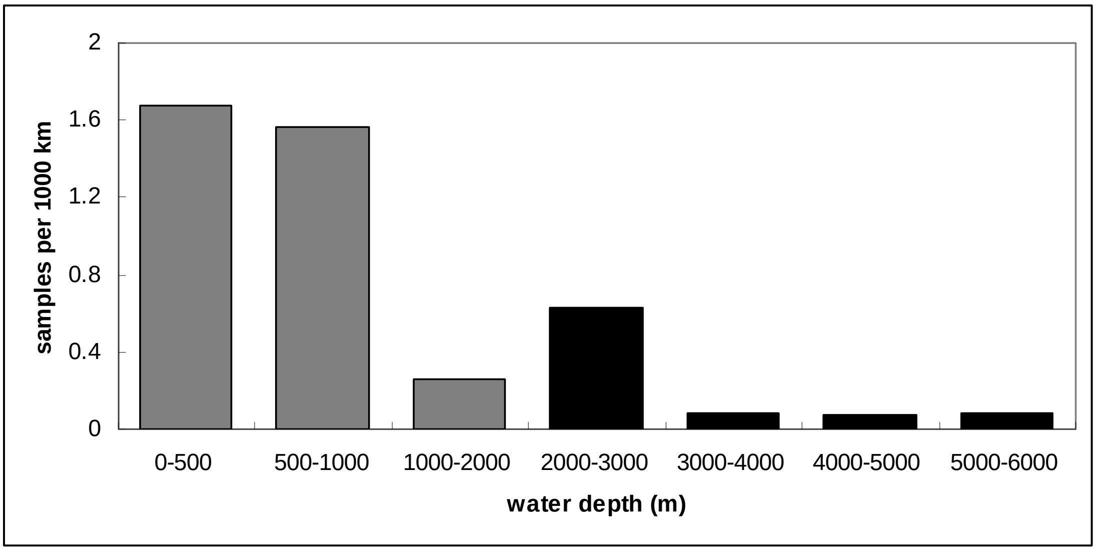


Figure 4-35. Sediment data density in the Christmas and Cocos (Keeling) Islands territories described as samples per 1,000 km for water depth classes. Grey bars indicate that this area contains inadequate data to interpret sedimentology (<3 samples).

Substrate description

Christmas and Cocos (Keeling) Islands territories contain both hard and soft substrates.

Rocks and sediments collected from the region indicate that the following hard substrate types are present:

- Volcanic material (sheet lavas, pillow lavas, volcaniclastics, altered volcanics)
- Intrusive Igneous rocks and metamorphic rocks
- Carbonates (Corals, shallow-water and pelagic limestones)
- Manganese crusts
- Sedimentary rock types

Hard substrates are most commonly exposed on elevated topography, particularly larger seamounts and on the investigator ridge. Large rocks and debris eroded from seamounts also accumulates on the abyssal plain at the foot of seamount slopes, particularly adjacent to seamounts surrounding Christmas Island.

Sediments range from mud to gravel dominated, and from homogeneous to poorly sorted. Most sediments have bi- and multi-modal grainsize distributions, reflecting low levels of volcanic (pumice and volcaniclastics) manganese gravel in otherwise fine-grained sediments, or episodic transport and deposition of sand and gravel to generally low energy (mud dominated) environments at the base of seamount slopes.

Soft substrates dominate the abyssal plain and features occurring there such as deep/hole/valleys and basins, seamount peaks, saddles, plateaus, terraces and low relief areas of seamount slopes.

Sediment on the abyssal plain and in basin and deep/hole/valley features are typically mud-dominated with low concentrations of volcanic (pumice/lava fragments/ volcaniclastics transported into the area predominately aerially) or manganese (nodule/crust) gravels. The exception to this is around the base of seamount slopes where debris eroded of adjacent topography results in highly variable and poorly sorted sediment types including abundant gravels (coral fragments, limestone fragments, manganese crust, volcanic material, sedimentary rocks), sand and mud. Around large seamounts in the Christmas Island central ridge, these may extend up to 20 km from the base of the slope. Around smaller topographic features and seamounts in the west of the volcanic province (Cocos (Keeling) Islands territory) coarse sediments do not accumulate in significant volumes and extend only short distances from the base of slopes.

Sediments on seamounts are dominated by sand with frequent gravels but lower levels of mud than found elsewhere in the region. Gravels on seamounts tend to be most commonly volcanic material (less pumice and more lava than elsewhere), carbonate and sedimentary rock fragments. Sediments on smaller seamounts away from the main volcanic ridge have higher mud contents, as do seamounts at the western end of the volcanic province. Seamount slopes and features within these generally show a fining of sediment (increasing mud and decreasing gravel content) with increasing water depth. On larger seamounts, coarse sediments commonly extend downslope into greater water depths than on smaller seamounts c.

4.2.5 Comparison of Christmas and Cocos (Keeling) Islands territories

The Christmas Island territory is dominated by abyssal plain/deep ocean floor (~60% of the Christmas Island EEZ area), with the most abundant features associated with volcanic topography: seamount slope/plateaus (~22%) and seamount/guyots (~10%). Relative to the AEEZ, the Christmas Island territory is rich in seamount/guyots (containing 26% of the area of seamount/guyots in the entire AEEZ) and abyssal plain (containing 7% of the area of this feature type within the AEEZ).

The water depths within the Christmas Island territory range from 0-6,420 m, with the majority of the area (62%) occurring in 5,000-6,000 m water depth.

The Cocos (Keeling) Islands territory comprises mainly abyssal plain/deep ocean floor (~62%), however dominant feature types within this area differ from those in the Christmas Island territory. The Cocos (Keeling) Islands territory contains frequent basins (~13% total Cocos (Keeling) Islands territory area), and the only ridge and associated trench/trough features in the Christmas and Cocos (Keeling) Islands territories. Volcanic topography is less abundant than in the Christmas Island territory, and includes seamount/guyots (~3% of the Cocos (Keeling) Islands territory area) and associated slope/plateaus (~10%). Relative to the AEEZ, the Cocos (Keeling) Islands territory is rich in ridges (~16% total AEEZ area of this feature type), seamount/guyots (~15%), and abyssal plain/deep ocean floor (~13%).

Water depths within the Cocos (Keeling) Islands territory range from 0-6,416 m. The majority of the area (~58%) occurs in 5,000-6,000 m range, and 34% in the 4,000-5,000 m water depth range.

Christmas Island territory

Christmas Island is located 300 km south of the Java Trench, at the junction of the East Christmas Rise and a WSW trending rise terminating at the Cocos (Keeling) Islands. Christmas Island is roughly T-shaped, rising to 330 m above sea level (total height of the seamount is 5,000 m). The terrestrial morphology reflects its tectonic history – the island is split into seven terraces from the coastline to a central plateau which has higher areas to the Northeast, West and South. The Southwest and ESE coastlines are step-faulted; however the North coast is little affected by faulting. Faults are orientated in two main directions: east-west and NNW-SSE. Terraces developed by this faulting provide evidence for several stages of uplift. The coastline is dominated by limestone cliffs, including caves formed by wave action. Limestone is the dominant rock type outcropping on the island. There is a major NE structural trend in the island, evident in the faults and dykes occurring in the outcrop.

The geological sequence includes interbedded sequence of volcanic and carbonate rocks, capped with a layer of phosphate. The oldest rocks outcropping on the island are volcanics. These are overlain by a thin irregular layer of pyroclastics, followed by thin Eocene limestones and conglomerates, volcanics interbedded with Miocene limestone (which forms the ramparts of the terraces and the plateau). Recent fringing reef limestones outcrop almost continuously about the coastal terrace.

The volcanic rocks are mainly basaltic, and increase in acidity as they become younger, varying from andesite to limburgite. Their composition is similar to those found on other islands in the Indian, Atlantic and Pacific Ocean basins, but different to those in the Indonesian orogenic belt. The carbonate rocks are mostly of reef-wall and lagoonal origin, the phosphate is mainly due to the deposition of bird guano.

Rocks of the lower (Eocene) volcanic series outcrop at several places on the east and west coasts and inland cliffs where no fringing reef is developed. Rocks of the lower carbonate facies are composed of calcareous mud (30-40%) with whole benthic forams dominating the remainder of these facies. This lagoonal facies is interbedded with cherty carbonate rock containing volcanic debris. The upper (Miocene) volcanic rocks outcrop in the inland cliffs and on the central plateau and hills. They seem to all be limburgites. The upper carbonate rocks are mainly composed of calcite, though some dolomite and aragonite is present. The fauna is mainly a reef-wall facies, with some lagoonal facies present. The phosphate deposits, the bulk of which are incoherent, occur mainly on the upper plateau and hills and consist of three main mineral groups: apatite, barandite & crandallite-milisite. It is thought that the phosphate originates from deposition of guano and the subsequent geochemical changes to the limestone are due to weathering and leaching, as well as submarine replacement of material and direct precipitation of phosphatic solutions. Most of the phosphitisation occurs in the limestone, but some is also evident in the volcanics. There is no agreement on when the phosphitisation of the volcanics occurred.

From the geology it can be inferred that Christmas Island was a seamount during the Oligocene and emerged in the late Miocene. It is a volcano of the composite (or Strato volcano) type, and it has been suggested the shape of the island reflects rift zones extending from vents outside the main caldera (Polak 1976). Volcanic activity ceased in the early Tertiary, with final phase volcanism continuing into the Pliocene. This was followed by uplift and subsidence, with the caldera then becoming a lagoon. The bulge from the Java trench is responsible for the SSW tilting.

Table 4-11. Area composition of geomorphic feature in the Christmas and Cocos (Keeling) Islands territories and the percentage contribution to the Australian EEZ within each category (note: features listed as n/a in Area columns for Christmas and Cocos (Keeling) Islands territories not present in those EEZs. Seamount slope/plateau listed as n/a in % Aus EEZ as this was a feature changed only within the Christmas and Cocos (Keeling) Islands territories).

Feature	Area - CI	Area - CKI	% Aus EEZ CI	% Aus EEZ CKI
Abyssal-plain/deep ocean floor	165688	291281	7.1%	12.5%
Seamount slope/plateau	61459	46061	n/a	n/a
Seamount/guyot	26355	14663	26.2%	14.6%
Terrace	12580	10073	2.2%	1.8%
Deep/hole/valley	6381	n/a	3.7%	n/a
Knoll/abyssal-hills/ hills/mountains/peak	2569	8011	2.3%	7.1%
Saddle	1928	n/a	1.3%	n/a
Land	154	14.1	0.002%	0.0002%
Shelf	31.8	218	0.003%	0.018%
Pinnacle	27.6	n/a	0.50%	n/a
Basin	n/a	62381	n/a	8.7%
Ridge	n/a	18311	n/a	15.5%
Trench/trough	n/a	16103	n/a	7.5%

Table 4-12. Water depths as a percentage of Australian EEZ area within each category.

Water depth	Christmas Island as % of AEEZ	Cocos (Keeling) as a % of AEEZ
0-500 m	0.0	0.1
500-1000 m	0.0	0.1
1000-2000 m	0.6	0.4
2000-3000 m	2.2	1.4
3000-4000 m	5.8	4.2
4000-5000 m	26.9	34.4
5000-6000 m	62.3	57.7
>6000 m	2.0	1.6

Except for areas cleared for phosphate mining (the prospectivity for other types of economic deposits is poor) and habitation, the island is covered in dense tropical rainforest. There is little evidence of surface drainage due to subterranean drainage in high porous areas underlying the carbonate rocks. Surface runoff is limited to the monsoon season (Dec-Mar) and springs on the margin of the island. This severely restricts the amount of terrigenous sediment being transported into the coastal marine environments, affecting which species can become established in the habitats formed.

Cocos (Keeling) territory

North Island (a closed ring atoll) has been declared a National Park, with admittance by permit only. Lenses of freshwater are present on Home, West Horsburgh and South Island. The remaining islands which comprise the atoll chain that is too small to maintain an aquifer.

The two atolls are on the same submarine structure, being connected by a ridge at roughly 730 m bsl (Gibson-Hill 1950).The islands forming the south atoll vary in size and are connected by coral reef, except on either side of Horsburgh Island, where there is a broad channel 12-14m deep (Woodroffe & Falkland 1997) (though there are some isolated patches of reef between Horsburgh and West islands). North Keeling's shore rises steeply and then slopes gently down to the interior lagoon. It is thought that is was formed from the amalgamation of two small islands (Gibson-Hill 1950).

Holocene reefal limestones are underlain by Pleistocene limestones, occurring at 8-13m below sea level. Radiocarbon dating from boreholes taken in the South Keeling Island group set reef establishment at around 7,000 years BP, with rapid reef growth (though still lagging behind sea level rise). This was followed by a period of reef-flat building (approximately 5,000-3,500 years BP) and in the final phase of development, as sea level fell, reef-island formation and infilling of the lagoon (Woodroffe & Falkland 1997). The islands are built of coral clinker, in most cases standing on a breccia platform, the majority with fairly steep, seaward facing shingle beaches, and gentler sloping sandy beaches facing the lagoon (Gibson-Hill 1950). The level of the boundary between Pleistocene limestones and Holocene sediments, known as the "Thurber Discontinuity", (up to 24 m bsl) indicates a subsidence rate for the south atoll of 0.02-0.2-1 mmy (Woodroffe & Falkland 1997).

4.3 Christmas and Cocos (Keeling) Islands subregions

In order to help understand the biophysical assets and features of these two territories we have subdivided them into seven separate subregions, based on a range of key attributes, including depth, geomorphology, oceanography and other physical parameters. We also provide a finer scale regionalisation for the Island-scale reef systems (Section 3.4 ‘Key Habitats’) to ensure that these key features were characterised in adequate detail.

Project scientists from CSIRO and GA participated in two workshops and used a range of tools (GIS layers, literature and expert opinion) to agree on subregion features and boundaries. The features of these territories that formed the basis of this subregionalisation are described in Section 3.3.1. This is followed by more detailed descriptions of each subregion in 3.3.2 to 3.3.9.

As the two territories are separated by a significant expanse of ocean, each has been treated separately when assessing the composition of their subregions.

Christmas Island territory

The area comprising the Australian EEZ around Christmas Island can be divided into three geomorphically and ecologically distinct subsystems (Figure 4-36), with the Christmas Island shallow reef system (or key habitat) also treated separately (see 3.4.1).

Central Ridge: The seamount chain running through the centre of the territory contains shallow seamounts linked by slope environments and other relatively shallow water geomorphic features. It includes closely related seamounts (the Golden Bo’sun Bird and Vening Meinsz seamount chains), that include Christmas Island. This subregion is a geologically and ecologically differentiated from the two regions on either side (see 3.3.3) due to: (i) the possible relatedness of the seamounts in this area, being more likely to have formed from the same source than those on the abyssal plain to the east; and (ii) because of the barrier the seamounts form to some fauna in the subregions to the East and West. The subregions’ boundaries were allocated based on the topography of the seamount system, including extent of their slopes, and the likely footprint of sediment slumping around their bases. The boundary line was delineated to the east by the 5,000 m bathymetric contour. Seamounts to the east and west were considered geographically separated from the Central Ridge.

Wharton Basin: To the east of the Central Ridge subregion is the Wharton Basin subregion. This comprises an extensive area of abyssal plain with isolated seamounts. These seamounts have lower elevations than most of those in the central ridge subregion and are not obviously connected to the main seamount chain.

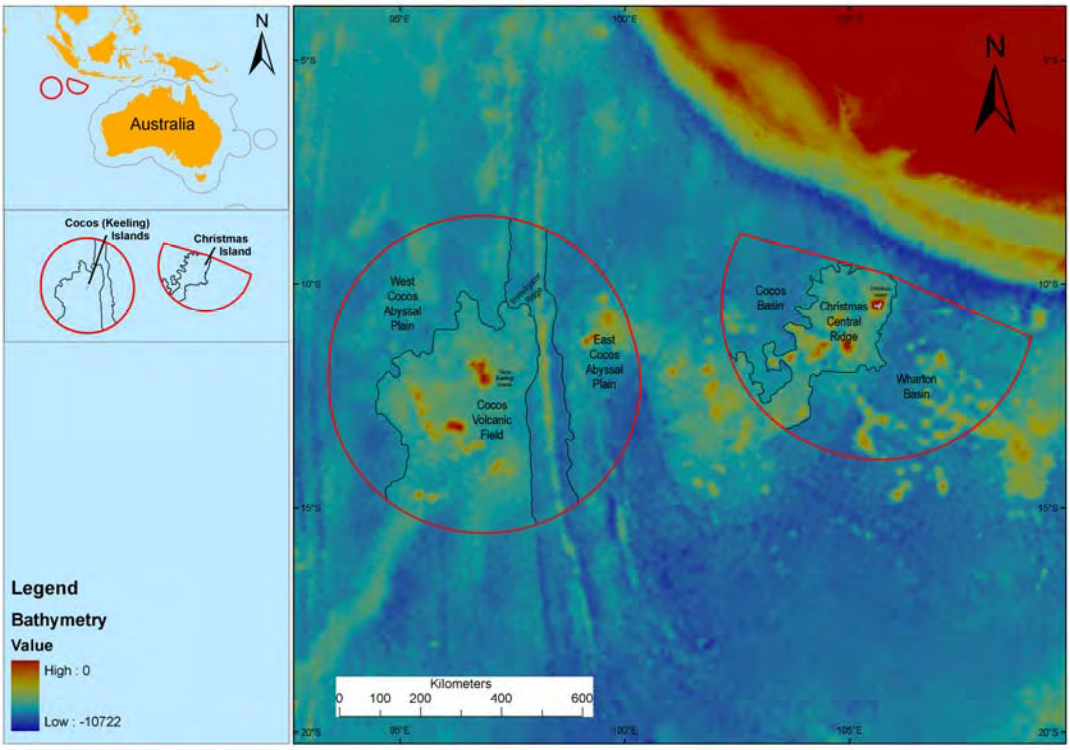


Figure 4-36. Subregions of the Christmas and Cocos (Keeling) Islands territories. A and B (not yet included) give detail of subregion defined as shallow water area surrounding islands.

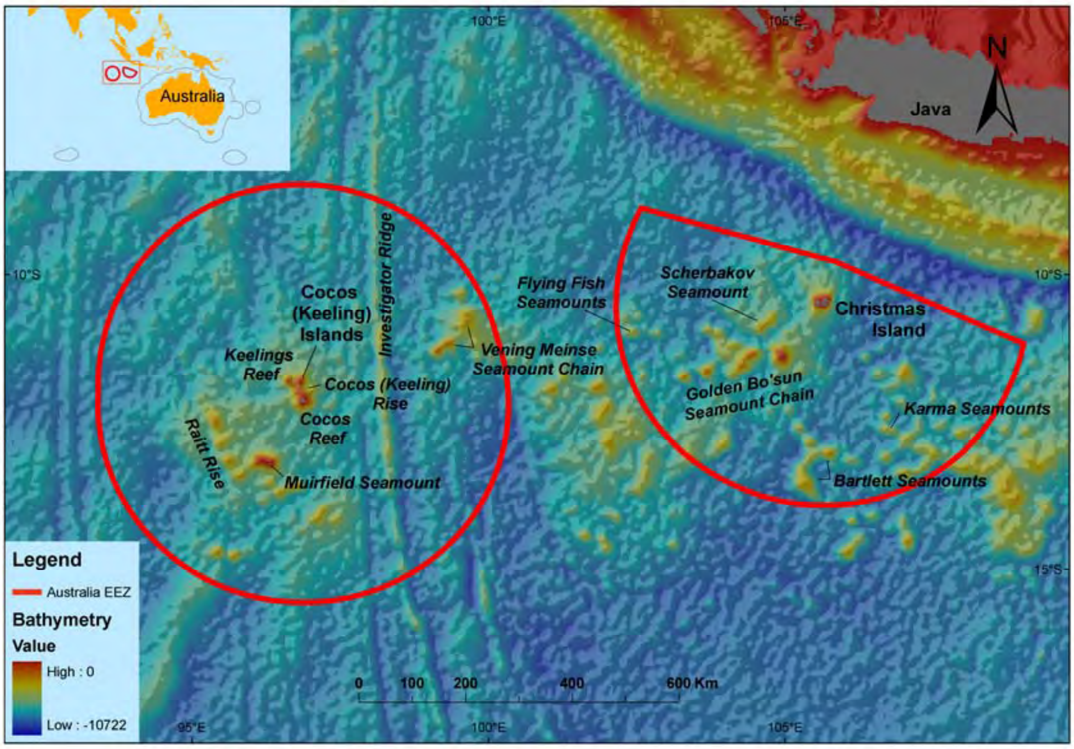


Figure 4-37. Named features of the Christmas and Cocos (Keeling) Islands territories.

Cocos Basin: This occurs to the western side of the Central Ridge subregion and comprises another large area of abyssal plain with a small cluster of deep seamounts on its western boundary. The small cluster of seamounts is similar to those seamounts in the Wharton Basin subregion. However, the Wharton and Cocos Basin subregions warrant separate status based on their separation both spatially and due to the likely barrier effect of the central ridge that occurs between them.

Cocos (Keeling) territory

The area comprising the Australian EEZ around Cocos (Keeling) Islands was divided into four geomorphically and ecologically distinct subregions (Figure 4-36), with the Cocos (Keeling) Islands reef system (or key habitat) treated separately.

Investigator Ridge: The most significant physiographic feature in the Cocos (Keeling) Islands territory is the Investigator Ridge. This continuous north-south trending ridge and associated trenches are likely to support unique marine communities, warranting its separation as a distinct subregion. Its boundaries encompass both the main ridge and adjacent trenches. These trenches are sedimentologically and bathymetrically different to the surrounding abyssal plain. However, at the northern end of the ridge (within the territory) trenches are less developed the boundary has been placed closer to the ridge edge on the eastern side and further from the ridge on the western side.

East Cocos Abyssal Plain: To the east of the Investigator Ridge the EEZ is dominated by abyssal plain, but with an isolated group of seamounts belonging to the Vening-Meinsz chain. This region was designated as the East Cocos Abyssal Plain subregion.

Cocos Volcanic Field: The large cluster of seamounts to the west of the Investigator Ridge has been segregated along the 4,000 m bathymetry line to differentiate the Cocos Volcanic Abyssal Plain subregion. These seamounts include the one on which the Cocos (Keeling) Island and its reef systems have formed. This region was designated as the Cocos Volcanic Field subregion.

West Cocos Abyssal Plain: The remaining area in the west and north of the Cocos (Keeling) Islands territory is physically similar enough to warrant being one continuous subregion, the West Cocos Abyssal Plain subregion. It consists of abyssal plain and basins extending below the 4000 m contour, although with a few isolated seamounts and deeper basins within.

Contrasts in sea water characteristics between subregions

Comparative statistics between subregions were calculated for primary productivity (mg C/m^2) (Figure 4-38), ChlA (mg/m^3) (Figure 4-39), sea surface height (m) (Figure 4-40), sea surface temperature (C^o) (Figure 4-41); and for salinity (ppt), oxygen saturation (mg/l), nitrogen (uM), phosphorous (uM), Silicon (uM) (Appendix A).

Primary productivity was lowest in summer and highest in spring in all subregions and shows a slight lag behind ChlA concentrations in the region. Both parameters are also higher in the more eastern Christmas Island territory. This is also reflected in higher mean nitrogen and phosphorous concentrations in this territory compared to the Cocos (Keeling) Islands territory. Sea surface height also seems to be slightly higher in the more western territory throughout the year.

At depths between 500 and 2000 m silicate concentrations are also higher in the Christmas Island Territory. Although there is a surface peak in mean silicon concentrations in the West Cocos Abyssal Plain subregion compared to all others.

Compared to the broader region, the ChlA concentrations are slightly lower in the Christmas Island Territory than in the offshore NW shelf regions (Brewer *et al* 2007). However, phosphorus and nitrogen concentrations were similar between these regions, with the exception of higher nitrogen at 150 m depth compared to the equivalent NW region depth and lower nitrogen at 500 m compared to the similar environment in the NW continental shelf region. Silicate concentrations were similar between the offshore territories and the NW shelf regions at all depths.

There is little variation in the other parameters (temperature, salinity and oxygen) between the Territories or subregions, with the possible exception of relatively higher oxygen concentrations in the Cocos Volcanic Field subregion at 150 m and 500 m depths, compared to the other subregions.

Influence of cyclones between subregions

Cyclone activity varies considerably between the two Territories with the Christmas Island Territory encountering almost half the cyclone activity as seen in the Cocos (Keeling) Islands Territory (Figure 4-42, Figure 4-43, Table 4-13). These activity rates contrast with the much (up to about ten fold) higher cyclone activity seen along the NW continental shelf (Brewer *et al*., 2007). Since 1952 there have been 27 tropical cyclones which have caused severe wind gusts of at least 90 km/h. On average, this equates to approximately one causing damaging winds every 2 years and one causing destructive winds every 14 years.

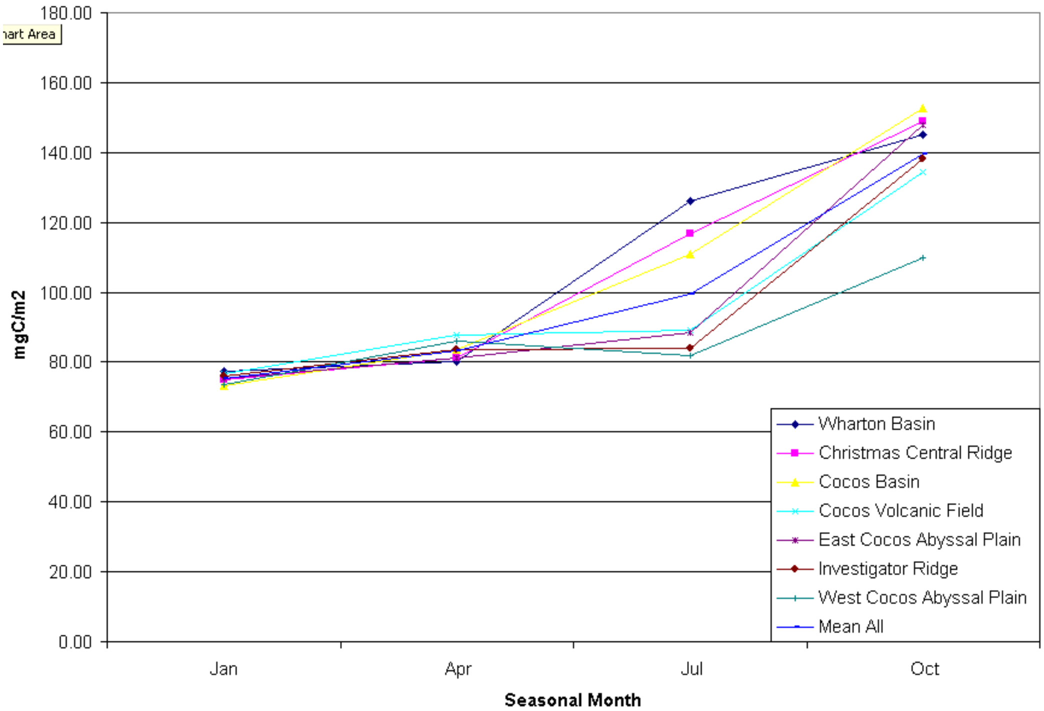


Figure 4-38. Primary productivity for the subregions for the four seasonal quarters. Data sourced from the National Marine Bioregionalisation of Australia (Commonwealth of Australia, 2005).

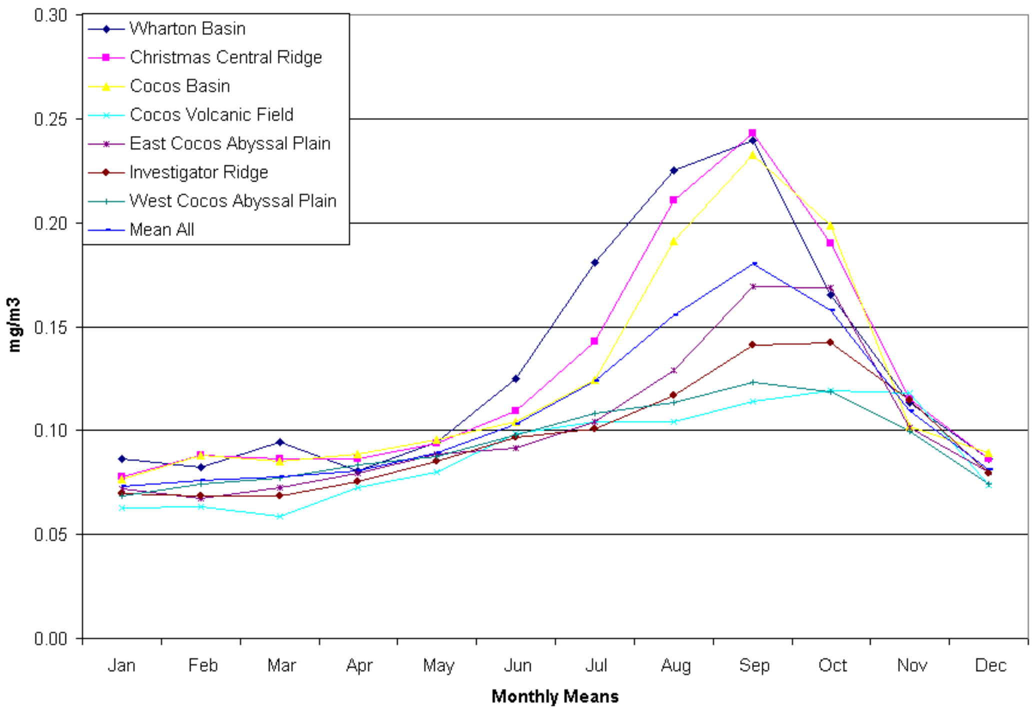


Figure 4-39. ChlA concentrations for the subregions for the 12 months of the year. Data sourced from the National Marine Bioregionalisation of Australia. (Commonwealth of Australia, 2005).

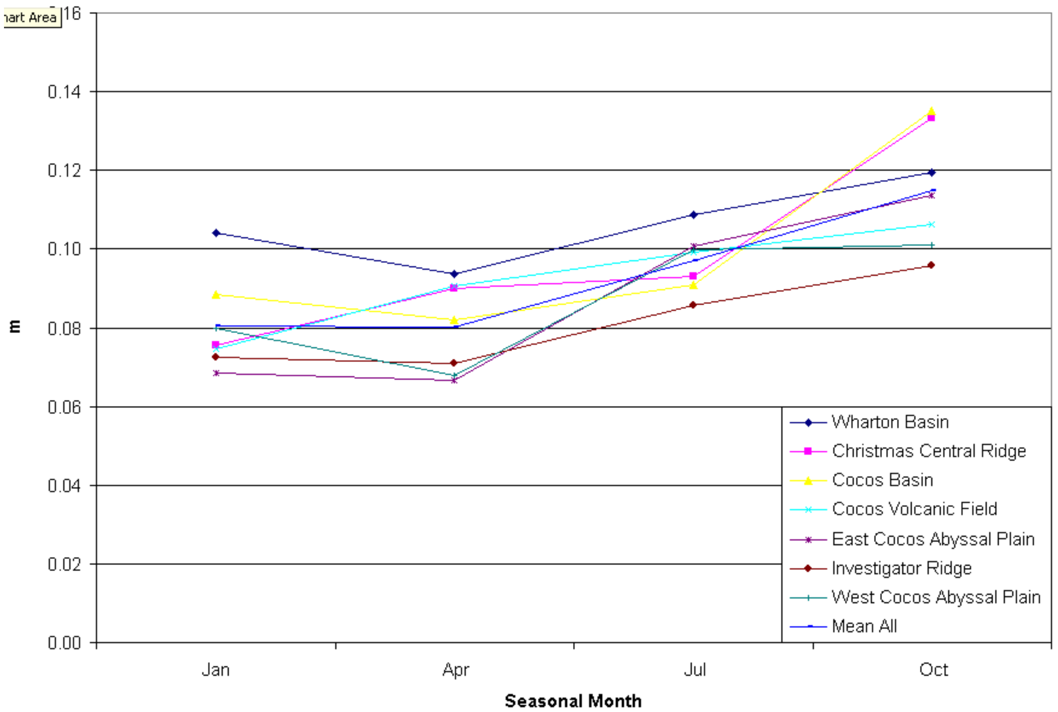


Figure 4-40. Sea surface height for the subregions for the four seasonal quarters. Data sourced from the National Marine Bioregionalisation of Australia (Commonwealth of Australia, 2005).

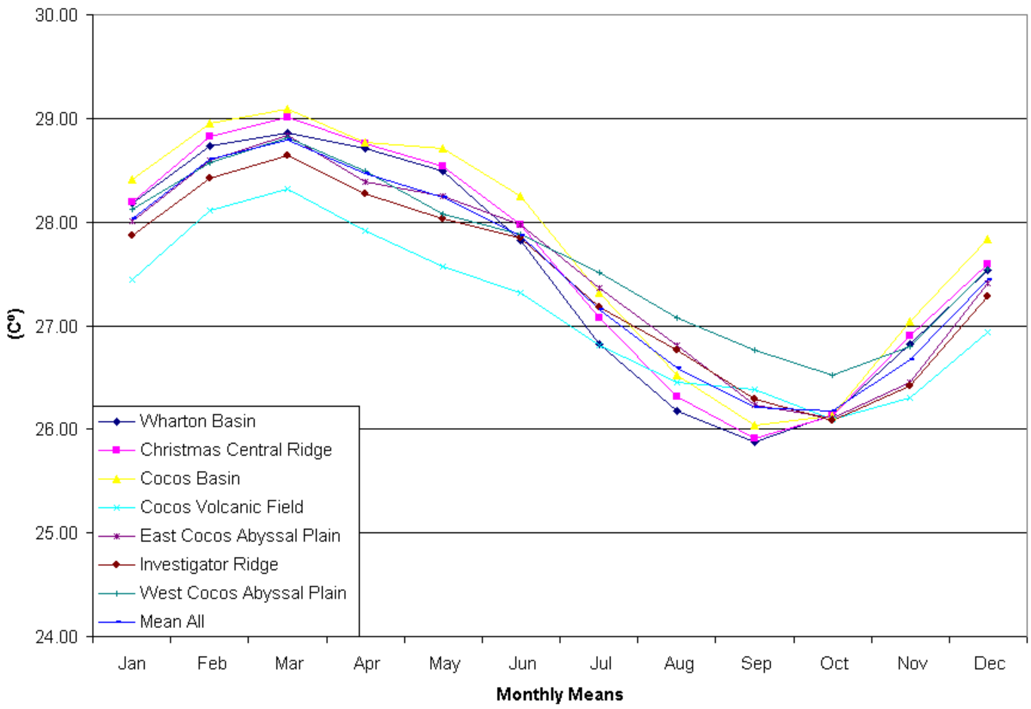


Figure 4-41. Sea surface temperature for the subregions for the 12 months of the year. Data sourced from the National Marine Bioregionalisation of Australia (Commonwealth of Australia, 2005).

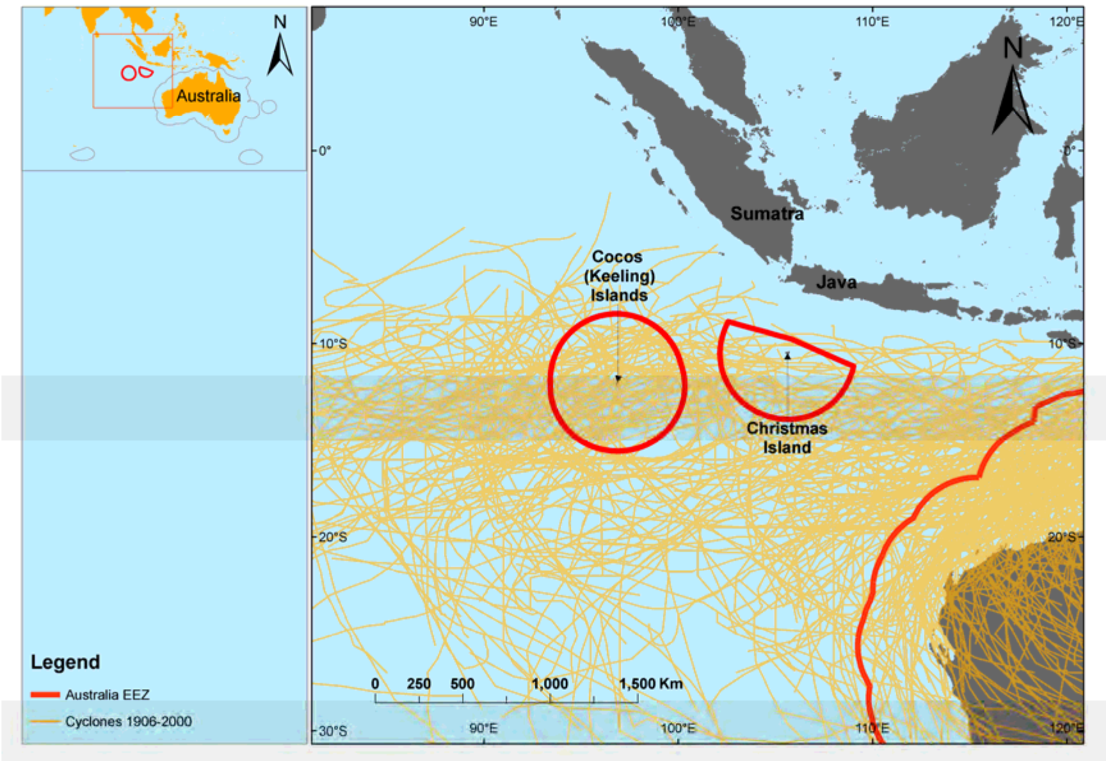


Figure 4-42. Cyclone tracks (1906-2000) for the North West Marine Region. Data derived from Bureau of Meteorology cyclone data.

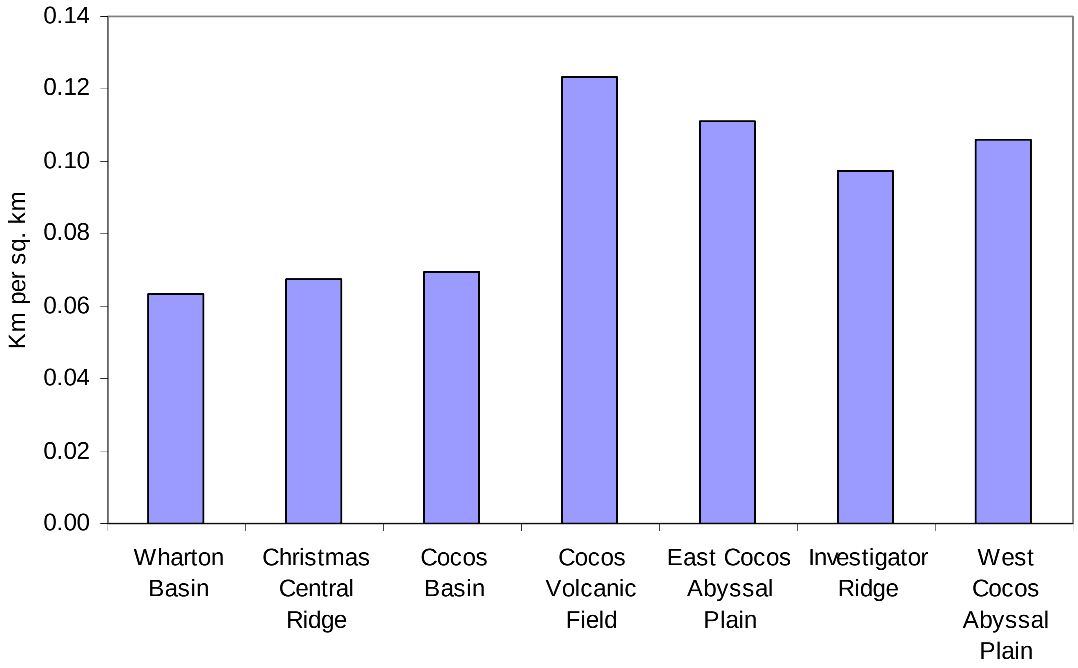


Figure 4-43. Mean annual cyclone activity (1906-2004) for the subregions of the Christmas and Cocos (Keeling) Islands territories, cyclone path per square km within each subregion. Data derived from Met Bureau cyclone data.

Table 4-13. Mean annual cyclone activity (1906-2004) for the subregions of the Christmas and Cocos (Keeling) Islands territories, including number of cyclones and cyclone path per square km within each subregion. Data derived from Met Bureau cyclone data.

Subregion name	Count	Path per sq km per yr (m)
Wharton Basin	33	0.064
Christmas Central Ridge	30	0.068
Cocos Basin	27	0.070
Cocos Volcanic Field	74	0.123
East Cocos Abyssal Plain	57	0.111
Investigator Ridge	62	0.097
West Cocos Abyssal Plain	69	0.106

4.3.1 Christmas Island – Wharton Basin subregion

The Wharton Basin subregion covers an area of approximately 145,500 km² (20% of the Christmas and Cocos (Keeling) Islands territories) and is the most eastern of the Christmas and Cocos (Keeling) Islands territory subregions (Figure 4-44). It is named for the fact that it is made up of the northern part of the broader Wharton Basin that extends to the southeast. It is characterised by deep abyssal regions with numerous seamounts and other features common to the Volcanic Province that extends throughout the Christmas and Cocos (Keeling) Islands territories (Figure 4-45).

Geological and biophysical drivers

Water depths range from 1,823-6,420 m, with more than 90% of the total area occurring in depths >4,000 m, and approximately 4% occurring in depths >6,000 m (Figure 4-46, Table 4-14). This subregion contains some of the deepest habitats in the Christmas and Cocos (Keeling) Islands territories. It contains 25% of the total area of the territories where water depths are >5,000 m and 43% of the area >6,000 m.

Rising from the abyssal plain are numerous seamounts including the Karma and Bartlett Seamounts (Table 4-15, Figure 4-37). Seamount peaks in this subregion occur in water depths ranging from 1,800 m to >5,000 m, although more than 75% of the total area of seamounts occurs in water depths >3,000 m. They vary in height from 100 to >3,000 m.

A total of 33 seamounts occur in the subregion, representing 21% of the total number and 14% of the total area of seamounts in the AEEZ. However, these are generally smaller than those in the adjacent Central Ridge subregion. Most of the Wharton Basin seamounts are conical in shape with steep slopes and roughly 20-30 km diameter and are of late Cretaceous volcanic origin.

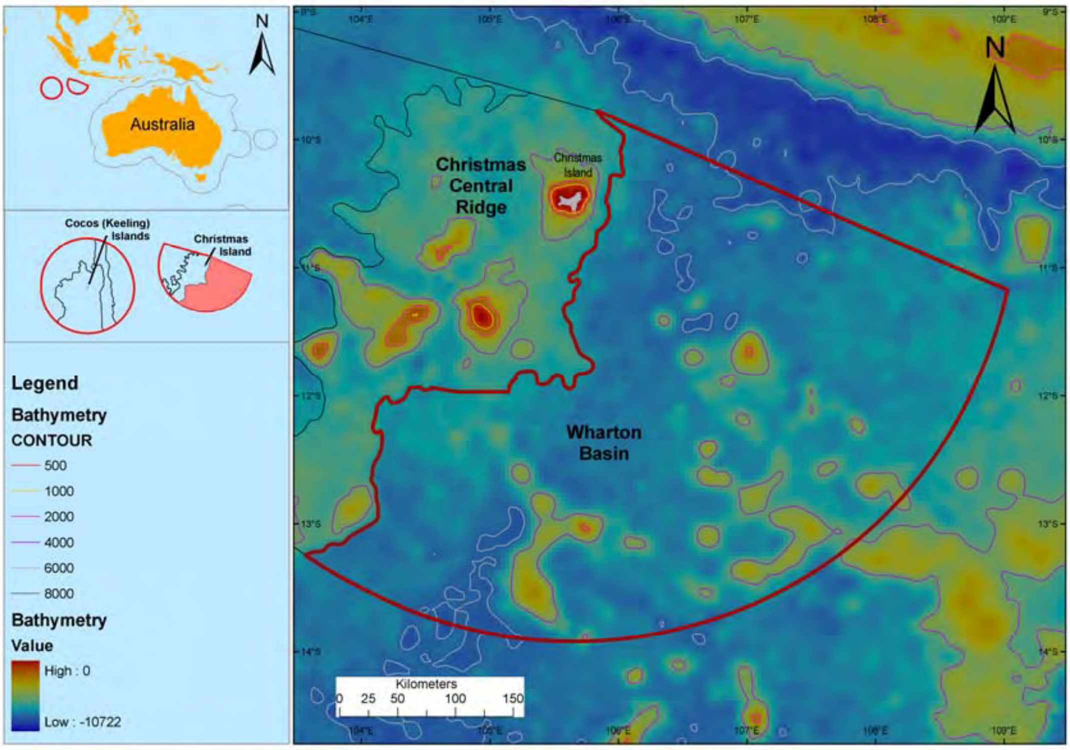


Figure 4-44. Bathymetry of the Wharton Basin subregion.

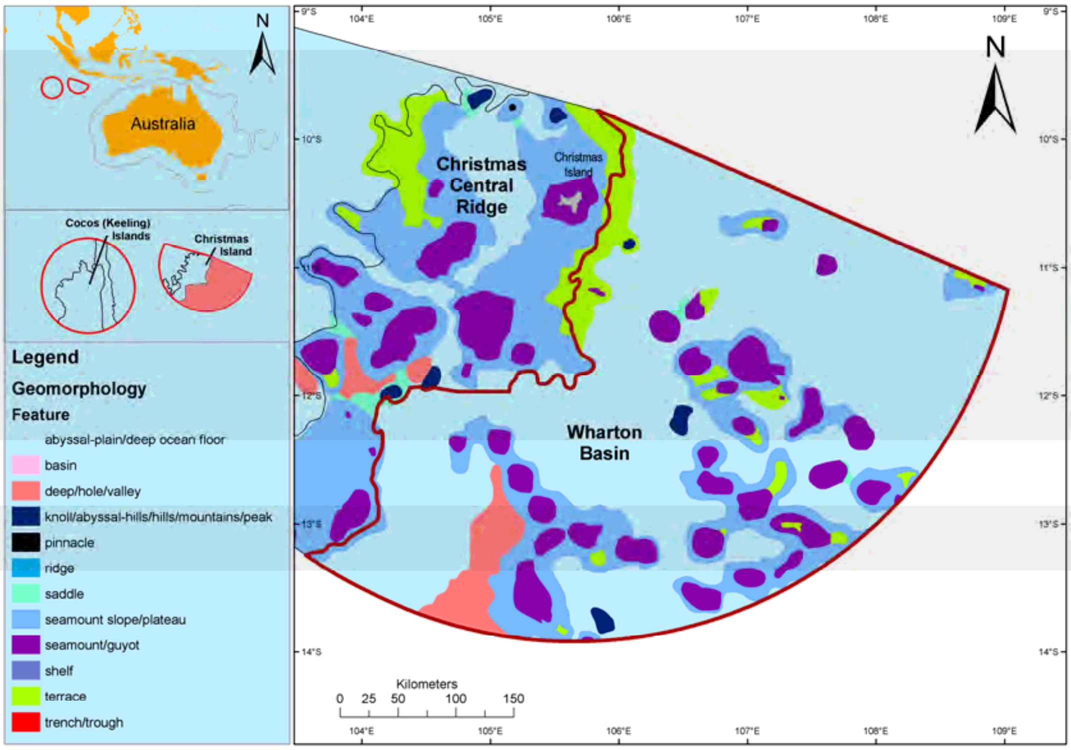


Figure 4-45. Geomorphology of the Wharton Basin subregion.

Table 4-14. Bathymetry characterisation of the Wharton Basin subregion. Bathymetry range for the entire subregion is 1,823-6,420 m (mean 5,220, stdev 679).

Water Depth (m)	Area (km^2)	Percentage area of subregion
1000-2000 m	114	0.1
2000-3000 m	2627	1.8
3000-4000 m	7230	5.0
4000-5000 m	21363	14.7
5000-6000 m	108645	74.7
>6000 m	5500	3.8

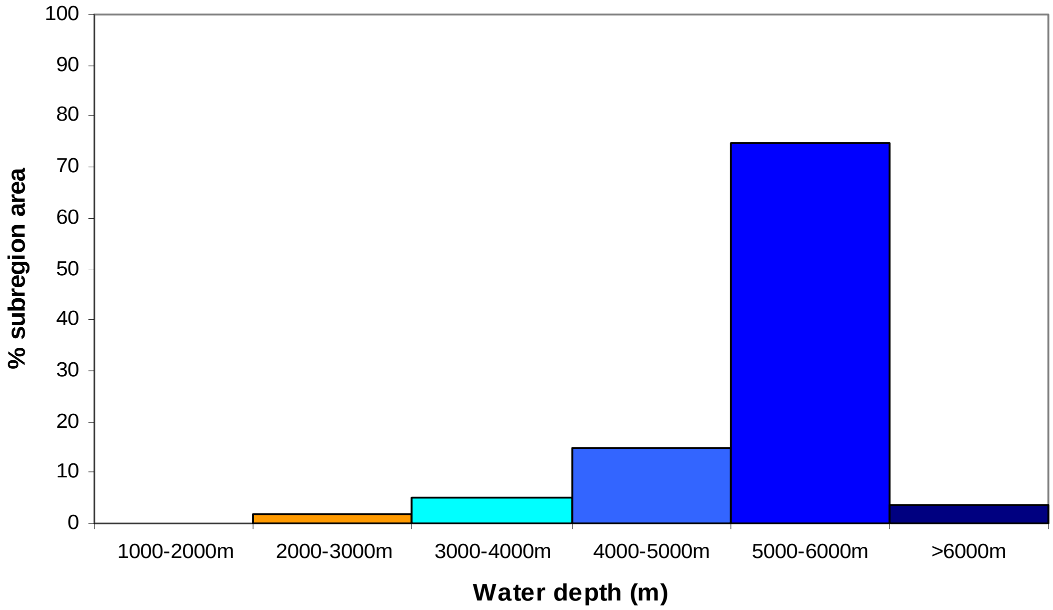


Figure 4-46. Bathymetric characterisation of the Wharton Basin subregion, showing percentage breakdown of the subregion by the area covered for each bathymetry class.

Table 4-15. Water depth within geomorphic features in the Wharton Basin subregion.

Feature	Maximum depth	Minimum depth	Mean depth	STD
Terrace	5820	2720	4990	469
Seamount slope/plateau	6230	2480	4850	584
Seamount/guyot	6000	1820	3840	874
Knoll/abyssal-hills/ hills/mountains/peak	5910	4690	5220	267
Saddle	5980	3600	5210	450
Deep/hole/valley	6230	4900	5950	161
Abyssal-plain/deep ocean floor	6420	3560	5480	285

Topography associated with seamounts, including slopes (22,684 km^2, 8.2%), terraces (5,946 km^2, 4.1%) and saddles (185 km^2, 0.3%), cover approximately 42,900 km (29%) of the subregion. This represents 28% of the total area of seamounts/peaks, 21% slopes, 26% terraces and 19% total area of saddles in the Christmas and Cocos (Keeling) Island territories (Table 4-16). These features are distinguished from areas of similar geomorphology in the Central Ridge subregion by their occurrence in significantly deeper water. A total of 14 of the 33 seamounts have peaks in 2000-3000 m, 9 have peaks in 3000-4000 m, and 8 in >4,000 m water depth.

The remainder of the subregion consists abyssal plain (97,250 km, 67%) occurring in water depths from 3,500 to 6,250 m (Table 4-16). Geomorphic features on the abyssal plain include a single deep/hole/valley (4,600 km^2, 3.2%) and knoll/abyssal hills/mountains/peaks ranging in elevation from approximately 30 - 200 m and covering 760 km^2 (0.5% subregion area).

Water depths of >6,000 m occur in the deep/hole/valley and on the abyssal plain in the north of the subregion where topography is influenced by the adjacent Java Trench. Deep/hole/valleys in the Christmas and Cocos (Keeling) Islands territories are unique to the Wharton Basin and Christmas Island end of the Volcanic Province, and this subregion contains 72% of the total area these features in the Christmas and Cocos (Keeling) Islands territories.

Little is known about the geomorphology of the large expanses of deep abyssal plain that dominate this subregion. Deep abyssal plains, in general, cover approximately 40% of the ocean floor. They are typically covered by silt, mostly deposited from suspended fines derived from the continental margins and the remains of planktonic organisms (marine snow) which sink from the upper pelagic waters. In the case of the Wharton Basin subregion, the vast majority of sediment will be of pelagic origin due to the area’s isolation from continental land masses. These habitats may also contain some scattered regions of hard bottom particularly on the margins at the base of the continental slope.

Between flat areas and major seamount provinces there are areas characterised by small scale roughness, varying sediment thickness (0-200 m) and frequent outcrops of the basement. Abyssal hill heights vary from 30-40 to 200 m. In areas of basement ridges and larger seamounts, the sediments are found only in small pockets between peaks and in narrow gulfs between seamounts.

A total of 10 sediment data points are distributed across the subregion in depths ranging from 2,076 m to 6,000 m (Figure 4-31). Data points cover 4 of the 7 geomorphic features represented in this subregion with the highest densities achieved in water depths of 5,000 - 6,000 m on the abyssal plain and 2,000 - 3,000 m on seamounts. One point is located in each of deep/hole/valley & terrace feature types.

Sediments range from sand-dominated to mud-dominated with little or no gravel detected at any site sampled. This is likely to be a result of sampling bias toward deep water areas located some distance from the base of seamount slopes where gravels are most likely to accumulate. Rock dredges indicate that gravels occur frequently across the region, however in deepwater areas they generally occur in low concentrations and comprise volcaniclastics (pumice) and/or manganese nodules. Nodules are more common in the south and volcaniclastics in the north. This is similar to gravel distribution observed elsewhere on the abyssal plain in the Christmas Island EEZ.

Abyssal plain and deepwater features occurring there generally comprise mud-dominated sediment, except at one site at the foot of a large seamount where sand dominates. Similar sandy environments are likely to occur along the western boundary of this subregion where abyssal plain meets the large seamounts of the central ridge. Gravels sourced from erosion of topographic features (comprising eroded volcanic rock, and possibly carbonates and sedimentary rocks) occur around the base of seamounts/knolls (see rock dredge results below). However, for smaller seamounts/knolls the volume of eroded material and extent of these deposits is expected to be reduced compared to those found around larger seamounts of the Central Ridge. The only large deposits of eroded material are likely to occur around the base of larger seamounts of the central ridge that occur on the western edge of the region.

In areas of basement ridges and larger seamounts, the sediments are found only in small pockets between peaks and in narrow gulfs between seamounts. Sediments sampled from seamount peaks are most commonly dominated by sand, but also contain significant amounts of mud at most sites.

A total of 27 rock dredges have been taken in this subregion (Figure 4-32). These were collected from seamounts and associated slopes, terraces and saddles (14 dredges) and abyssal plain (13 samples). Volcanic rock types (lavas and volcaniclastics) occur across most of the subregion with the exception of some areas of abyssal plain in the southeast of the subregion.

Manganese nodules frequently occur on the abyssal plain in the south of the subregion but is absent from samples from northern areas of abyssal plain. Manganese also occurs on southern seamounts and surrounding slopes in water depths ranging from 3,200 - 4,900 m. Most sites sampled throughout the area in 1992 did not contain manganese nodules (Exon *et. al.* 1993). Distribution of manganese nodules suggests variation in physical conditions on the abyssal plain the north and south of the region. However, it is difficult to define what these differences are. A number of factors can influence nodule formation including water chemistry (including oxygenation of water, often relating to depth) and input of terrestrial sediments. Nodule distribution is the Wharton Basin is likely to be controlled by a combination of factors. Nodule absence in the north of the region may reflect higher rates of terrigenous input due to proximity to Indonesia or greater water depths than occur on abyssal plain to the south. Crusts found are thicker in comparison to an area in the Indian Ocean being mined by the Indian government but carry only moderate grades of economically interesting elements (Cu, Co & Ni).

Carbonate (late Cretaceous shallow water limestone) and sedimentary rocks were collected from two seamounts and their slopes, and carbonate teeth were collected on the abyssal plain near a small abyssal hill in the centre of the subregion, but these rock types were not detected elsewhere.

Table 4-16. Geomorphological characterisation of the Wharton Basin (WB) subregion and comparisons with (i) the total subregion area and (ii) combined Christmas and Cocos (Keeling) Islands (CI & CKI) territory areas.

Feature	**WB subregion areas (km^2)**	**Percent total WB subregion area**	**Percent total area of feature type in CI & CKI territories**
Abyssal-plain/deep ocean floor	97238	66.8	21.3
Seamount slope/plateau	22683	15.6	21.1
Seamount/guyot	13881	9.5	33.8
Terrace	5946	4.1	26.2
Deep/hole/valley	4600	3.2	72.1
Knoll/abyssal-hills/hills/mountains/peak	755	0.5	7.1
Saddle	375	0.3	19.5
Total	**145478**	**100**	

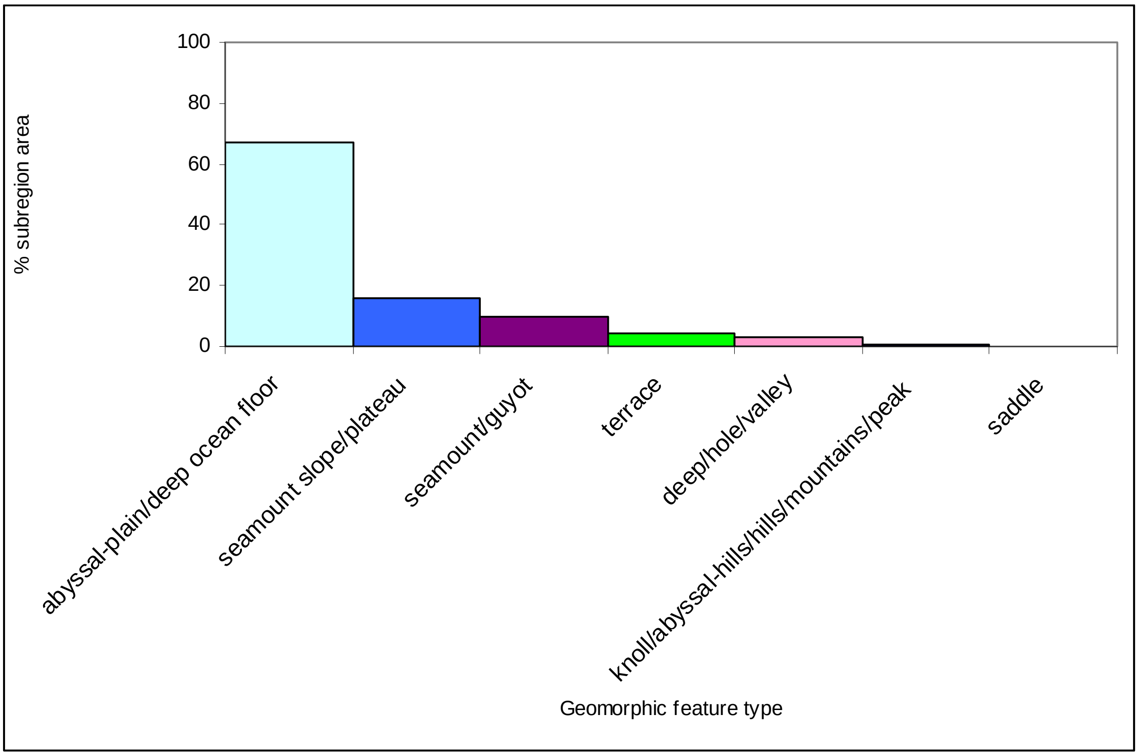


Figure 4-47. Geomorphology of the Wharton Basin subregion, showing percentage breakdown of the subregion by the area covered for each geomorphic feature type present.

Table 4-17. Representation of geomorphic features within the Wharton Basin subregion as a percentage of the total number and area of these features within the entire AEEZ.

Feature	**Percentage (number) of feature in AEEZ**	**Percentage (area) of feature in AEEZ**
Abyssal-plain/deep ocean floor	23.5	4.2
Seamount slope/plateau	39.1	20.2
Seamount/guyot	21.2	13.8
Terrace	11.4	1.04
Deep/hole/valley	0.4	2.70
Knoll/abyssal-hills/hills/mountains/peak	2.5	0.65
Saddle	8.3	0.19

Ecological processes, habitats and biodiversity

The surface waters of the Wharton Basin subregion appear to mostly fall under the influence of the Indonesian Throughflow, the SE and NW monsoonal winds and their impact on upwelling from Javanese coastal waters (see 4.1.4). This system produces a cooler, more productive pelagic environment in winter and spring and a warmer, oligotrophic pelagic environment in summer and autumn.

The subregion has the highest level of primary productivity of all the subregions (Figure 4-14, Figure 4-15, Figure 4-16) based on its proximity to the ChlA plumes generated by upwelling off the South Java coast during spring (July-Oct) and transported into the territory by winds, currents and eddies (see 4.1.4). During summer the more oligotrophic conditions where nutrient recycling processes are important in maintaining standing crops of nanoplankton feeders. During theses times the deep ChlA maxima (~70-100 m depth) is likely to be a critical habitat for the larvae of many species and in turn a feeding zone for larger predators.

The main tertiary consumers in the subregion include local or migrating populations of pelagic fish such as southern bluefin tuna (SBT) (*Thunnus maccoyii*), sharks, trevallies, tunas, scads, wahoo and foraging seabirds that either migrate seasonally or range through the system following schools of small pelagic fish. SBT spawning grounds occur in this region and include the Christmas Island territory and areas to the east (Figure 4-49). The larvae of these tuna hatch during the period of peak primary productivity in spring and summer, when they can feed on the plankton and micronekton that are more abundant at this time. They are transported towards the Australian coast in the South Java Current during the NW monsoon, then in the warm waters of the Indonesian Throughflow and Leeuwin Currents into southern Australia where they are ultimately fished by Australian and New Zealand fisheries (Figure 4-49). The spawning adults are fished in the NE Indian Ocean by a range of fishing fleets from Japan, Korea, Taiwan and Indonesia. The historical Japanese longline catches also indicate that this subregion is a region of relatively high pelagic productivity (reflected in high biomass of pelagic fish) (Figure 4-50).

The hard substrates that occur on seamounts within the southern sections of the subregion are likely to provide surfaces and topographical structure for recruitment and growth of passive, sessile, epi-benthic suspension feeders (Genin *et al.*, 1986) such as deep sea corals, sponges, crinoids, ascidians and bryozoans. These communities provide habitats for a range of demersal deep water squids, crustacean and small fishes (e.g. lanternfishes and Myctophidae and small, bioluminescent species that may vertically migrate), which are prey for larger cephalopods and fish including grenadiers (*Macrouridae*) hatchetfish (*Argyropelecus* spp.) (Richer de Forges, 2000; Hixon and Beets, 1993; Norse and Crowder, 2005).

Most of the seamounts within the subregion are relatively deep (>2000 m) and the deeper seamounts (>3000 m) are a unique feature of this subregion. Little is known about the communities that live on the tops and slopes of these seamounts. However, it seems likely that their unique position in the water column, and geographically, will support unique benthic and demersal communities.

These features are mainly under the influence of deeper, slow-moving but widely distributed water masses. The water column characteristics of the area are probably also unique due to the influence of the higher productivity waters that occur in the area, particularly in spring.

Bottom currents are forced around the contours of the seamounts and ridges, forming counter-rotating vortices on the upstream and downstream flanks. In the shallower seamounts (rising to within 2000 m of the surface) this action can lead to the formation an eddy on the slope of the seamount or one directly above the seamount, known as a Taylor column (Koslow, 2007). These contain a relatively high biomass of plankton and micronekton. Therefore, the eddies, by their nature are an important food source for tertiary consumers such as tuna and other pelagics (Young *et al.*, 2001; Young *et al.*, 2003; Landsell and Young, 2007).

The depth of the calcite compensation depth is a key determinant of sediment types and hence any biological communities. The relatively low nutrient/productivity of the pelagic environment in this general region (e.g. compared to the NW shelf) may result in a relatively low biomass of benthic communities. These deep, abyssal demersal environments are largely reliant for their energy input on falling detritus or particulate organic matter (marine snow) and the occasional large carcass directly supplied by the pelagic environment. However, productivity flows between the pelagic and demersal environment in this subregion are generally limited. Much of the detrital energy is cycled through bacterial-detrital food webs. Other components of these benthic communities include a range of infauna (meiofauna and microfauna) including filter-feeders and detritivores. Few species will migrate between the pelagic and benthic environments.

Given the area is influenced by the South Java Current and other dynamic oceanographic conditions, we expect there to be a high level of connectivity with other areas within the Christmas and Cocos (Keeling) Islands territories, and the neighbouring slopes of the Australasian continental slopes to the east; in particular, within the shallower water mass layers where connectivity between subregions is greatest.

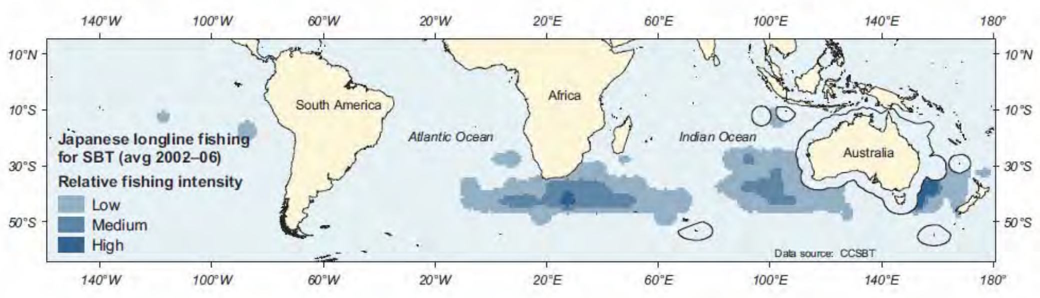


Figure 4-48. Spatial patterns of fishing of Southern Bluefin Tuna by Japanese longlines, 2002 to 2006 (AFMA/BRS data).

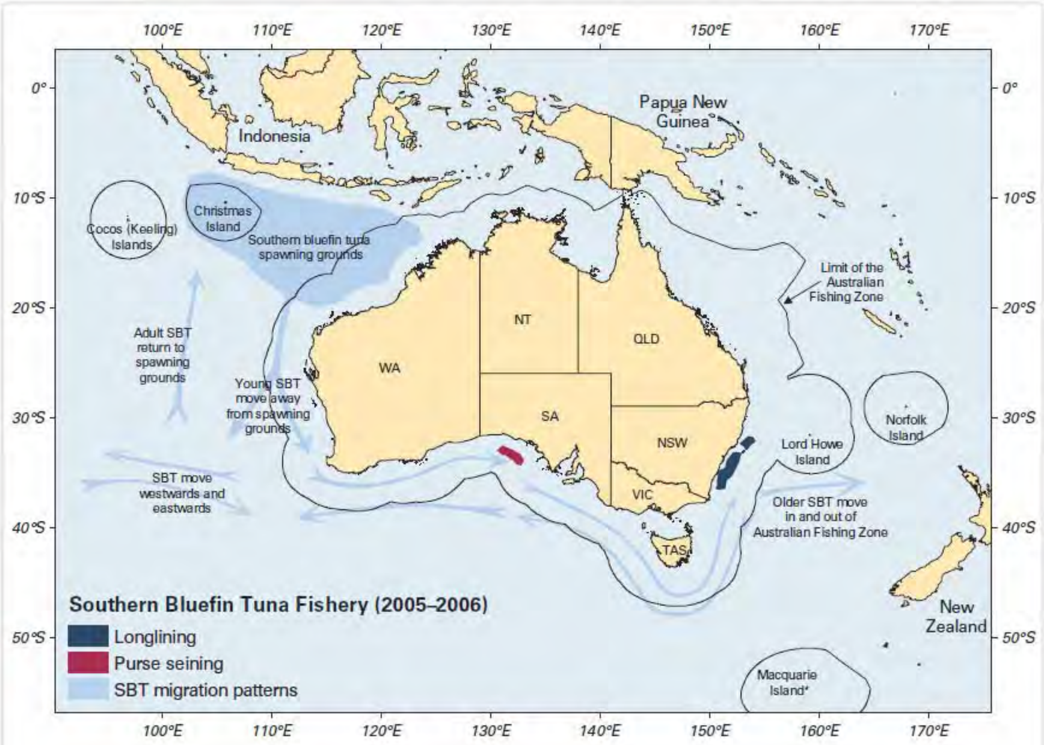


Figure 4-49. Southern bluefin tuna distribution and movements (BRS Status reports, 2007).

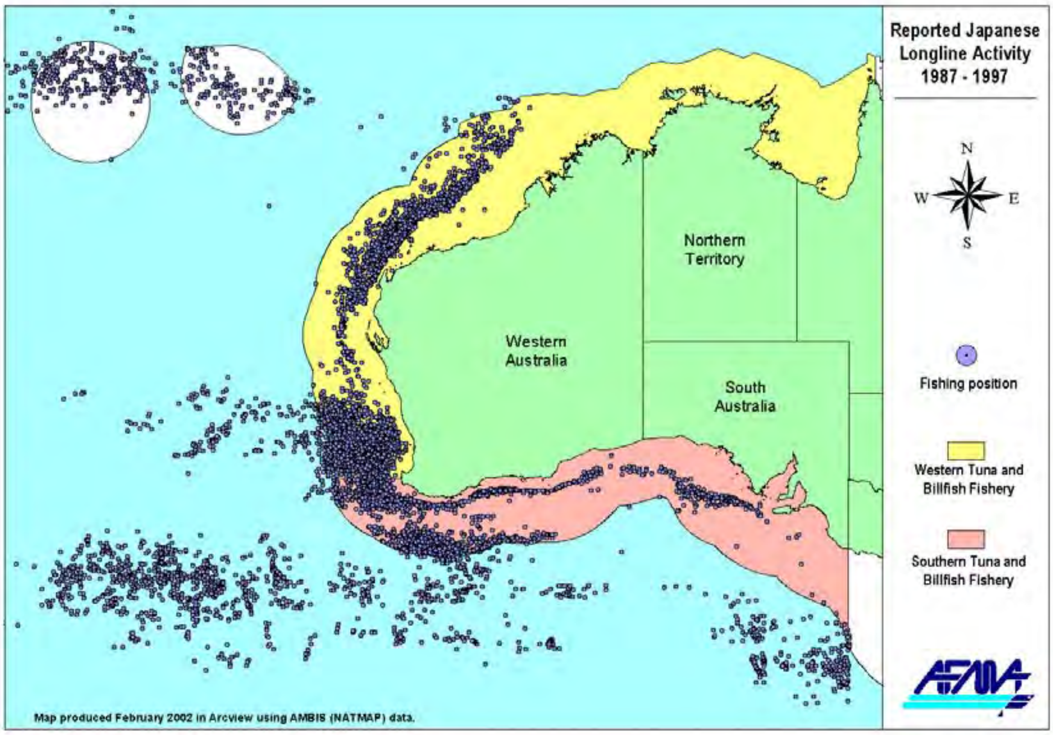


Figure 4-50. Historical Japanese longline effort distribution indicating regions of high pelagic fish biomass.

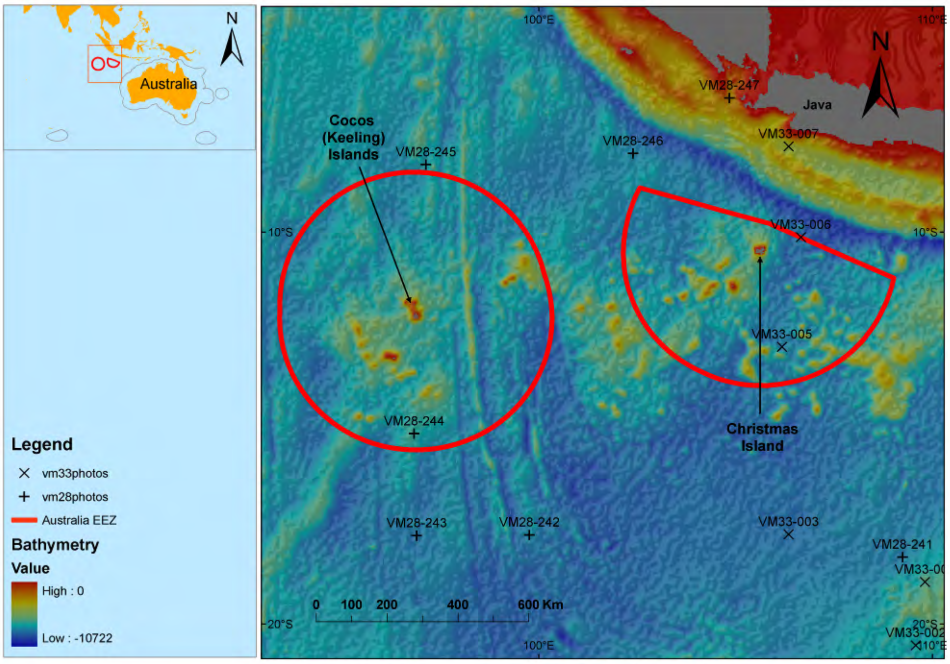


Figure 4-51. Location of benthic photographs from Russian cruises carried out in 1971 and 1976. Most of the photos are of benthic habitats around 3000 m water depth. For full details of photos location, depth and benthic components, see Appendix B.

Assessment of conservation values

The Wharton Basin subregion contains a range of features with potentially high conservation value. The subregion is relatively remote and has had little human disturbance with the exception of variable levels of pelagic fishing effort over recent decades. The waters are included in the Western Tuna and Billfish Fishery. However, little fishing effort or illegal, unregulated and unreported (IUU) fishing currently occurs in this region due to navy patrolling in the region. The mid-water and benthic environments are largely undisturbed. None of the subregion is currently protected other than through fishing effort regulation.

This subregion is likely to have a range of biogeographically unique characteristics. The broader region contains a unique complex of water mass and current interactions in the surface layers. Of the two NW external territories, primary productivity is highest in the Wharton Basin subregion due to its proximity to seasonal upwelling forced by the local climate and oceanographic conditions. This productivity is reflected in fishery catches for large pelagics, in domestic and international fleet statistics, and is probably related to the location of SBT spawning behaviour. However, little is known about most of the other species groups in these environments and the impact on this productivity on communities in the deeper water masses.

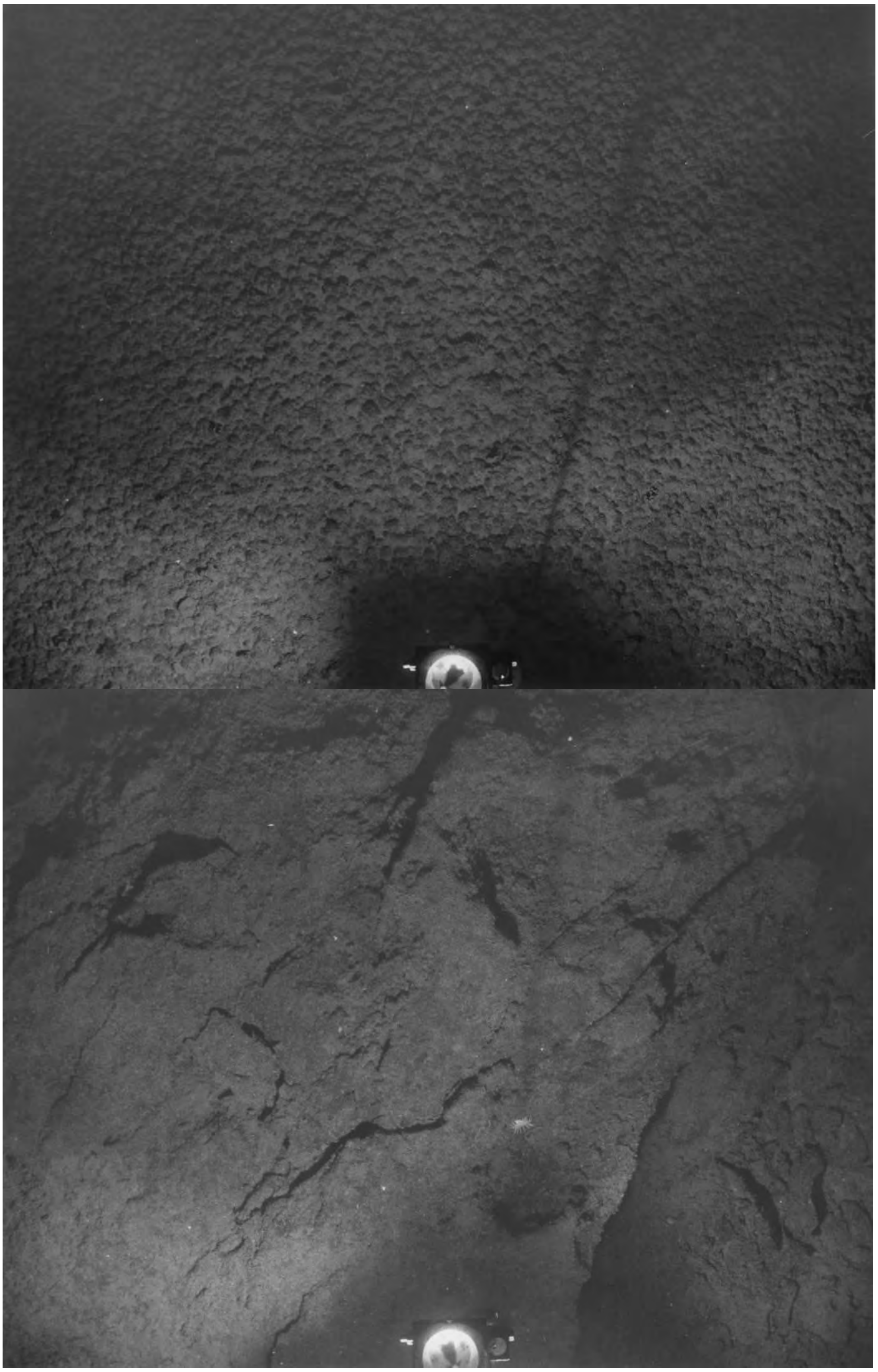


Figure 4-52. Photographs of the benthic habitat at location VM33-005 showing manganese nodules and rocky substrate (depth 2982 m).

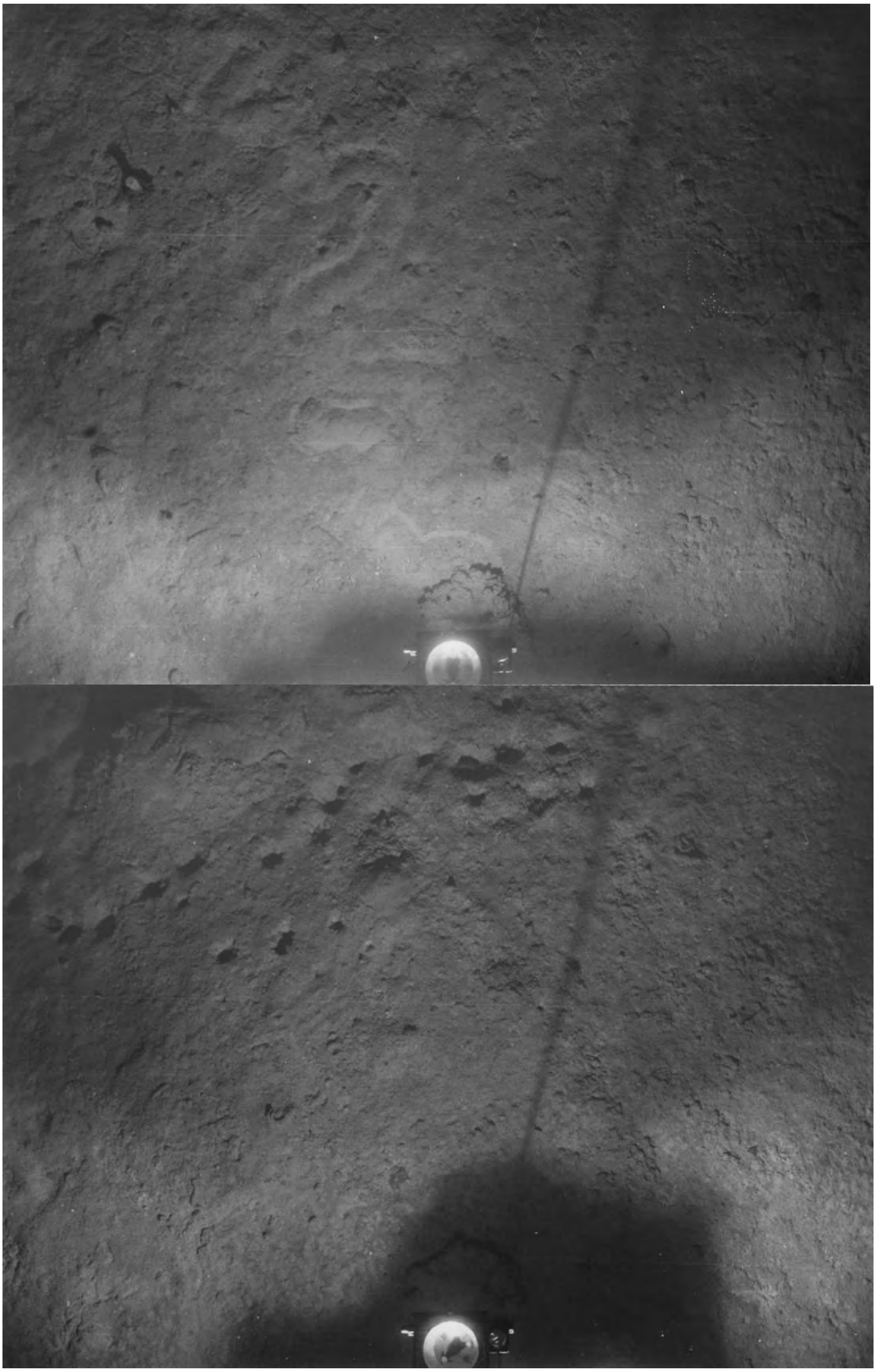


Figure 4-53. Photographs of the benthic habitat at location VM33-006 showing soft sediment substrate (depth 3175 m).

The 33 seamounts found in the Wharton Basin subregion are largely conical with steep slopes and represent 14% of all seamounts in the Australian EEZ (and 34% of seamounts (or guyots) with the Christmas and Cocos (Keeling) Islands territories). Furthermore, most are deep water seamounts extending to greater than 4000 m of the surface and these represent half of the deeper water seamounts (> 4000 m) in the Australian EEZ. These habitats are quite unique in that sense, and although little is known of the ecological communities on the deep seamounts, they are likely to support unique communities on a regional and national scale. Although species richness and biodiversity levels on these seamounts are largely unknown, our knowledge of seamounts communities (in general) and the unique combination of their geographic location and depth (and associated water mass and substrate properties) suggest that the Wharton Basin seamounts are ecologically unique and significant in a local and national context.

This subregion is dominated by abyssal plain (67%) including some of the deepest areas within the AEEZ. It contains almost half (43%) of the deepest abyssal plain environments (>6000 m) and most of the deep/hole/valley environments (72%) within these two territories. These deeper environments are also likely to have sparse, but unique community types associated with them.

There are a range of species that are listed (under the EPBC Act) that either use the Wharton Basin region as a foraging ground or other habitat, or are likely to (see 4.1.5). However, most of the sightings for species such as whales, dolphins, seabirds and turtles are made from either Christmas or Cocos (Keeling) Islands, or vessels in close proximity to these islands. So it is difficult to know, in most cases, how intensely these species use the Wharton Basin subregion.

Threats

Changes in climate may influence the dynamics and strength of the monsoon winds and current patterns which may change the mixing and upwelling regime in this subregion. This may influence pelagic productivity and to some extent benthic productivity. The deeper environments are low energy, stable nature, and likely to have relatively narrow physicochemical tolerances.

Climate change induced alterations to ocean currents such as the South Java Current, will potentially impact connectivity and nutrient dynamics of the seamounts in the region. Ocean acidification will impact on planktonic populations for calcifying organisms, and will likely result in changes to zooplankton species composition. Phytoplankton will also be affected, primarily through nutrient cycling mechanisms. The full impact of these changes is largely unknown, but likely to be significant.

Other climate impacts include warming seas (+1.8°C by 2070, Maunsell Climate impacts report) and potentially stronger (though less frequent) cyclones. These changes are unlikely to have a significant impact on the communities of this subregion.

The seamount and abyssal plain environments both contain manganese nodule habitats. These habitats are mined in other parts of the world (e.g. at lower ore concentration levels in Indian Ocean abyssal environments). However, the associated communities are poorly understood, but likely to be highly sensitive to physical disturbance, with very long recovery time frames.

The Wharton Basin area is a known fishing ground for larger SBT, with the Japanese fishing fleet having low levels of effort in the area to the west of the Christmas Island territory (Figure 4-50). The sustainability of this fishing pressure has been questioned in the past and fishing vessels entering the AEEZ waters to target SBT may be a significant risk to these and associated populations.

4.3.2 Christmas Island – Central ridge subregion

The Central Ridge subregion covers an area of approximately 69,220 km² (9% of the Christmas and Cocos (Keeling) Islands territories) and sits in between the Wharton Basin and Cocos Basin subregions (Figure 4-36). It has been differentiated and characterised by a shallow seamount chain that forms part of the volcanic province within the broader Wharton Basin (Figure 4-9, Figure 4-54, Figure 4-55). Unlike the more isolated seamounts found in the neighbouring subregions, these seamounts are extensively connected by shallower habitats, forming a unique subregion within the context of these external territories and broader Australian EEZ.

Geological and biophysical drivers

Water depths in the subregion range from 0-5,800 m, with 80% of the total area occurring in depths >4000 m, and <5% in depths <2000 m (Figure 4-54, Figure 4-56). The subregion is dominated by volcanic topography (47,249 km, 68% of the subregion area) and including minor areas of adjacent abyssal plain (13,154 km, 19% of the subregion area) to the south east (Wharton Basin) and northwest (Cocos Basin) (Figure 4-56, Figure 4-57). This is the only subregion in the Christmas and Cocos (Keeling) Islands territories that is not dominated by abyssal plain/deep ocean floor.

Relative to other subregions in the Christmas and Cocos (Keeling) Islands territories, the Central Ridge contains 28% of the total high relief volcanic topography (seamounts/guyots), 32% of all slope environments, 26% of the terraces, 76% of the total area of saddles and the only pinnacle in the Christmas and Cocos (Keeling) Islands territories (Table 4-20).

There are a total of 8 large (>25 km diameter) and 11 small seamounts occur within the subregion, representing approximately 12% of the total number and 11% of the total area of seamounts in the Australian EEZ. These include the Golden Bo'sun Seamount Chain, the Karma Seamounts, Bartlett Seamounts, Flying Fish Seamounts and Scherbakov Seamount (Figure 4-36). The seamounts in this area are frequently above 2,000 m below sea level and have an average diameter of 40-50 km. The importance of the volcanic topography in this subregion is further demonstrated by the seamount slope and plateau features which make up about half of the subregion, but also constitute about one third of all seamount slope and plateau features in the Australian EEZ.

Seamount morphology within the subregion varies, although most have steep slopes and narrow peaks. Some large terraces (5,820 km, 8.4%) also occur on these seamount slopes (Figure 4-55). Excepting Christmas Island, the highest seamount peaks reach within 1,000 m of the sea surface (Figure 4-54). Lesser peaks and terraces/plateaus associated with volcanic topography occur in water depths up to 5,300 m (Table 4-19).

Much of the abyssal plain in this subregion represents the base of slope environments, often isolated and protected from ocean currents by surrounding elevated areas. Water depths on the abyssal plain and features occurring in this subregion range from approximately 4,000-6,000 m, but do not exceed 6,000 m (Table 4-19). This is relatively shallow compared to adjacent abyssal plains of the Wharton (5,500-5,700 m) and Cocos (4,600 - 5,400 m) Basins.

Geomorphic features occurring on the abyssal plain include knoll/abyssal hills/mountains/peaks (1629 km, 2.4%), Deep/hole/valleys (1,337 km, 1.9%) and saddles (1,471 km, 2.1%) (Figure 4-55). The deep/hole/valley geomorphological features represent 21% of these environments area in the Christmas and Cocos (Keeling) Islands territories, which are restricted to the Wharton Basin and Christmas Island end of the volcanic ridge.

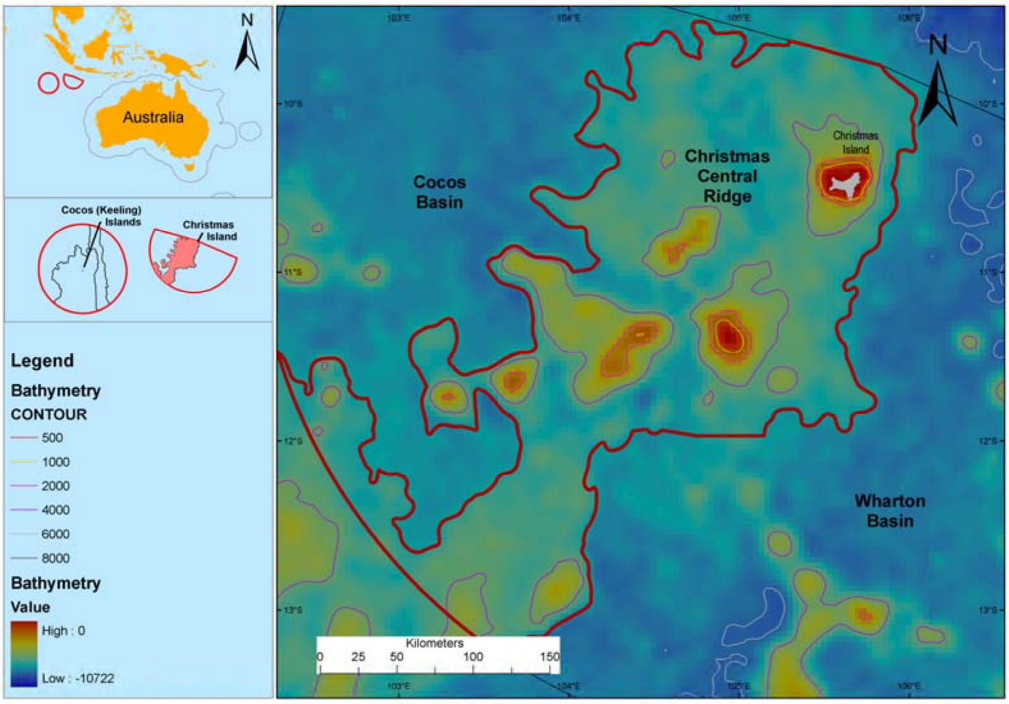


Figure 4-54. Bathymetry of the Central Ridge subregion.

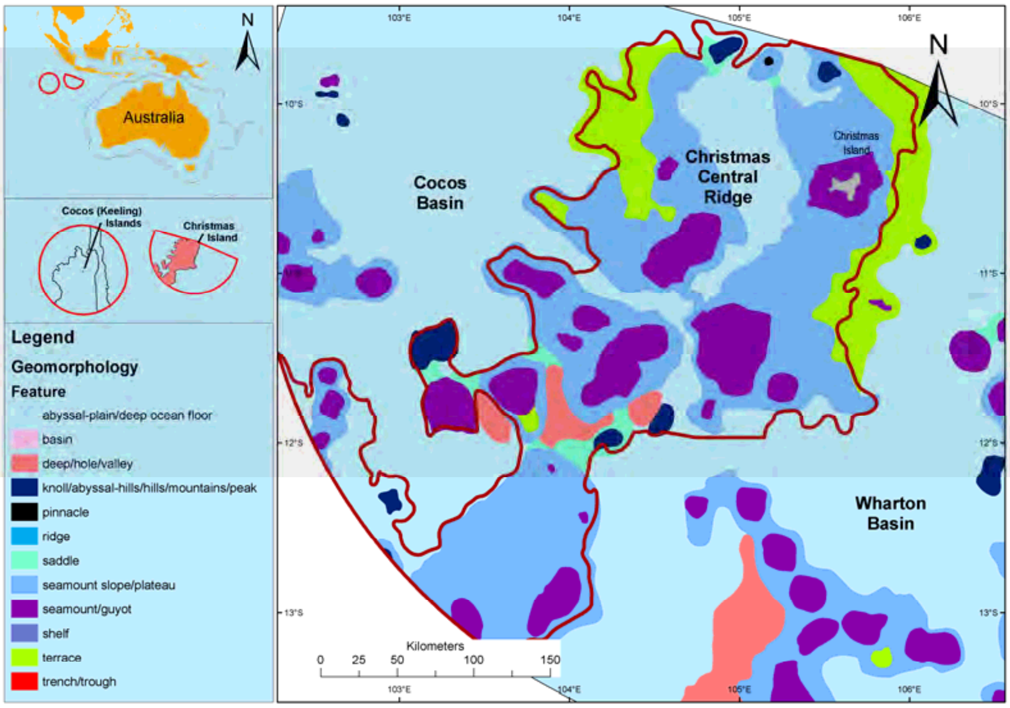


Figure 4-55. Geomorphology of the Central Ridge subregion.

Table 4-18. Bathymetry characterisation of the Central Ridge subregion. Bathymetry range for the entire subregion is 0-5,823 m (mean 4,352, stdev 800).

Water depth (m)	Area (km^2)	Percentage area of subregion
Coastal/land	140	0.2
0-500 m	93	0.1
500-1000 m	112	0.2
1000-2000 m	1615	2.3
2000-3000 m	3124	4.5
3000-4000 m	8300	12.0
4000-5000 m	49812	72.0
5000-6000 m	6021	8.7

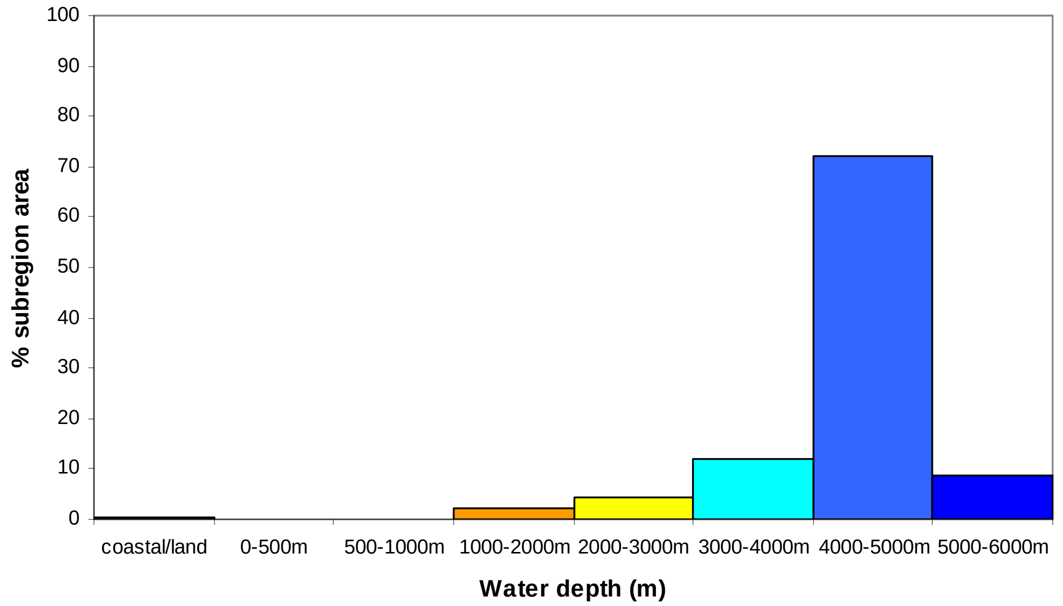


Figure 4-56. Bathymetry characterisation of the Central Ridge subregion, showing percentage breakdown of the subregion by the area covered for each bathymetry class.

Table 4-19. Water depth within geomorphic features in the Central Ridge subregion.

Feature	Maximum depth	Minimum depth	Mean depth	STD
Abyssal-plain/deep ocean floor	5930	4210	5130	282
Deep/hole/valley	5870	4510	5180	270
Knoll/abyssal-hills/ hills/mountains/peak	5280	4190	4740	219
Pinnacle	4620	4470	4520	36
Ridge	3580	0	1640	845
Saddle	5410	4210	4830	176
Seamount slope/plateau	5810	0	4400	476
Seamount/guyot	5330	0	2960	1055
Shelf	200	0	80	83
Terrace	5744	2860	4980	252

A total of 13 sediment data points are distributed across the region (Figure 4-31). These occur in water depths ranging from 500 to 5,000 m, although highest densities are achieved in 4,000-5,000 m (lower seamount slope/plateaus) and 2,000 – 3,000 m (seamounts). No samples occur on the abyssal plain (19% of the subregion). Sediment samples indicate sediment texture ranges from homogeneous mud to gravel (volcanic rocks and coral pebbles) with only minor mud or sand present. Sediment texture is highly correlated with water depth (Figure 4-31), with sand-dominated sediments generally restricted to water depths <3000 m, and mud-dominated sediments to deepwater (4000-6000 m). Gravels are common on seamounts and their slopes, and dominate sediment at one location in <1,500 m water depth in proximity to Christmas Island. Seamount peaks, associated terraces and seamount slope/plateaus comprise both steep rocky outcrop and areas of sediment accumulation. Sediments on seamount peaks are generally dominated by sand, while samples from lower slopes are more often dominated by mud.

Samples from the abyssal plain adjacent to seamounts are frequently sand-rich to sand-dominated, with gravel present. Large volumes of debris including large blocks of rock can also be identified in this area in high resolution multibeam bathymetry data, as it contrasts strongly with generally fine-grained sediments found elsewhere on the abyssal plain. Accumulations of coarse sediment and rock results from erosion and transport down conduits in seamount slopes. These areas are likely to represent significantly different physical habitats from elsewhere on the abyssal plain due to seafloor sediment character and frequency of disturbance from down-slope sediment transport.

A total of 22 rock dredge samples were taken in this subregion (Figure 4-32). These have been collected from seamounts and associated slopes, plateaus, terraces and saddles (18 dredges) and abyssal plain that occur between these features (4 dredges). Similar rock types were found across most of the volcanic topography (lavas and volcaniclastics) and extending onto areas of abyssal plain. Carbonate and sedimentary rocks were common on seamounts and seamount slopes, but absent on the abyssal plain. Manganese nodules and/or crusts were found at all except one location sampled on the abyssal plain. They were also found less frequently on volcanic topography in the south of the region in water depths exceeding 2,500 m. Manganese nodules also occurred in sediment samples from this area, forming a minor component of one sample from a seamount peak and another from the abyssal plain at the base of a seamount slope. Rock types dredged from seamounts suggest that hard substrates on seamounts are most commonly volcanic rock types of variable texture (lavas, pillow lavas), with less common carbonate (relict reefs) and sedimentary rocks.

From geological sampling, it has been determined that the seamounts in the area are late Cretaceous in age and consist of alkali-olivine basalt and trachyte consistent with formation by a hotspot. Associated rocks are mixed sediments consisting of rounded hyaloclastic and volcaniclastic grains set in carbonate. They are situated on a large uplifted block 800-1,000 m above the abyssal plain floor, and have a NE-SW trend along fracture zones. There is also a large number of smaller mounts on this plateau. This is an area of divergent upwelling (which probably existed as far back as the Miocene).

Sediment thickness in the Christmas Island area ranges from (east-west) 100 to 400-500 m. The lack of sediments (usually <200 m thick) on the Christmas Island rise indicates that prospects for hydrocarbon accumulation are poor in the area surrounding Christmas Island. Though there was some iron mineralisation discovered in one site from the DSDP, it is not likely to be widespread and is also at water depths and distance beneath the sea floor which would make recovery uneconomic (Jongsma 1976).

Slopes on the flanks of the rise average between five and eight degrees. It is possible that the Christmas Island rise was formed as a mid ocean spreading ridge and that the uplifted block is a fragment of this ridge.

Table 4-20. Geomorphological characterisation of the Central Ridge (CR) subregion and comparisons with (i) the total subregion area and (ii) combined Christmas & Cocos (Keeling) Islands (CI & CKI) territory areas.

Feature	**CR subregion areas (km^2)**	**Percent total CR subregion area**	**Percent total area of feature type in CI & CKI territories**
Seamount slope/plateau	34161	49.4	31.8
Abyssal-plain/deep ocean floor	13153	19.0	2.9
Seamount/guyot	11430	16.5	27.9
Terrace	5823	8.4	25.7
Knoll/abyssal-hills/ hills/mountains/peak	1629	2.3	15.4
Saddle	1470	2.1	76.3
Deep/hole/valley	1337	1.9	20.9
Land	154	0.22	91.7
Pinnacle	27	0.04	100
Shelf	31.8	0.05	12.7
Total	**69220**	**100%**	**n/a**

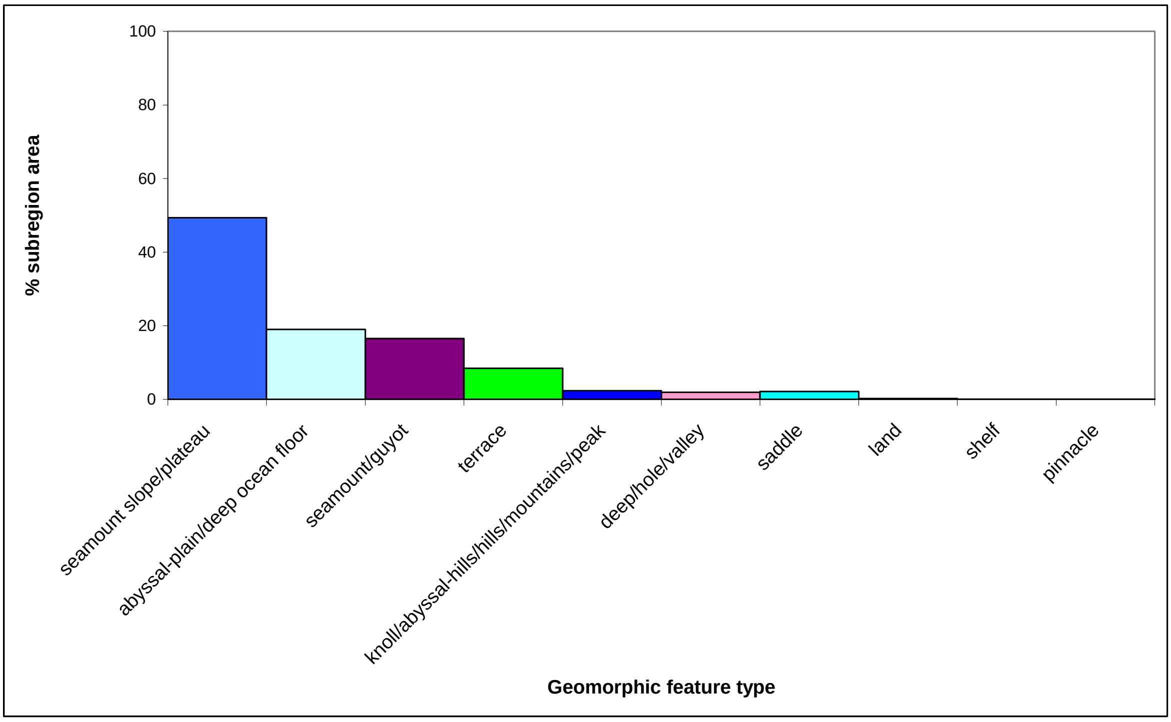


Figure 4-57. Geomorphology of the Central Ridge subregion, showing percentage breakdown of the subregion by the area covered for each geomorphic feature type present.

Table 4-21. Representation of geomorphic features within the Central Ridge subregion as a percentage of the total number and area of these features within the entire AEEZ.

Feature	Percentage (number) of feature in AEEZ	Percentage (area) of feature in AEEZ
Seamount slope/plateau	34.8	31.8
Abyssal-plain/deep ocean floor	5.88	0.57
Seamount/guyot	12.2	11.4
Terrace	3.03	1.02
Knoll/abyssal-hills/hills/mountains/peak	3.55	1.45
Saddle	19.4	1.00
Deep/hole/valley	1.29	0.78
Land	0.08	0.002
Pinnacle	0.22	0.50
Shelf	0.84	0.003

Ecological processes, habitats and biodiversity

The surface waters of the Central Ridge subregion also fall under the influence of the Indonesian Throughflow, the SE and NW monsoonal winds and their impact on currents and upwelling from Java's coastal waters (see 4.1.4). This provides seasonal spring peaks in productivity from upwelling-induced ChlA blooms (Figure 4-14, Figure 4-15 and Figure 4-16).

This pelagic productivity also appears to be enhanced by more local processes. The interaction of strong, SE monsoonal wind-driven currents with the seamounts, guyots and peaks in the subregion may be important in triggering instabilities, eddies and possible Taylor columns and Von Karmen Vortex sheet effects downstream of the islands and seamounts (Figure 4-58). Large eddies, visible in ocean colour images, suggest that nutrient rich deeper waters are being drawn into the photic zone to enhance primary productivity. The high ChlA biomass in these features appear to subsist for days and weeks (Schroder *et al*., unpublished 2009); long enough for the enhanced plankton to cascade through a range of trophic levels. Surface productivity may also be supply organic matter to the deep, where deep eddying features associated with seamounts may entrap particulate matter. This is reflected in commercial catches of pelagic fish (Figure 4-13) and anecdotally by game fishers based on Christmas Island, and supported by Samadi (2006, in Poore and O'Hara, 2007) who suggests that seamounts may be 'oases of high productivity (rather than centres of endemism)'.

During the summer months NW monsoonal winds drive warmer oligotrophic waters into the region and halt any upwelling. The pelagic system then relies on nutrient recycling processes and productivity at the deep ChlA maximum where nutrients and light can co-incide.

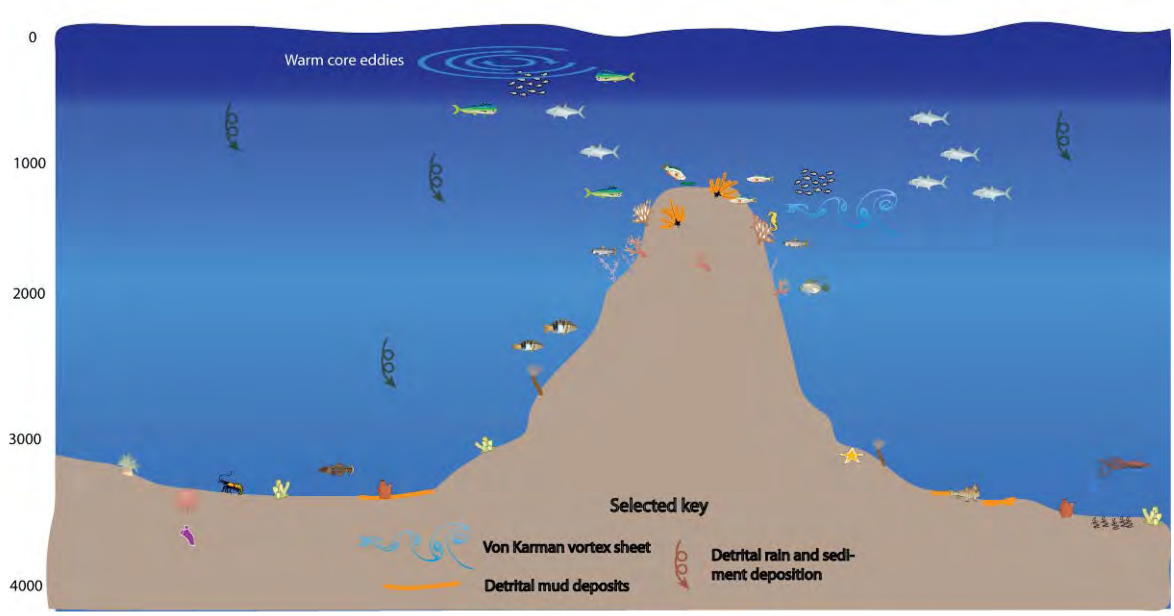


Figure 4-58. Diagrammatic representation of a seamount habitat, biophysical processes and associated currents and species groups.

The main pelagic tertiary consumers in the subregion are similar to those in the Wharton Basin (Section 4.3.1). However, the presence of seamounts provides residence for additional pelagic species that use the productivity associated with seamount driven currents and eddies, as well as preying on species that are associated with the demersal and benthic seamount communities (see below). Pelagic species such as bluefin trevally (*Caranx melampygus*), small-toothed jobfish (*Aphareus rutlians*) and Wahoo (*Acanthocybium solandri*) are often associated with shallower reef and slope structures and common around Christmas Island. They are representative of the additional pelagic diversity that is associated with shallower peaks seen in this subregion.

Anecdotal information from game fishers around Christmas Island suggest that flying fish and small pelagics are an important part of the pelagic food web in these waters, especially when the water temperatures drop in association with spring upwelling. These support seasonal influxes of large pelagics in addition to the year-round species (e.g. Wahoo which also appear to spawn year round). Other species appear to have different cues, such as sailfish which are caught in larger numbers when water temperatures begin to warm.

Although there have been no assessments or surveys of the seamount slope communities in this region, it is likely that they are relatively diverse communities compared to other demersal communities at similar depths. The resuspension and removal of fine sediments from seamount slopes facilitates recruitment and settlement of sessile benthic fauna, without risk of clogging and burial. Currents also deliver food and remove wastes from these communities. These hard substrates are therefore likely to support a diverse range of benthic animals, plants and demersal communities.

The sedentary benthic fauna are likely to be dominated by suspension feeders such as corals, sponges, crinoids and ascidians (e.g. Rogers, 1994; Genin *et al.*, 1986). These in turn provide complex, heterogeneous habitat (shelter and food) for a wide range of more mobile fauna including a broad taxonomy of benthic and demersal macrofauna (e.g. crustaceans, molluscs, annelids, echinoids, fish). These complex benthic and demersal slope communities are able to support a range of demersal tertiary consumers including fish (e.g. Ruby snapper (*Etelis coruscabs* and *Etelis carbunculus*), sharks, large squid and cuttlefish.

These slope communities will show stratification in their species composition with depth based on tolerances to a range of drivers including light levels and other gradients (e.g. temperature, pressure, carbonate, nitrogen, oxygen, phorphorous and silica), as well as community associations. However, the depth zonation of the benthic and demersal communities is not reflected in the vertical gradients and stratification of the slope-associated pelagic communities (Norse and Crowder, 2005), which differ with depth relatively independently of the benthic communities.

The terrace, saddle, knoll, basin and deep hole environments in this subregion are unusually associated with the seamounts, either through deposition from seamount slopes into these environments (e.g. reflected in relatively coarser sediments compared to similar features in other subregions), or protection from surrounding currents and water masses. Although very little is known about the biological communities associated with these features, it is likely that their unique location provides habitats for unique community structures and possibly a range of endemic species.

Assessment of Conservation values

The Central Ridge subregion contains a range of features with likely high conservation value. The subregion is relatively undisturbed except for habitation on Christmas Island, and the associated local recreational and charter fishing operations that operate from there. None of the subregion is currently protected other than through fishing effort regulation.

Pelagic communities influenced by upwelling from the southern Java coast as described earlier and in a similar way to the Wharton Basin subregion (see 4.3.1). Productivity appears to be further enhanced in this subregion by eddies, divergent upwelling and mixing associated with the shallower seamounts.

These seamounts and associated features (slopes, terraces and plateaus) dominate this subregion and comprise about one-third of all seamount/slope features in the Christmas and Cocos

(Keeling) Islands territories, and about 12% of seamounts in the AEEZ. These levels of representation will increase markedly if only shallower seamount environments are compared.

The abyssal plain environments also have unique features due to their association with the seamounts in this subregion. They generally have coarser sediments compared to similar depth environments due to erosion from the seamount slopes and protection from deeper ocean currents compared to more exposed deeper habitats. These conditions create unique environments which are likely to support unique benthic and demersal communities.

Christmas Island and its shallower slopes also contain a range of very unique and diverse environments. The cliff, beach and reef environments are not represented anywhere else in the north western AEEZ, although the regions connectivity with Indo-west Pacific locations appears to have limited the amount of marine endemism in these habitats.

Surveys of the fish fauna of Christmas Island have identified 607 fish species, including 4 endemics and 2 near endemics. Of these, 50 species are not found in other Australian waters, 28 are found in extraordinary abundance and 8 are hybrid species. Many species show Indian Ocean and Pacific species hybridisation. These statistics appear to demonstrate how the unique geographic location and isolation of the Christmas Island habitats have resulted in uniquely tailored community structures.

This same pattern can be seen in other species groups, particularly seabirds. Christmas Island is a breeding site for a wide range of seabirds, including two endemics (Abbott's booby, *Papasula abbotti* and the Christmas Island Frigatebird, *Fregata andrewsi*). These and many other seabird species will also be using the surrounding waters for foraging, at least for part of the year. Whale species also use these waters although little is known about their level of dependence on this subregion or activities other than migration (4.1.5). Dolphin species also use the coastal waters and are thought to breed in the area (Bottlenose, Short-beaked common and Spinner dolphins). However, it is not clear whether they occur in other subregions, or are solely dependent on the Central Ridge subregion. Whale sharks are known to occur in the waters surrounding Christmas Island, with several tracked on their migration from the Ningaloo region into the Christmas Island territorial waters (Figure 4-19). They are seen in a range of size classes, providing some evidence that the region may be an important juvenile habitat for this unique species (Hobbs *et al*., 2009). It has also been shown that whale sharks feed on the spawn of the endemic Christmas Island red land crabs (*Gecarcoidea natalis*) (Meekan *et al.,* In Press), but it may be the relatively high pelagic productivity, in general, that attracts whale sharks to this subregion.

Threats

Climate change, again appears to be the major threat to many of the key assets of this subregion. Variations in currents are thought to affect the success of red crab recruitment for example, and this is likely to be similar for many species that rely on pelagic larval delivery back to the Island or neighbouring habitats. Other species, such as whale sharks (*Rhincodon typus*) and manta rays (*Manta birostris*) appear to rely on the relatively high productivity of the region. Increased water temperatures and corresponding changes to the mixing depth layer may affect productivity and food availability for these and many other species. The shallow reef systems are also susceptible to coral bleaching as sea temperatures rise, as seen in 1998. Increased cyclonic activity and intensity could also have a significant impact on seabird breeding success.

Recreational fishing is a culturally important activity for the local community and their impacts on the unique reef fish communities should be clearly understood. Charter fishing for pelagic fish occurs in the waters within about 12 nm of the island, but effort levels don't appear to be a major threat to the structure of the pelagic ecosystem.

Development on the Island is an ongoing threat. Terrestrial runoff from cleared land and coastal infrastructure (e.g. new vessel mooring or port development) can both have significant impacts on local reef systems, and as these are relatively unique and limited in extent, caution must be shown and rigorous assessments made before any new developments are approved. Many introduced terrestrial species are impacting endemic species, including crazy ants, cats, dogs, rats, lizards and snakes. Marine pollution and debris also impact crab and turtle shoreline habitats.

Spinner dolphins (*Stenella longirostris*) are sighted year round and likely to feed and breed in the waters of the Central Ridge subregion.

4.3.3 Christmas Island – Cocos Basin subregion

The Cocos Basin subregion is the south-eastern extent of the larger Cocos Basin that extends over 1000 kilometres to the northwest, to the Ninety East Ridge. It covers an area of approximately 62,476 km² (8% of the Christmas and Cocos (Keeling) Islands territories) and is characterised by the large extent of relatively featureless abyssal plain that is largely not impacted by slope processes from adjacent seamounts (Figure 4-59, Figure 4-61). The abyssal plain environments appear to be largely disconnected from the abyssal plan to the east of the Central Ridge subregion, further justifying the separation of this region e.g. see Figure 4-37).

Geological and biophysical drivers

Water depths in the subregion range from 1,839 - 5,965 m, with more than 90% of the total area occurring in depths >4,000 m (Table 4-22, Figure 4-59). The subregion is dominated by abyssal plain (55,296km^2, 88.5% subregion area) where no other geomorphic features have been identified. Water depths in this area range from 4,200 - 6,000 m and are typical of the abyssal plain of the Cocos Basin extending to the north of the AEEZ.

The subregion includes volcanic topography (5,850 km^2, 9.3% subregion area) (Table 4-25, Table 4-24) in the southwest representing an extension of the main volcanic ridge that is isolated from other similar shallow areas by approximately 40 km of abyssal plain. Large seamount features are restricted to the southwest corner of the subregion and relief decreases to the north. Seamount morphology is similar to that in the adjacent Central Ridge subregion. Features include 5 conical seamount/guyots with diameters <25 km and elevations not exceeding 3,000 m.

The highest seamount peaks reach within 2,000 m of the sea surface (Table 4-23) while lesser peaks occur in water depths up to 5,300 m. Lower relief topography found elsewhere on the abyssal plain (knoll/abyssal hills/ mountains/peaks (184 km^2, 0.3%) occurs in water depths of 4,800 - 5,500 m. A single deep/hole/valley (445 km^2, 0.7%) associated with the adjacent volcanic ridge and similar to one located in the Wharton Basin subregion covers 5,659 km^2 (8.9%) in an embayment on the south eastern boundary of the subregion (Figure 4-60).

Immediately to the west of the Christmas Island rise is the boundary between two crustal provinces. Ages and lithologies of dredged samples, as well as calcareous nannofossil assemblages found, indicate that the large seamounts in the Vening-Meinsz chain developed rapidly, and had shoaled by the Campanian, and as some were close to or above sea level, the formation of flat topped platforms (giving their present morphology of flat topped guyouts) occurred during the Campanian-Maastrichtian. There have also been studies of the magnetic lineations of the sea floor which suggest that it formed during the Late Cretaceous. There are suggestions (but ambiguous) of reef forms present, most likely shelly algal biostromes dominated by rudists and Inoceramus species. The sea mounts returned to bathyal depths by the Neogene.

A total of 19 sediment data points are distributed across the subregion (Figure 4-31). These occur in water depths ranging from 2,470 - 5750 m, with the highest densities achieved in depths between 5,200 and 5,800 m (abyssal plain/deep ocean floor, 16 data points). Samples also achieve coverage of the largest seamount and seamount slope/plateaus surrounding it. No data points occur in knoll/abyssal hills/ mountains/peaks or deep/hole valley features.

Sediment data suggest sediment texture is homogeneous across most of the area of seamount slopes and abyssal plain/deep ocean floor. Sediments are dominated by mud, with lesser sand and only minor gravel, although rock dredges indicate this is present in higher concentrations locally. The exception to this is in the east of the subregion where gravely mud covers a large area of abyssal plain extending from the base of the central ridge. These samples are at the base of the slope of the main volcanic ridge and gravels at this location are composed of sedimentary and volcanic rock fragments and pumice. Some of this material is likely to have been eroded from adjacent seamounts and transported down slope in debris flows. Gravel detected more than 70 km from the nearest significant topography is composed of pumice and lesser volcanic rock fragments and indicates gravels may be present in low concentrations across much of the abyssal plain in this subregion. A single sample from a seamount in the south of the subregion indicates sandier sediments are present in these areas.

A total of 26 rock dredges occur in this subregion (Figure 4-32). These were collected from the abyssal plain (23 dredges) and slope surrounding seamounts in the south west of the subregion (3 dredges, water depths 3,700 - 5,700 m). Volcanic rocks (lavas and volcaniclastics) were the most abundant lithologies, occurring across all areas sampled. Carbonates were restricted to seamount slopes, suggesting these would also be present on shallower areas of the seamounts. Manganese nodules and crusts were most abundant on areas of the abyssal plain that occur between volcanic topography, and were also detected at one location on lower seamount slopes. However, manganese was not detected on featureless areas of the abyssal plain in the northern half of the subregion, despite numerous sample points.

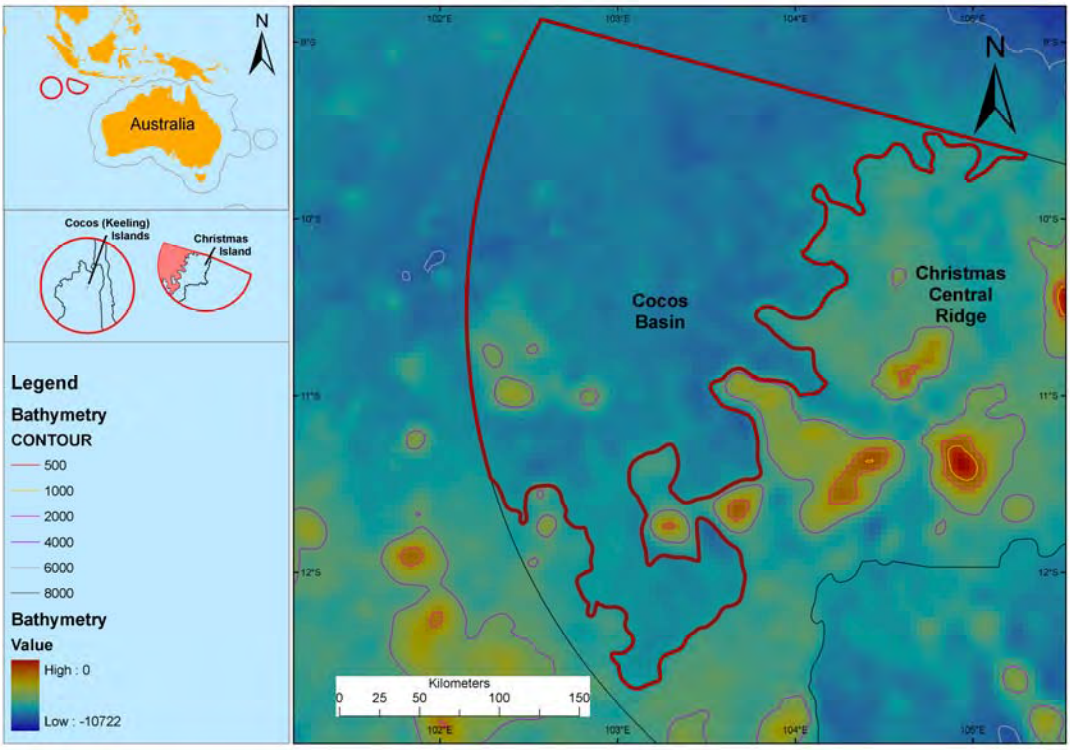


Figure 4-59. Bathymetry of the Cocos Basin subregion.

Table 4-22. Bathymetry characterisation of the Cocos Basin subregion. Bathymetry range for the entire subregion is 1,840-5,965 m (mean 5355 m, stdev 385 m).

Water Depth (m)	Area (km^2)	Percentage area of subregion
1000-2000 m	20.2	0.03
2000-3000 m	333	0.53
3000-4000 m	633	1.01
4000-5000 m	3462	5.54
5000-6000 m	58027	92.9

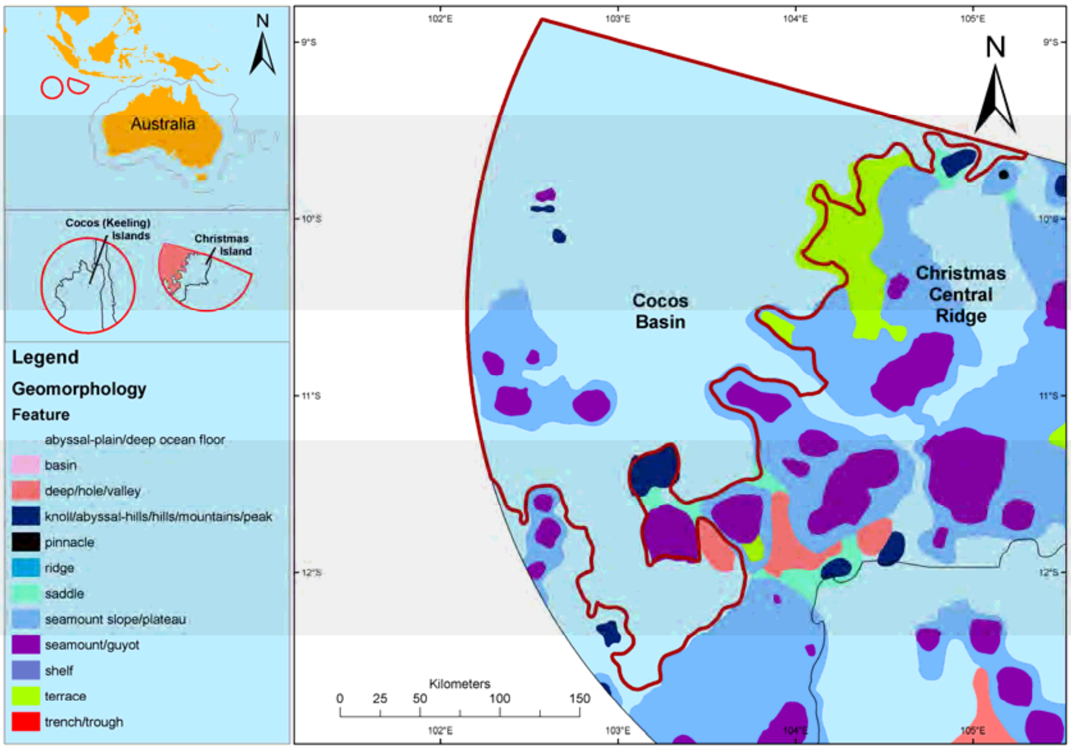


Figure 4-60. Geomorphology of the Cocos Basin subregion.

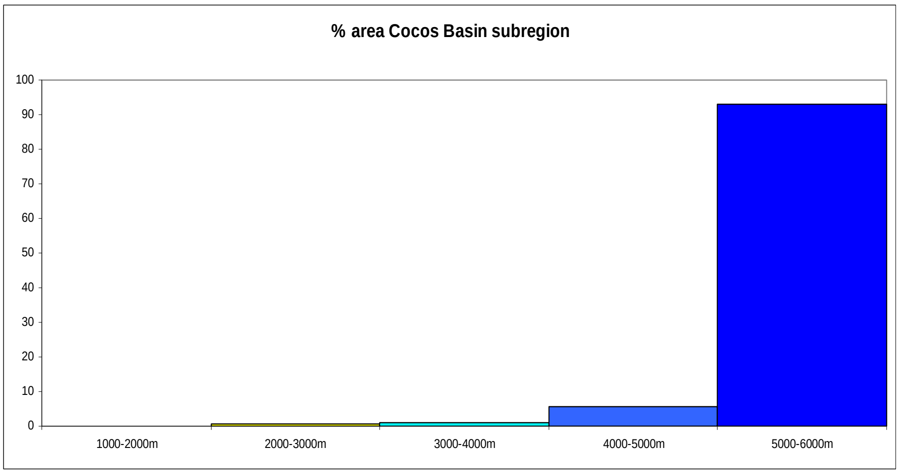


Figure 4-61. Bathymetry characterisation of the Cocos Basin subregion, showing percentage breakdown of the subregion by the area covered for each bathymetry class.

Sediment data suggest sediment texture is homogeneous across most of the area of seamount slopes and abyssal plain/deep ocean floor. Sediments are dominated by mud, with lesser sand and only minor gravel, although rock dredges indicate this is present in higher concentrations locally. The exception to this is in the east of the subregion where gravely mud covers a large area of abyssal plain extending from the base of the central ridge. These samples are at the base of the slope of the main volcanic ridge and gravels at this location are composed of sedimentary and volcanic rock fragments and pumice. Some of this material is likely to have been eroded from adjacent seamounts and transported down slope in debris flows. Gravel detected more than 70 km from the nearest significant topography is composed of pumice and lesser volcanic rock fragments and indicates gravels may be present in low concentrations across much of the abyssal plain in this subregion. A single sample from a seamount in the south of the subregion indicates sandier sediments are present in these areas.

A total of 26 rock dredges occur in this subregion (Figure 4-32). These were collected from the abyssal plain (23 dredges) and slope surrounding seamounts in the south west of the subregion (3 dredges, water depths 3,700 - 5,700 m). Volcanic rocks (lavas and volcaniclastics) were the most abundant lithologies, occurring across all areas sampled. Carbonates were restricted to seamount slopes, suggesting these would also be present on shallower areas of the seamounts. Manganese nodules and crusts were most abundant on areas of the abyssal plain that occur between volcanic topography, and were also detected at one location on lower seamount slopes. However, manganese was not detected on featureless areas of the abyssal plain in the northern half of the subregion, despite numerous sample points.

Table 4-23. Water depth within geomorphic features in the Cocos Basin subregion.

Feature	Maximum depth	Minimum depth	Mean depth	STD
Terrace	5370	4940	5110	84
Seamount slope/plateau	5870	2050	4770	606
Seamount/guyot	5330	1840	3840	943
Knoll/abyssal-hills/hills/mountains/peak	5570	4840	5230	199
Saddle	5420	4170	5060	268
Deep/hole/valley	5850	4250	5320	338
Abyssal-plain/deep ocean floor	5960	4230	5440	193

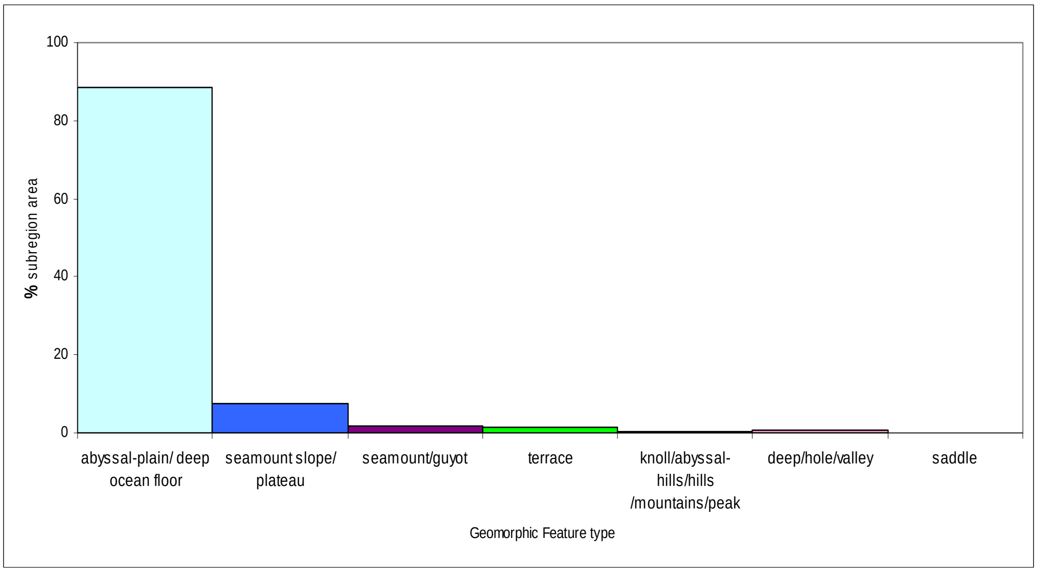


Table 4-24. Geomorphology of the Cocos Basin subregion, showing percentage breakdown of the subregion by the area covered for each geomorphic feature type present.

Table 4-25. Geomorphological characterisation of the Cocos Basin (CB) subregion and comparisons with (i) the total subregion area and (ii) combined Christmas & Cocos (Keeling) Islands (CI & CKI) territory areas.

Feature	CB subregion areas (km^2)	Percent total CB subregion area	Percent total area of feature type in CI & CKI territories
Abyssal-plain/deep ocean floor	55296	88.5	12.1
Seamount slope/plateau	4614	7.4	4.3
Seamount/guyot	1043	1.7	2.5
Terrace	810	1.3	3.6
Deep/hole/valley	444	0.7	7.0
Knoll/abyssal-hills/hills/mountains/peak	184	0.3	1.7
Saddle	81	0.1	4.2
Total	**62472**	**100**	**n/a**

Table 4-26. Representation of geomorphic features within the Cocos Basin subregion as a percentage of the total number and area of these features within the entire AEEZ.

Feature	Percentage (number) of feature in AEEZ	Percentage (area) of feature in AEEZ
Abyssal-plain/ deep ocean floor	5.9	2.4
Seamount slope/ plateau	26.1	3.3
Seamount/guyot	3.8	1.0
Knoll/abyssal-hills/hills /mountains/peak	0.5	0.09
Deep/hole/valley	1.3	0.26

Ecological processes, habitats and biodiversity

The surface waters of the Cocos Basin subregion fall under the influence of the Indonesian Throughflow, the SE and NW monsoonal winds and their impact on upwelling from Javanese coastal waters (see 4.1.4). This combination of factors produces a cooler, more productive pelagic environment in winter and spring and a warmer, oligotrophic pelagic environment in summer and autumn.

Although the general ITF influence in this subregion is oligotrophic, the subregion has a relatively high level of primary productivity during spring (in particular) compared to subregions in the Cocos (Keeling) Islands territory (Figure 4-14, Figure 4-15, Figure 4-16). This likely a result of it's proximity to the ChlA plumes generated by upwelling off the South Java coast during spring (July-Oct) and transported into the territory by winds, currents and eddies (see 4.1.4). During summer there are more oligotrophic conditions when a deep ChlA maxima occurs as standing crops of nanoplankton feeders quickly utilise nutrients that are transported above the thermocline. This productivity is critical to the larvae of many species and in turn a feeding zone for larger predators.

The main tertiary consumers in the subregion include local or migrating populations of pelagic fish such as yellowfin (*Thunnus albacares*) and bigeye (*Thunnus obesus*) tuna, sharks, trevallies, tunas, scads, wahoo and foraging seabirds that either migrate seasonally or range through the system following schools of small pelagic fish. The historical Japanese longline catches also indicate that this subregion is an area of relatively high pelagic productivity (reflected in high biomass of pelagic fish) (Figure 4-50).

The small number of seamounts within the southern half of the subregion is likely to have some hard substrates that provide surfaces and topographical structure for recruitment and growth of passive, sessile, epi-benthic suspension feeders (Genin *et al.*, 1986), such as deep sea corals, sponges, crinoids, ascidians and bryozoans. These communities provide habitats for a range of demersal deep water squids, crustacean and small fishes (e.g. lanternfishes and Myctophidae and small, bioluminescent species that may vertically migrate), which are prey for larger cephalopods and fish including grenadiers (*Macrouridae*) hatchetfish (*Argyropelecus* spp.) (Richer de Forges, 2000; Hixon and Beets, 1993; Norse and Crowder, 2005).

Most of the seamounts within the subregion are relatively deep (>2000 m). Little is known about the communities that live on the tops and slopes of these seamounts. However, it seems likely that their unique position in the water column, and geographically, will support unique benthic and demersal communities. These features are mainly under the influence of deeper, slow-moving but widely distributed water masses.

Much of the northern part of the subregion would be dominated by soft sediments and associated communities of burrowing and bioturbating invertebrates such as holothurian and polychaetes (Figure 4-62).

The relatively productive nature of the waters of the subregion may be providing a relatively high biomass of benthic communities through energy flows from the pelagic system. These deep, abyssal demersal environments are largely reliant for their energy input on falling detritus or particulate organic matter (POM, marine snow) and the occasional large carcass directly supplied by the pelagic environment. Much of the detrital energy is cycled through bacterial-detrital food webs. Other components of these benthic communities include a range of infauna (meiofauna and microfauna) including filter-feeders and detritivores. Few species will migrate between the pelagic and benthic environments.

Given the area is influenced by the Indonesian Throughflow Current and other dynamic oceanographic conditions, we expect there to be a high level of connectivity with other areas within the Christmas and Cocos (Keeling) Islands territories, and to a lesser extent with neighbouring slopes of the Australasian continental slopes to the east; in particular, within the shallower water mass layers where connectivity between subregions is greatest.

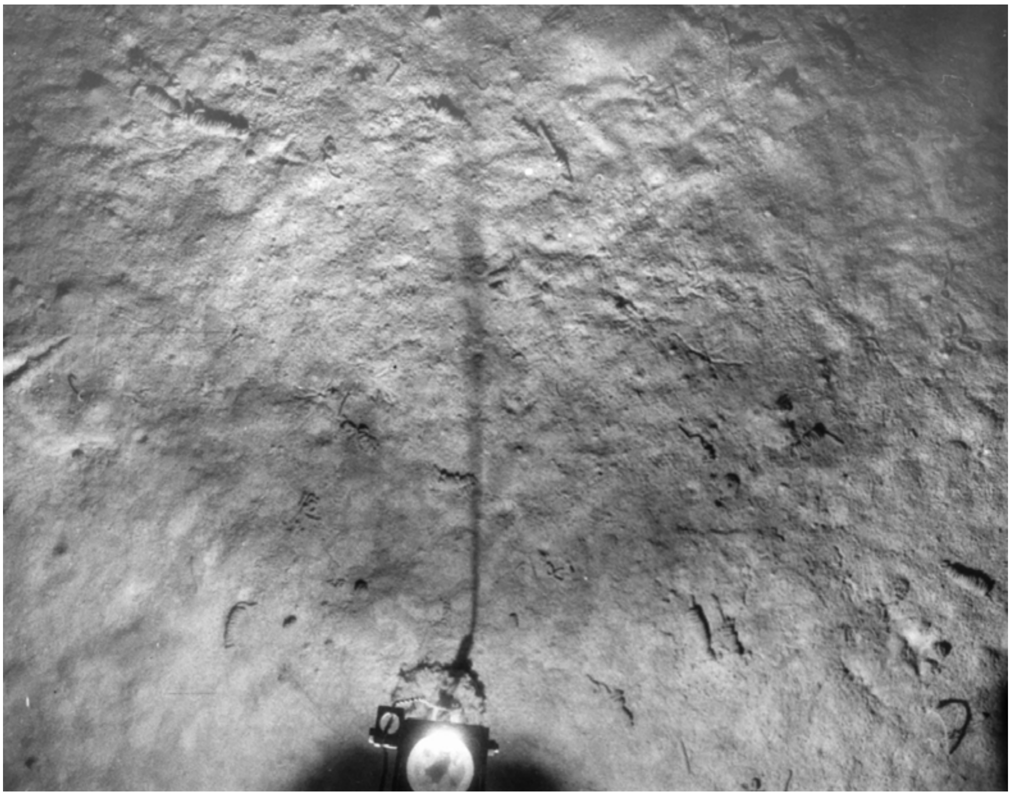


Figure 4-62. Photographs of the benthic habitat at location VM28-246 showing soft sediment and holothurians casting (depth 2995 m).

Assessment of conservation values

The Cocos Basin subregion is relatively remote and has had little human disturbance with the exception of variable levels of pelagic fishing effort over recent decades. However, little fishing effort or illegal, unregulated and unreported (IUU) fishing is reported to currently occur in this subregion. The benthic environments are largely undisturbed. None of the subregion is currently protected other than through fishing effort regulation.

The broader region contains a unique complex of water mass and current interactions in the surface layers. Primary productivity is relatively high due to its proximity to seasonal upwelling forced by the local climate and oceanographic conditions. This productivity is reflected in fishery catches for large pelagics, in domestic and international fleet statistics. However, little is known about most of the other species groups in these environments and the impact on this productivity on communities in the deeper water masses.

The subregion has a relatively small number (5) of seamount features that are probably similar to those of the nearby Christmas Rise. Little is known of the ecological communities on these deep seamounts.

This subregion is dominated by abyssal plain (93%) that is likely to have sparse, but unique community types associated with them.

There are a range of species that are listed (under the EPBC Act) that may either use the Cocos Basin region as a foraging ground or other habitat (4.1.5). However, there has been little scientific study of species such as whales, dolphins, seabirds and turtles in the subregion so the importance of this subregion for these species is largely unknown.

Threats

Changes in climate may influence the dynamics and strength of the monsoon winds and current patterns which may change the mixing and upwelling regime in this subregion. This may influence pelagic productivity and to some extent benthic productivity. The deeper environments are low energy, stable nature, and likely to have relatively narrow physicochemical tolerances.

Climate change induced alterations to ocean currents such as the South Java Current, will potentially impact connectivity and nutrient dynamics of the seamounts in the region. Ocean acidification will impact on planktonic populations for calcifying organisms, and will likely result in changes to zooplankton species composition. Phytoplankton will also be affected, primarily through nutrient cycling mechanisms. The full impact of these changes is largely unknown, but likely to be significant.

Other climate impacts include warming seas (+1.8°C by 2070, Maunsell Climate impacts report) and potentially stronger (though less frequent) cyclones. However, these changes are unlikely to have a significant impact on the communities of this subregion.

There are restricted areas of manganese nodule habitats associated with the seamounts in the south of the subregion. They are unlikely to be mined, however, their associated communities are poorly understood, and are likely to be sensitive to physical disturbance, with long recovery time frames.

4.3.4 Cocos (Keeling) – East Cocos Abyssal Plain

The East Cocos Abyssal Plain covers an area of approximately 93,780 km² (13% of the Christmas and Cocos (Keeling) Islands territories) and is the most western of the Cocos (Keeling) Islands territory. Its western boundary runs along the boundary of the trough associated with the Investigator Ridge. It is named for its association with the southern section of the broader Cocos Basin. It is characterised by a deep abyssal region with a large seamount complex (Figure 4-63, Figure 4-64) forming the Vening-Meinse Seamount Chain (Figure 4-37).

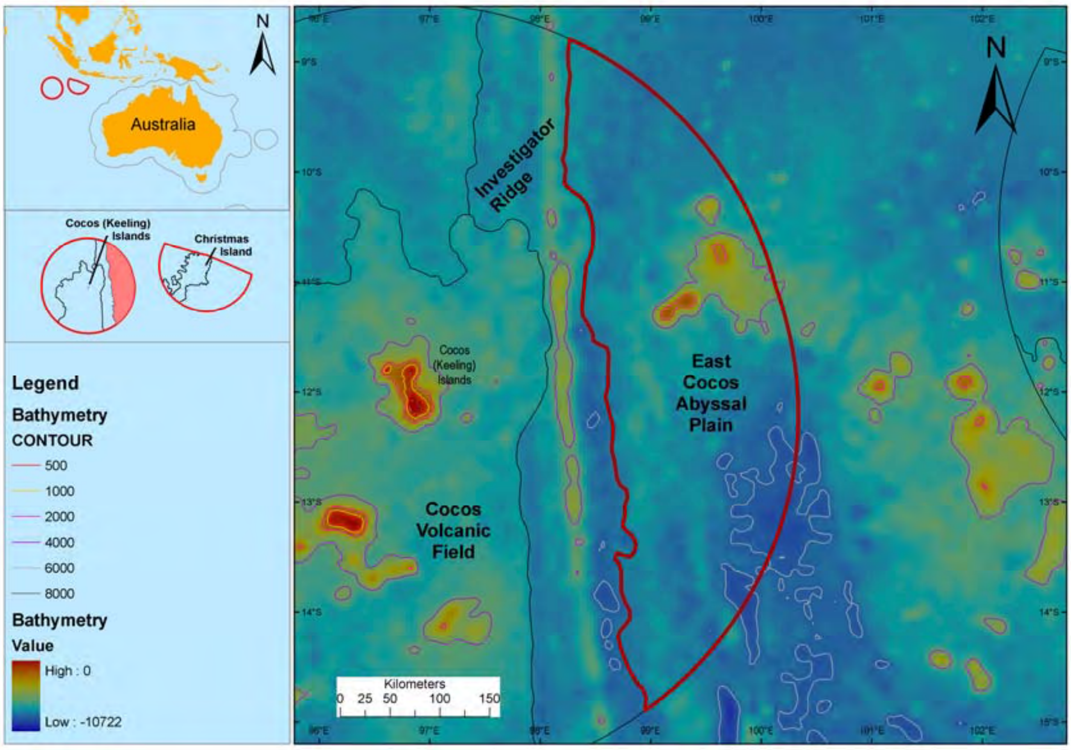


Figure 4-63. Bathymetry of the East Cocos Abyssal Plain subregion.

Geological and biophysical drivers

Most of the subregion is made up of deep abyssal plain or basin environments with >80% of the subsystem having depths >4000 m, and >5% in >6,000 m. Water depths on the abyssal plain range from 3,600 to 6,400 m (Figure 4-65, Figure 4-66). Depths >6,000 m are restricted to a large basin in the south of the subregion and represent 39% of the total area of the Christmas and Cocos (Keeling) Islands territories occurring in water depths >6,000 m. Less than 1% of the subregion occurs in depths <2,000 m, and this occurs on seamounts in the NE of the subregion.

The subregion is dominated by areas of abyssal plain where no other features have been identified (56,027 km^2, 60% subregion area, Table 4-28, Table 4-29). The remaining area comprises two large low-relief basins that extend beyond the EEZ boundary and cover 18,310 km^2 (20% of the subregion) and isolated low relief abyssal hills that cover 1,774 km^2 (2% of the subregion) in the south of the subregion (Figure 4-67, Figure 4-68, Table 4-28). Abyssal hills are elongate in a north-south direction and have elevations of approximately 800 m.

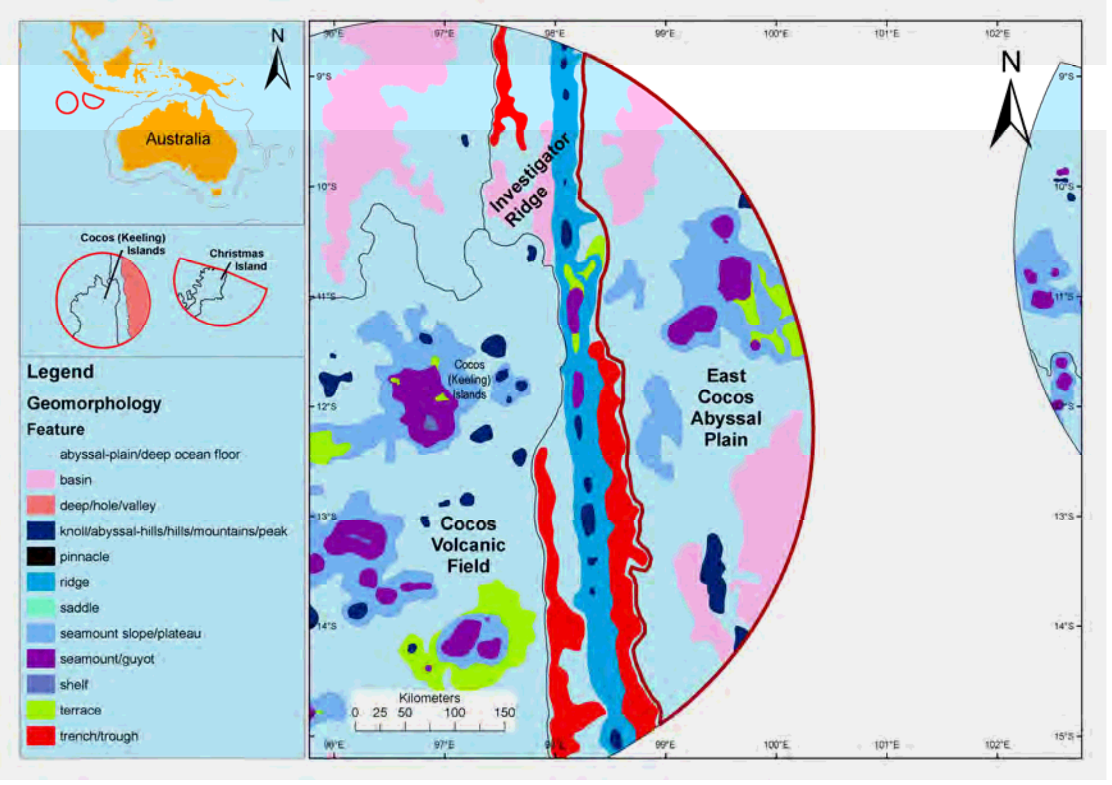


Figure 4-64. Geomorphology of the East Cocos Abyssal Plain subregion.

A total of four seamounts occur in the subregion (Figure 4-64). The highest peak reaches a depth of 1,050 m, while lesser peaks occur in 1,800-3,500 m water depth (Figure 4-68). They have volcanic topography and represent the western extent of the volcanic province (17,670 km^2, 19% of subregion area, Table 4-30). The seamounts are connected by areas of slope/plateaus (12,868 km^2, 14% of subregion area) containing a series of small terraces (1,868 km^2, 2% of subregion area) on the southeast flank in water depths of approximately 3,000-5,000 m. Two isolated plateau features (4,000 km^2, 4% of subregion area) also occur to the west of the main seamount cluster (Figure 4-64).

A total of 4 sediment data points occur in the subregion (Figure 4-31). These all occur in deep water (5,100-5,600 m) immediately to the northwest of the seamounts. Sediment at all locations sampled was dominated by mud, with minor sand and no gravel present. However ,mud dominated sediment sampled from the base of the seamount slope suggests that erosion and deposition rates in this area are likely to be far lower than detected around volcanic topography at the Christmas Island end of the volcanic ridge. Three rock dredges have been done on the seamounts and have contained abundant carbonate and volcanic rock fragments (Figure 4-32).

Table 4-27. Bathymetry characterisation of the East Cocos Abyssal Plain subregion. Bathymetry range for the entire subregion is 1,050-6,410 m (mean 5,215, stdev 700).

Water Depth (m)	Area (km^2)	Percentage area of subregion
1000-2000 m	513	0.5
2000-3000 m	1614	1.7
3000-4000 m	4540	4.8
4000-5000 m	11965	12.8
5000-6000 m	70186	74.8
>6000 m	4966	5.3

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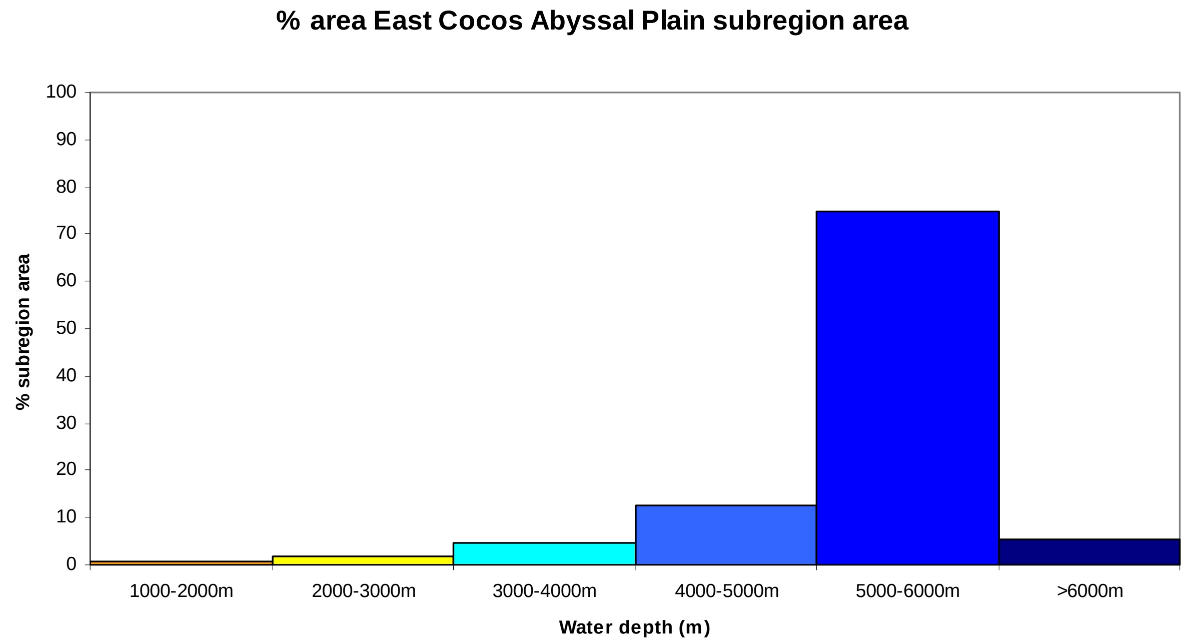


Figure 4-65. Bathymetry characterisation of the East Cocos Abyssal Plain subregion, showing percentage breakdown of the subregion by the area covered for each bathymetry class.

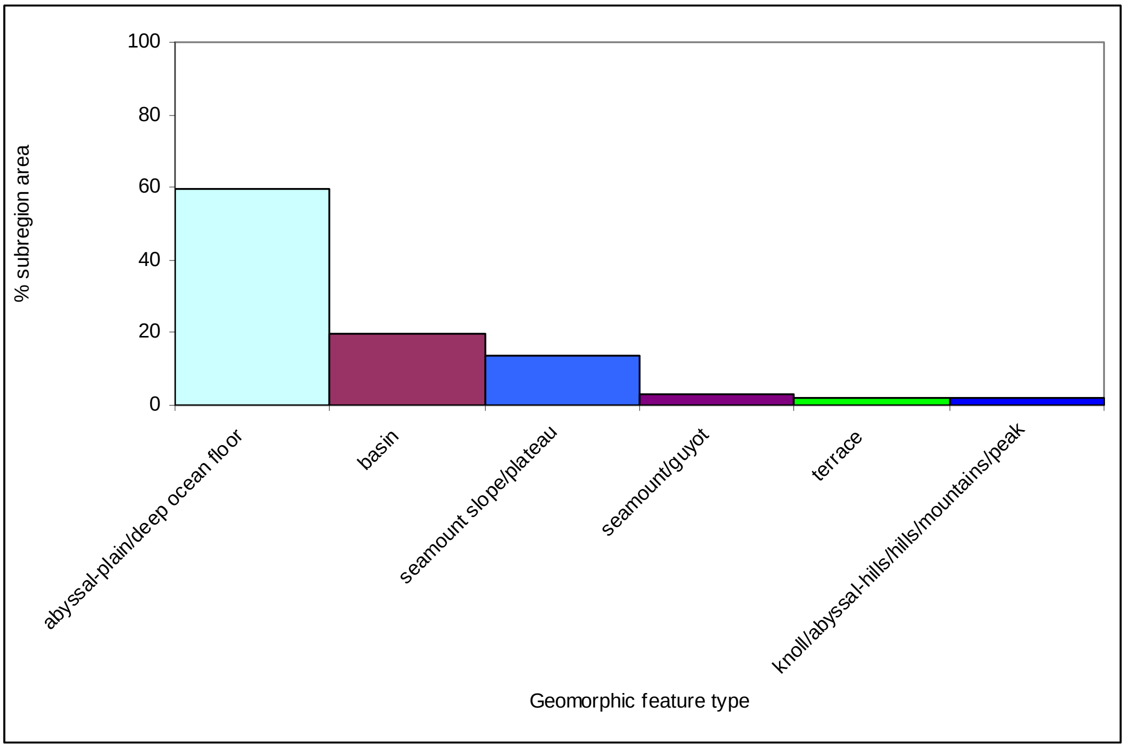


Table 4-28. Geomorphology of the East Cocos Abyssal Plain subregion, showing percentage breakdown of the subregion by the area covered for each geomorphic feature type present.

Table 4-29. Water depth within geomorphic features in the East Cocos Abyssal Plain subregion.

Feature	Maximum depth	Minimum depth	Mean depth	STD
Abyssal-plain/deep ocean floor	6000	3630	5340	213
Basin	6410	5250	5850	217
Knoll/abyssal-hills/ hills/mountains/peak	5760	4530	5270	185
Seamount slope/plateau	5670	2560	4540	622
Seamount/guyot	4610	1050	2700	709
Terrace	5060	2850	3890	545

Table 4-30. Geomorphological characterisation of the Central East Cocos Abyssal Plain (ECAP) subregion and comparisons with (i) the total subregion area and (ii) combined Christmas & Cocos (Keeling) Islands (CI & CKI) territory areas.

Feature	ECAP subregion areas (km^2)	Percent total ECAP subregion area	Percent total area of feature type in CI & CKI territories
Abyssal-plain/deep ocean floor	56026	59.7	12.3
Basin	18309	19.5	29.3
Knoll/abyssal-hills/ hills/mountains/peak	1773	1.9	16.8
Seamount slope/plateau	12868	13.7	12.0
Seamount/guyot	2936	3.1	7.2
Terrace	1868	2.0	8.3
Total	**93780**	**100**	**n/a**

Table 4-31. Representation of geomorphic features within the Central East Cocos Abyssal Plain subregion, as a percentage of the total number and area of these features within the entire AEEZ.

Feature	Percentage (number) of feature in AEEZ	Percentage (area) of feature in AEEZ
Abyssal-plain/deep ocean floor	5.9	2.4
Basin	6.4	2.6
Knoll/abyssal-hills/hills/mountains/peak	1.5	1.6
Seamount slope/plateau	13.0	12.0
Seamount/guyot	3.2	2.9
Terrace	3.0	0.3

Ecological processes, habitats and biodiversity

The subregion has an intermediate level of primary productivity among all the subregions (Figure 4-14, Figure 4-15 and Figure 4-16) due to the distance from upwelling events such as those associated with the Java coast. However, the shallow seamounts would be likely to have some significant upwelling or associated with them, which in turn will produce increased productivity and populations of pelagic fish such as bigeye (*Thunnus obesus*) and yellowfin tuna (*T. albacares*) (Figure 4-13).

The deep demersal environment is reliant for its energy input on falling detritus or particulate organic matter (marine snow) and the occasional large carcass directly supplied by the pelagic environment. In this instance, the generally low productivity of the surface waters in the subregion would result in a low productivity in the benthic system.

The hard substrates that occur on seamounts are likely to have epibenthic communities from a variety of animal groups, including deep-sea corals. These epi-benthic communities may in turn support populations of bentho-pelagic fish and cephalopods such as small fishes (lantern fishes and Myctophidae), and consequently feeding locations for associated predators (Richer de Forges, 2000; Hixon and Beets, 1993; Norse and Crowder, 2005). The seamounts would provide topographical structure favourable for recruitment and growth of passive suspension feeders (Genin *et al.*, 1986). These seamounts are relatively isolated and the last ones of the volcanic province before the Investigator Ridge. However, the water column characteristics of the area are probably unique to some extent due to the productivity profile of the waters that occur in the area.

Given the area is influenced seasonally by the South Java Current and other dynamic oceanographic conditions, we would expect a some connectivity with the Christmas Island territory and the neighbouring slopes of the Australasian continental slopes and a high level of connectivity with the Cocos (Keeling) Islands territory.

Assessment of Conservation values

The East Cocos Abyssal Plain subregion is relatively remote and has had little human disturbance with the exception of variable levels of pelagic fishing effort over recent decades. However, little fishing effort or illegal, unregulated and unreported (IUU) fishing is reported to currently occur in this subregion. The benthic environments are largely undisturbed. None of the subregion is currently protected other than through fishing effort regulation.

The surface waters of the subregion are mostly oligotrophic, with a peak in primary productivity during autumn and winter due to seasonal upwelling forced by the local climate and oceanographic conditions. This productivity is reflected in fishery catches for large pelagics, in domestic and international fleet statistics.

The seamounts of the Vening-Meinse Seamount Chain are likely to promote pelagic productivity and support significant pelagic communities. This will result in productivity flows to he demersal communities on the seamounts and support significant communities. These seamount communities are somewhat isolated from the seamounts of the volcanic province and are likely to se significant ecological features.

This subregion has large expanses of very deep abyssal plain (39% of the total area of the Christmas and Cocos (Keeling) Islands territories occurring in water depths >6,000 m) that are likely to have sparse, but potentially unique community types associated with them. The proximity of this abyssal plain to the adjacent Investigator Ridge would likely cause some down slope processes and current dynamics that would result in unique communities in the deep abyssal plains.

There are a range of species that are listed (under the EPBC Act) that may either use the East Cocos Abyssal Plain subregion as a foraging ground or other habitat (4.1.5). However, there has been little scientific study of species such as whales, dolphins, seabirds and turtles in the subregion so the importance of this subregion for these species is largely unknown.

Threats

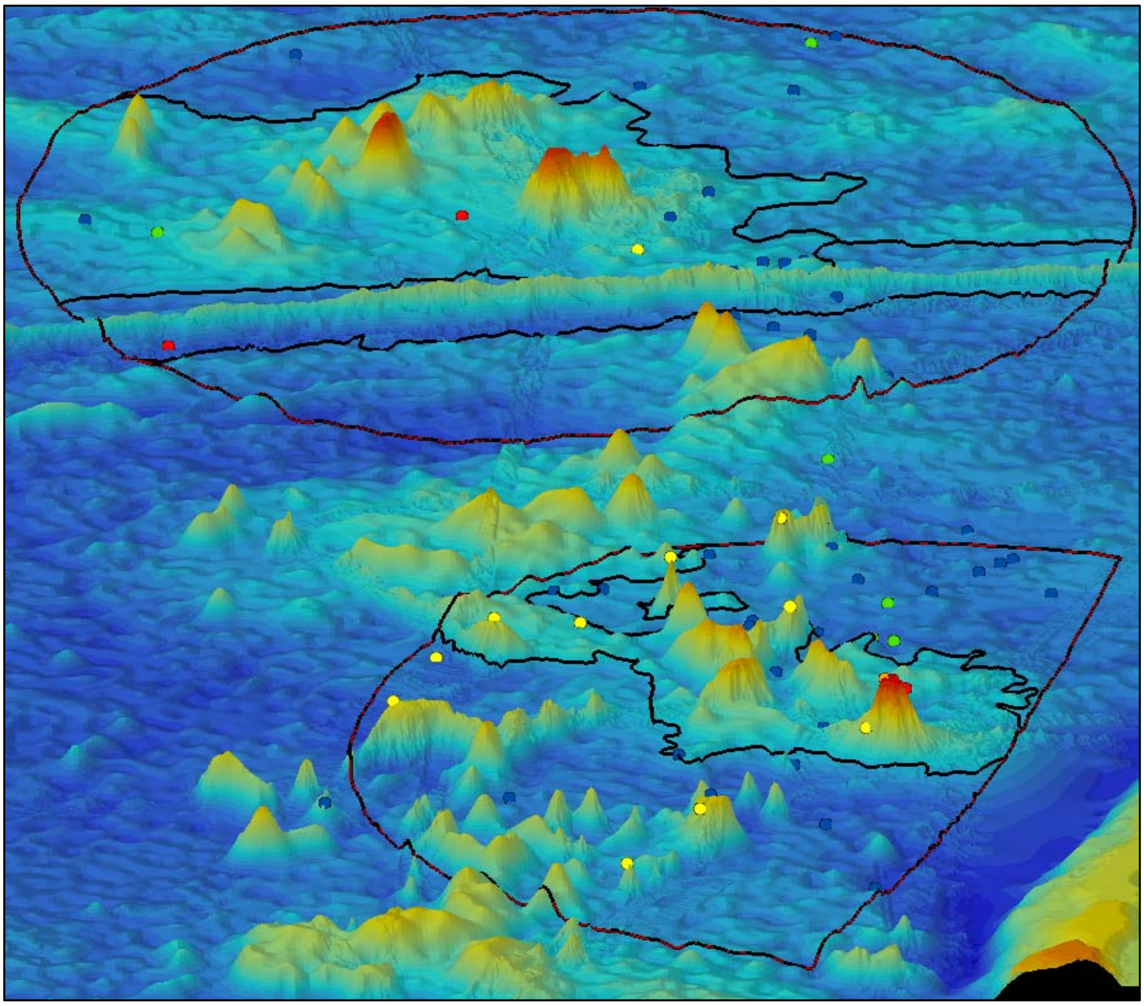
Changes in climate may influence the dynamics and strength of the current patterns which may change the pelagic productivity and to some extent benthic productivity of the subregion.

Changes to ocean currents such as the South Java Current, will potentially impact connectivity and nutrient dynamics of the seamounts in the region. Ocean acidification will impact on planktonic populations for calcifying organisms, and will likely result in changes to zooplankton species composition. Phytoplankton will also be affected, primarily through nutrient cycling mechanisms. The full impact of these changes is largely unknown.

Other climate impacts include warming seas (+1.8°C by 2070, Maunsell Climate impacts report) and potentially stronger (though less frequent) cyclones. These changes are unlikely to have a significant impact on the communities of this subregion.

The abundance and diversity of the deep abyssal biota has been rarely sampled, including the Indian Ocean abyssal environments. It is not clear how climate change impacts would affect these deeper communities. However, any physical disturbance may cause significant habitat and community degradation. For example, any new mining ventures that disturb these deeper environments are likely to have long-term impacts.

The area has previously been known as a fishing ground for pelagic tunas, with the Japanese fishing fleet expending significant effort in the area during the 1980s and 1990s.



Three dimensional view of the geomorphic features of the Christmas (nearest) and Cocos (Keeling) Islands territories.

4.3.5 Cocos (Keeling) – Investigator Ridge

A key geomorphological feature in the Christmas and Cocos (Keeling) Islands territories is the Investigator Ridge. The entire Investigator Ridge is an approximately 1,800 km long N-S striking fault zone which stretches from 18°S to 2°S (subducting beneath Sumatra). About 720 km of the ridge is within this subregion. Field mapping studies of the ridge revealed a steep west facing scarp and a more gentle, east facing slope, along most of the fracture zone, suggesting reactivation of the developing plate boundary between the eastern and western parts of the Indo-Australian plate. An approximately 15 km wide trough runs along the west side of the ridge for the full length of the ridge and which varies in width between 10-25 km (SO199 cruise report). With a steep western side, this trough is thought to represent a reactivated fracture zone, as magnetic profiles show that the E-W trending seafloor anomalies are interrupted by the west wall of the trough (SO199 Cruise report).

The demarcation boundary on the western side of this subregion was placed to include the basins to the north and south which appeared to be intimately connected to the ridge. South of 10°55'S the main crest of the ridge is offset to the east by ~10 km. From here to 11°20'S, the crest above 3,000 m bsl broadens by up to 15 km. Then around 11°S the ridge starts to gradually change strike from N-S to NNW-SSE.

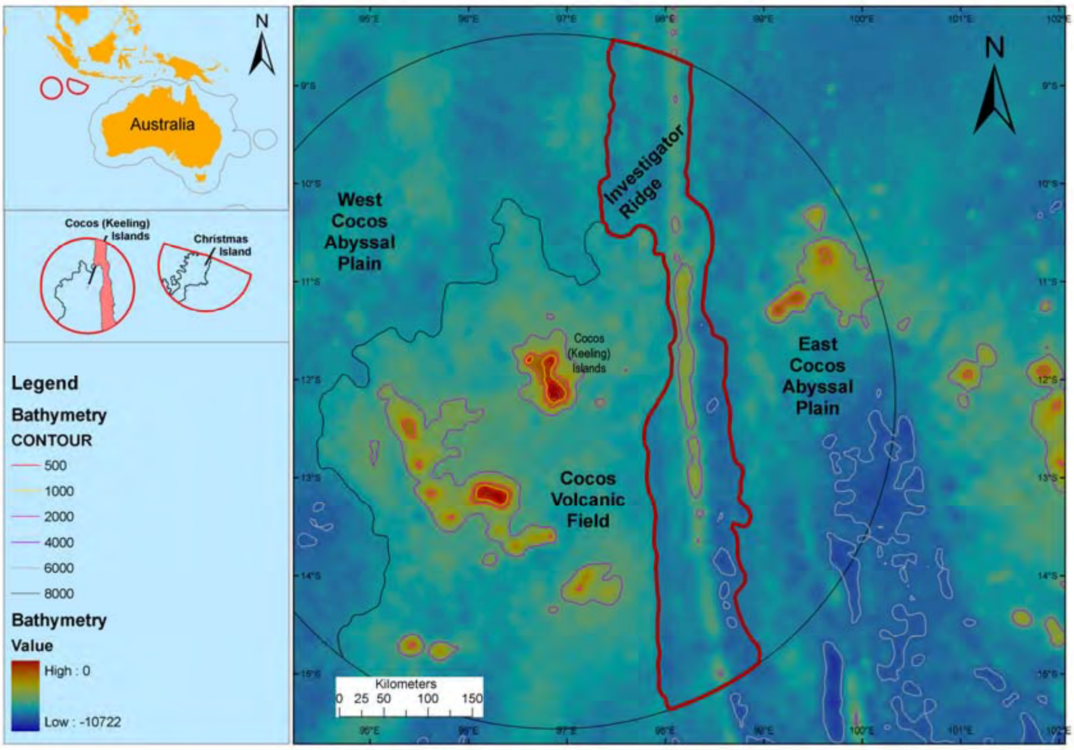


Figure 4-66. Bathymetry of the Investigator Ridge subregion.

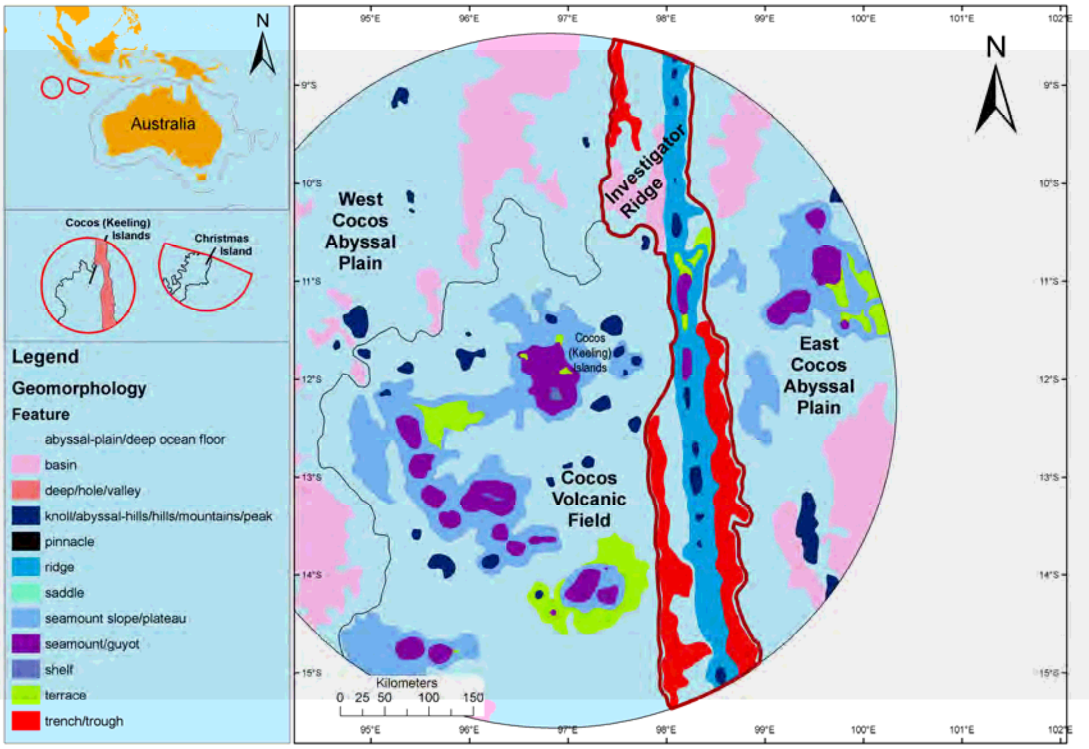


Figure 4-67. Geomorphology of the Investigator Ridge subregion.

This subregion covers an area of approximately 61,000 km^2 (8% of the Christmas and Cocos (Keeling) Islands territories). The subregion is characterised by elongate north-south trending topography including the Investigator Ridge (18,304 km^2, 35% subregion area) and associated trenches (16,102 km^2, 26% of the subregion area) that occur on the Cocos Basin abyssal plain to the east and west of the ridge (Figure 4-67). Ridge and trench features are not found elsewhere in the Christmas and Cocos (Keeling) Islands territories, and the occurrences in this subregion represent 15.5% and 7.5%, respectively, of the total area of these feature types in the AEEZ (Table 4-35).

The Investigator Ridge extends the length of the subregion and continues beyond the EEZ boundary to the north and south. Width and elevation of the ridge is greatest in the centre of the subregion, rising approximately 2,500 m above the adjacent Cocos Basin abyssal plain (water depth >5,000 m) and decreasing in elevation to the north and south. The ridge top is uneven, with variations in water depth from 2,500 - 4,500 m (Figure 4-66). Moderately flat areas of <3 km width and up to 30 km length occur in water depths of 3,500-4,500 m and are separated by more complex elevated topography. Slopes on both sides of the ridge contain numerous small scale north-south trending ridges and depressions.

Two elongate seamounts (total area 900 km^2, elevation ~2,000 m) occur on the ridge top and reach within 2,500 m of the sea surface (Figure 4-67, Table 4-33). Adjacent to these, a series of small terraces (total area 500 km) occur on the east facing slope and abyssal plain adjacent to the ridge. Water depths in these features range from 2,600 m at the foot of the seamounts to 5,500 m on the abyssal plain. Smaller knoll/ abyssal-hill/hill/mountain/peak features of similar shape to the seamounts occur along the ridge top to the north and south. The elevations of these ranges from 900 - 1,700 m and the highest reach within 3,000 m of the ocean surface.

Table 4-32. Bathymetry characterisation of the Investigator Ridge subregion. Bathymetry range for the entire subregion is 2,467-6,416 m (mean 5156 m, stdev 589).

Water Depth (m)	**Area (km^2)**	**Percentage area of subregion**
2000-3000 m	79	0.1
3000-4000 m	3605	5.9
4000-5000 m	13213	21.7
5000-6000 m	42099	69.0
>6000 m	1978	3.2

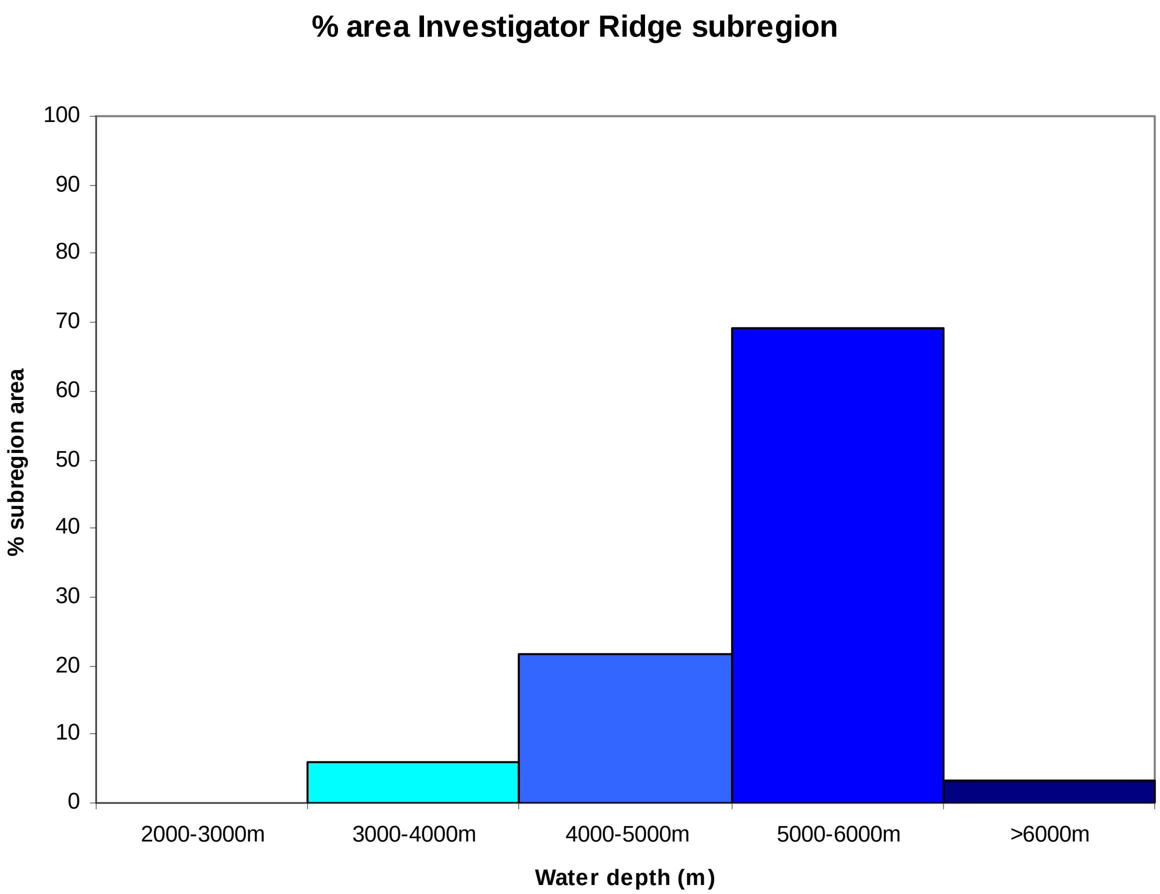


Figure 4-68. Bathymetry characterisation of the Investigator Ridge subregion, showing percentage breakdown of the subregion by the area covered for each bathymetry class.

Table 4-33. Water depth within geomorphic features in the Investigator Ridge subregion.

Feature	Maximum depth	Minimum depth	Mean depth	STD
Abyssal-plain/deep ocean floor	6000	3630	5340	214
Trench/trough	6410	5250	5850	233
Ridge	5760	4530	5270	560
Knoll/abyssal-hills/ hills/mountains/peak	5670	2560	4540	462
Basin	4610	1050	2700	113
Terrace	5060	2850	3890	744
Seamount/guyot	6000	3630	5340	368

Abyssal plain in this subregion can be divided into low relief basins in the northwest which are typical of seabed in areas of the Cocos Basin to the west, and elongate trenches that are unique to this subregion and associated with the Investigator Ridge. Trenches vary in depth and profile: to the east, trenches occur directly adjacent to the ridge with continuous slope from the ridge crest of the base of the trench. These trenches are relatively deep (approximately 1,100 m) and contain water depths from ~5,300-6,400 m. This is the only area of the subregion where water depths exceed 6,000 m and represents 16% of the Christmas and Cocos (Keeling) Islands territories area where water depths exceed 6,000 m. Trenches to the west of the ridge occur between 5 and 30 km from the base of the ridge in water depths of ~4,900-5,900 m, and have slightly lower relief.

Two sediment data points occur in the subregion in water depths >5,000 m (Figure 4-31). These both occur at the base of the ridge slope and suggest a wide range of sediment types accumulate in this zone. A total of 8 rock dredges occur on the ridge (Figure 4-32), providing coverage of seamounts and knolls that occur there.

Gravel dominated sediments were collected from 5,900 m water depth in the basin in the southeast of the subregion. Sediment in this basin is likely to be coarser and deposited at a greater rate due to its proximity to the ridge. Coarse clastic sediment deposition at water depths >6,000 m is rare in the EEZ. Mud dominated sediment with no coarse fraction was collected from 5200 m water depth on the abyssal plain in the northeast of the subregion. No sediment information was available for basins or any features to the east of the ridge. It is expected that the basin and abyssal plain to the west of the ridge will contain similar sediments to equivalent features in adjacent the West Cocos Abyssal Plain subregion.

Topography of the ridge top and slopes suggest they comprise both rock outcrops and sediment deposits. Dredging of the ridge top indicates rock type is highly variable along its length, including intrusive and extrusive igneous rocks, metamorphosed and brecciated rocks resulting from tectonic development of the ridge, and fragments of crystalline basement. Manganese crusts were collected from two locations on the ridge in 3,500 - 4,600 m water depth.

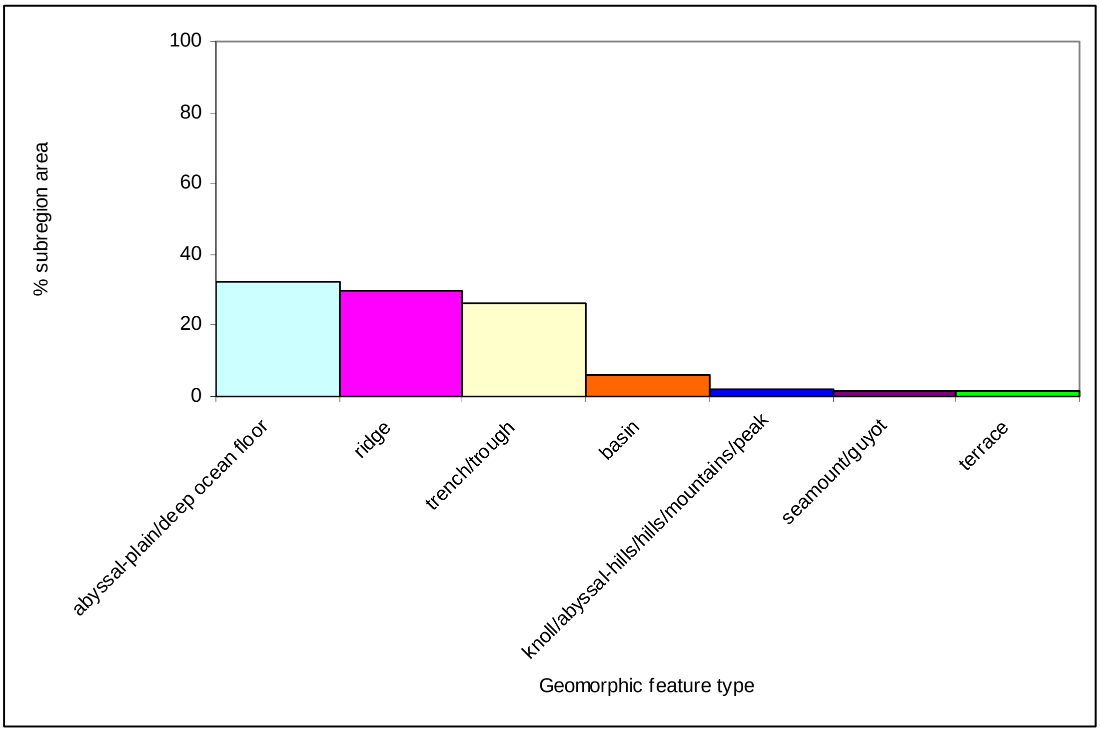


Figure 4-69. Geomorphology of the Investigator Ridge subregion, showing percentage breakdown of the subregion by the area covered for each geomorphic feature type present.

Table 4-34. Geomorphological characterisation of the Investigator Ridge (IR) subregion, and comparisons with (i) the total subregion area and (ii) combined Christmas & Cocos (Keeling) Islands (CI & CKI) territory areas.

Feature	**IR subregion Areas (km^2)**	**Percent IR subregion area**	**Percent total area of feature type in CI & CKI territories**
Abyssal-plain/deep ocean floor	19732	32.4	4.3
Ridge	18303	30.0	100
Trench/trough	16101	26.4	100
Basin	3798	6.2	6.1
Knoll/abyssal-hills/hills/mountains/peak	1318	2.2	12.5
Seamount/guyot	890	1.5	2.2
Terrace	831	1.4	3.7
Total	**60973**	**100**	**n/a**

Table 4-35. Representation of geomorphic features within the Investigator Ridge subregion as a percentage of the total number and area of these features within the entire AEEZ.

Feature	Percentage (number) of feature in AEEZ	Percentage (area) of feature in AEEZ
Abyssal-plain/deep ocean floor	11.8	0.85
Ridge	1.01	15.5
Trench/trough	9.4	7.5
Basin	2.1	0.53
Knoll/abyssal-hills/hills/mountains/peak	5.6	1.2
Seamount/guyot	1.3	0.89
Terrace	3.0	0.14

Ecological processes, habitats and biodiversity

Key ecological services that may be involved with this subregion comprise:

1. Alteration in water mass structures affecting the downstream and local water mass environments of communities;

2. Partitioning or reduction in exchange between the western and eastern sides of the ridge leading to differences in water mass composition and benthic exchanges on either side;

3. Potential restriction in the excursion of deep water species due to the presence of the ridge leading to situations that may favour local speciation processes across the divide;

4. Impact on current systems leading to potential enhancement of turbulence and mixing well above the level of the ridge leading to alterations in water mass and productivity with consequent implications for the rain of detritus and downstream environments;

5. Barrier to water mass exchange at depth leading to quiescent environments that may favour the production of manganese crusts and nodules;

6. The depth of the trenches are deep enough to be below the calcite compensation depth leading to dissolution of detritus shells and presence of unique deep trench environments and geological substrates with consequent, but unknown, implications for biological communities.

The surface water of the Investigator Ridge subregion are under the influence of water masses associated with the Indonesian Throughflow as discussed in the Regional setting chapter. Productivity in this subregion is higher in the northern half than the south, so specific protection measures aimed at pelagic species or species at depth that rely upon pelagic detritus, need to take account of this structuring.

At mid-depths down to about 1000 m are waters of the Intermediate Indian Central Water which are above the waters of the Antarctic Intermediate Water that extend down to approximately 2400 m. Below these waters are a variety of deep water masses that appear to be sourced from the Southern Ocean (with possibly some influence from the North Atlantic Deep Water). As discussed in the regional chapter, seamount and ridge structures can exert influences that extend

1000 m or more up the water column. In this case, the ridge extends to within 2500 m of the surface and given the extent of the structure we expect its influence to reach up to at least 500 m and more likely up to the surface. Baroclinic instabilities of the South Equatorial Current (Feng and Wijffels, 2002) as it moves across in the surface waters may also be affected leading to greater downstream productivity in the western waters of the Cocos (Keeling) Islands territory.

The steep western side is likely to contribute a range of materials resulting from tectonic and fracturing/fragmentation processes to the trench on that side of the ridge. At places where the ridge broadens (in some places by up to 15 km) at the crest, communities may have evolved to take advantage of the rain from the surface layer and any energetic ocean currents and processes caused by the interaction with the ridge (as demonstrated in the regional chapter).

Little is known of the communities at depth in this ridge and trench environment. The variety of elevations, widths and environments suggests that there is a rich and complex array of habitats that may be suited to communities that we know very little about.

The slopes on the both sides of the ridge contains numerous small scale north-south trending ridges and depressions that may act as receptacles for materials from above (biological and geological) and may also provide niche habitats and substrates for species.

The deep trenches of this subsystem are relatively deep at more than 1 km in places and water depths exceeding 6000 m. The wide variety of sediment types accumulating in these, which are depositing at a faster rate due to the supply of material from the steep ridges. Coarse material is expected in the deep trenches (below the calcite compensation depth) while in shallower environments of 5200 m or less, muddy sediments with associated infauna and prey are to be expected. The depth of the calcite compensation depth is a key determinant of sediment types and hence any biological communities.

The abyssal plain systems in this subregion are expected to contain similar communities to those in the abyssal subsystem of this territory, although some communities may have adapted to live at the interface between the abyss and the ridge subsystem.

Assessment of conservation values

Little is known about this subregion although is appears to have a range of unique features including an extensive, unbroken ridge rising from deep water (~5,000 m) and extending into shallower depths varying up to about 2,500 m. This ridge is likely to provide a range of hard substrate habitats on its surface and slopes that vary in depth, water mass characteristics, levels of productivity influence, etc. The combinations of characteristics are likely to support a diverse range of benthic and associated demersal community types that appear to be largely unimpacted by anthropogenic activity.

The deep troughs on either side of the ridge also provide habitat for unique community types given their association with and influence of the ridge and coarse sediments transferring from it. The calcite compensation depth also segregates these deep water habitats into those with fine sediments (~<5,000 m) and those without (~>5,000 m).

While little is known about the ecological communities in this subregion. It appears likely that this unique group of geomorphic features is supporting a wide range benthic and demersal community types, and possibly affecting increased productivity in associated pelagic communities.

Threats

Changes in climate may influence the dynamics and strength of the monsoon winds and current patterns which may change the mixing and upwelling regime in this subregion. This may influence pelagic productivity and to some extent benthic productivity. The deeper environments are low energy, stable nature, and likely to have relatively narrow physicochemical tolerances.

Changes to ocean currents such as the South Java Current, will potentially impact connectivity and nutrient dynamics of the seamounts in the region. Ocean acidification will impact on planktonic populations for calcifying organisms, and will likely result in changes to zooplankton species composition. Phytoplankton will also be affected, primarily through nutrient cycling mechanisms. The full impact of these changes is largely unknown.

Other climate impacts include warming seas (+1.8°C by 2070, Maunsell Climate impacts report) and potentially stronger (though less frequent) cyclones. These changes are unlikely to have a significant impact on the communities of this subregion.

The abundance and diversity of the deep abyssal biota has been rarely sampled, including the Indian Ocean abyssal environments. It is not clear how climate change impacts would affect these deeper communities. However, any physical disturbance may cause significant habitat and community degradation. For example, any new mining ventures that disturb these deeper environments are likely to have long-term impacts.

The Wharton Basin area is a known fishing ground for larger SBT, with the Japanese fishing fleet having low levels of effort in the area to the west of the Christmas Island territory (Figure 4-48). The sustainability of this fishing pressure has been questioned. Also, fishing boats entering the AEEZ waters to target SBT may be a risk to these populations.

4.3.6 Cocos (Keeling) – Cocos Volcanic Field

This subregion contains the large cluster of seamounts, which include the one on which the Cocos (Keeling) Islands have formed. This subregion covers an area of approximately 167,100 km² (22% of the Christmas and Cocos (Keeling) Islands territories). It comprises large areas of elevated volcanic topography (51,403 km^2, 31% of subregion area) and abyssal plain of the Cocos Basin that occurs directly adjacent to this topography (115,460 km^2, 69% of subregion area) (Figure 4-70, Figure 4-71). Water depths in the subregion range from 0-5,913 m, with more than 99% of the total area occurring in depths >2,000 m, and >85% in depths >4,000 m (Figure 4-70, Figure 4-72). This subregion contains 83% of the total area of the Christmas and Cocos (Keeling) Islands territories where water depths are <1,000 m. The Cocos Volcanic Field contains around 26% of the total area of seamount peaks, 31% slopes and 33% of terraces in the Christmas and Cocos (Keeling) Islands territories (Table 4-38). These seamounts represent approximately 11% of seamount area in the AEEZ.

A total of 13 large seamount/guyots (diameter >20 km) and several smaller peaks associated with these occur distributed across the subregion (Figure 4-71). The largest seamount within this area is the Muirfield seamount, to the south-west of South Cocos (Keeling) Islands, which rises from 4,000 m to 17m bsl (Figure 4-37).

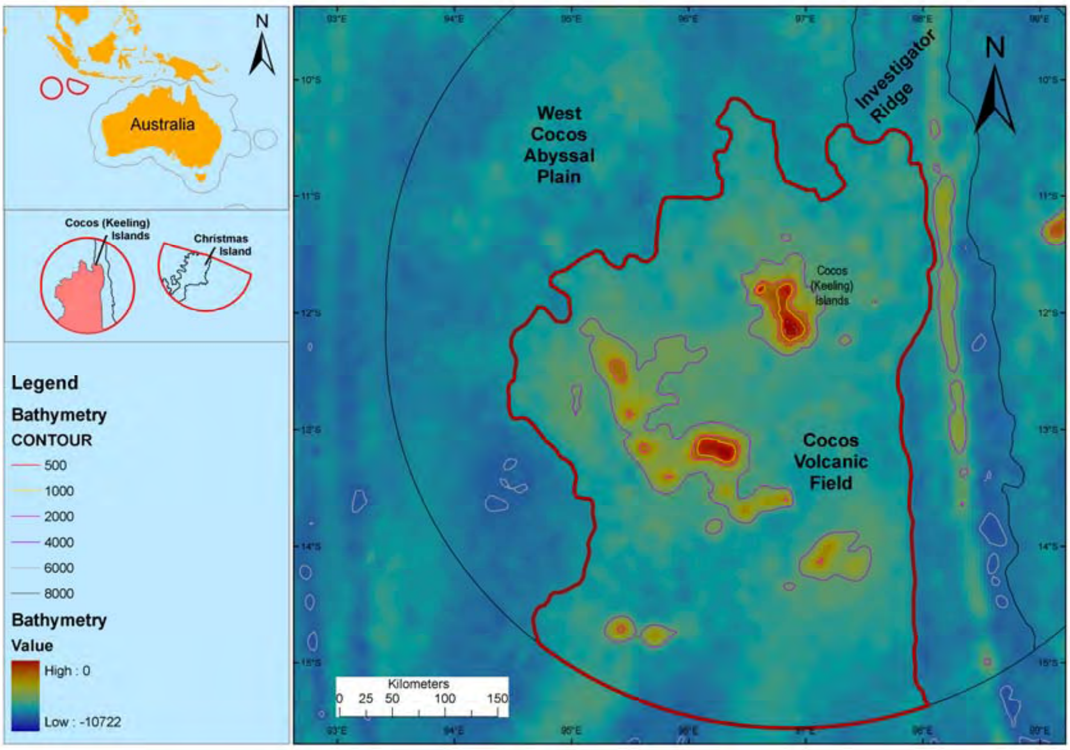


Figure 4-70. Bathymetry of the Cocos Volcanic Field subregion.

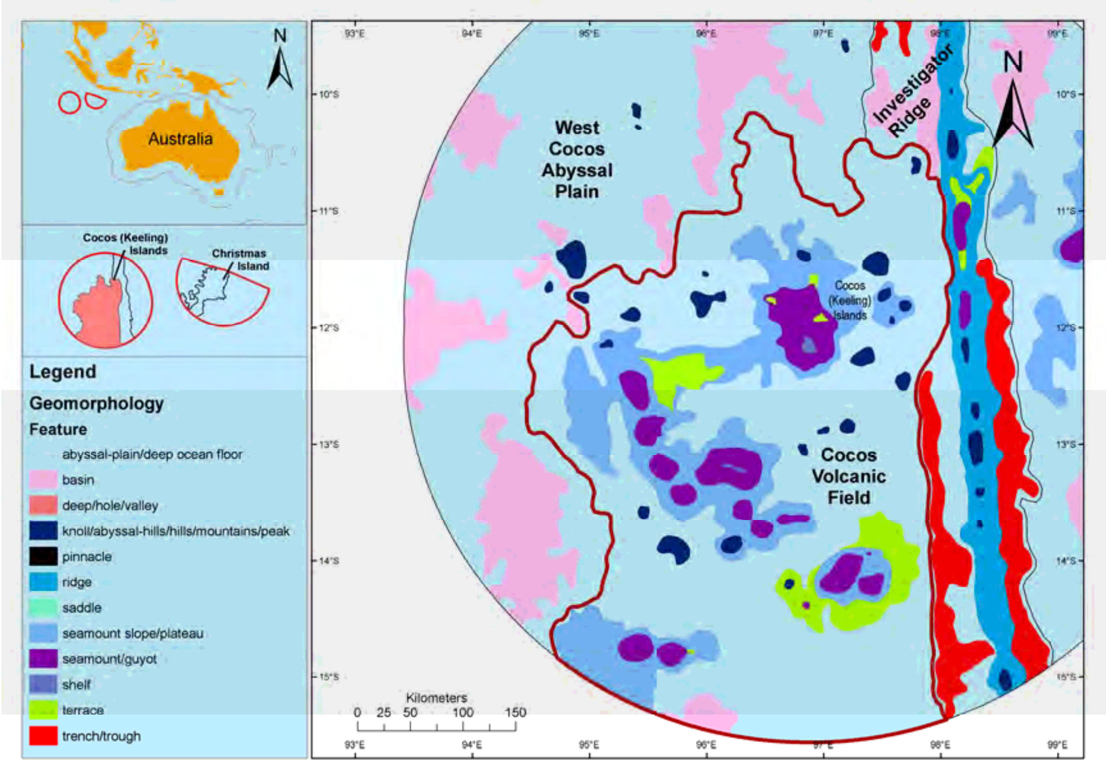


Figure 4-71. Geomorphology of the Cocos Volcanic Field subregion.

The age of the seafloor in this area is somewhere between 60 – 90 million years. The Cocos (Keeling) Islands are found within this subregion, though unlike Christmas Island, these are coral atolls. The atolls have evolved on a large guyot whose base is at a depth of approximately 5,000 m and has a diameter of ~70 km. Between the two atolls, the guyot plateau lies at a maximum depth of 1,000 m. The seamounts to the south of the Cocos (Keeling) Islands tend to be more ridge-like in morphology, with clusters of small volcanic cones. This subregion and the Christmas Central Ridge are the only subregions containing significant areas of volcanic topography and containing emergent islands.

Excepting the Muirfield seamount (130 km SW of South Cocos), other seamount peaks in the subregion occur between 1,300-3,000 m below the sea surface. Lesser peaks reach water depths up to 5,000 m. However, the area of seabed in water depths <2,000 m occurs concentrated in two locations - on the Cocos and Muirfield seamounts. This contrasts to the Central Ridge subregion where seabed in these water depths is distributed across numerous small peaks.

The thickness of the corals underlying the Cocos (Keeling) atolls is unknown. However basaltic rocks have been dredged in local waters to suggest that it is somewhere between 500-1,000 m (SO199 Cruise Report ex. Pulu Keeling National Park Plan of management, Darwin 1999). Hard rock sampling during Sonne Cruise 199 did not show any evidence of recent volcanism in this area (IFM-GEOMAR 2009), sea floor Jurassic in age, getting younger to the north of 12°S.

Geomorphology associated with the seamounts, include slopes that are broader and shallower than those in the Christmas Island region. Slopes are irregular and terraces (7,374 km^2, 4% of the Christmas and Cocos (Keeling) Islands territories) are common locally, particularly in the south east of the subregion. Unlike the Central Ridge subregion, volcanic topography in this subregion shows little connectivity and seamounts are frequently separated by large areas of abyssal plain with water depths of 4,500-5,000 m.

Water depths on the abyssal plain and features occurring there range from approximately 3,100-5,700 m (Table 4-37), which is relatively shallow compared to surrounding abyssal plain of the Cocos Basin, and significantly shallower than abyssal plain surrounding seamounts in the Central Ridge subregion. Geomorphic features occurring on the abyssal plain include Knoll/abyssal hills/mountains/peaks (3,619 km, 2% of the subregion) and a small part of a Basin that extend to the south of the territory (1,430 km^2, 0.86% of the subregion).

A total of 11 sediment data points occur across the subregion, though more than half of these are clustered in the subregion's north (Figure 4-31). Samples occur in water depths ranging from 2,338 to 4,935 m with the highest densities in water depths from 4,000 - 5,000 m. Data points cover 3 of the 9 geomorphic features represented in this subregion with similar densities achieved in Abyssal Plain/deep ocean floor (7 data points) and seamounts and associated slope/plateaus (4 data points). In addition to this, seven rock dredges detected lava fragments and volcaniclastics on larger seamounts, their slopes and adjacent abyssal plain (Figure 4-32).

Variable water depths and geomorphology in the subregion result in sediments ranging from gravel-rich with significant sand and mud fractions, to homogeneous mud-dominated. A relationship between sediment texture and water depth as observed in the Central Ridge subregion may occur in this subregion, but is difficult to assess as only rock dredges and no sediment samples are available for shallow water depths.

Table 4-36. Bathymetry characterisation of the Cocos Volcanic Field subregion. Bathymetry range for the entire subregion is 0-5,913 m (mean 4573 m, stdev 723).

Water Depth (m)	**Area (km^2)**	**Percentage area of subregion**
Coastal/land	52	0.03
0-500 m	501	0.3
500-1000 m	528	0.3
1000-2000 m	1578	0.9
2000-3000 m	4970	3.0
3000-4000 m	11491	6.9
4000-5000 m	112206	67.1
5000-6000 m	35775	21.4

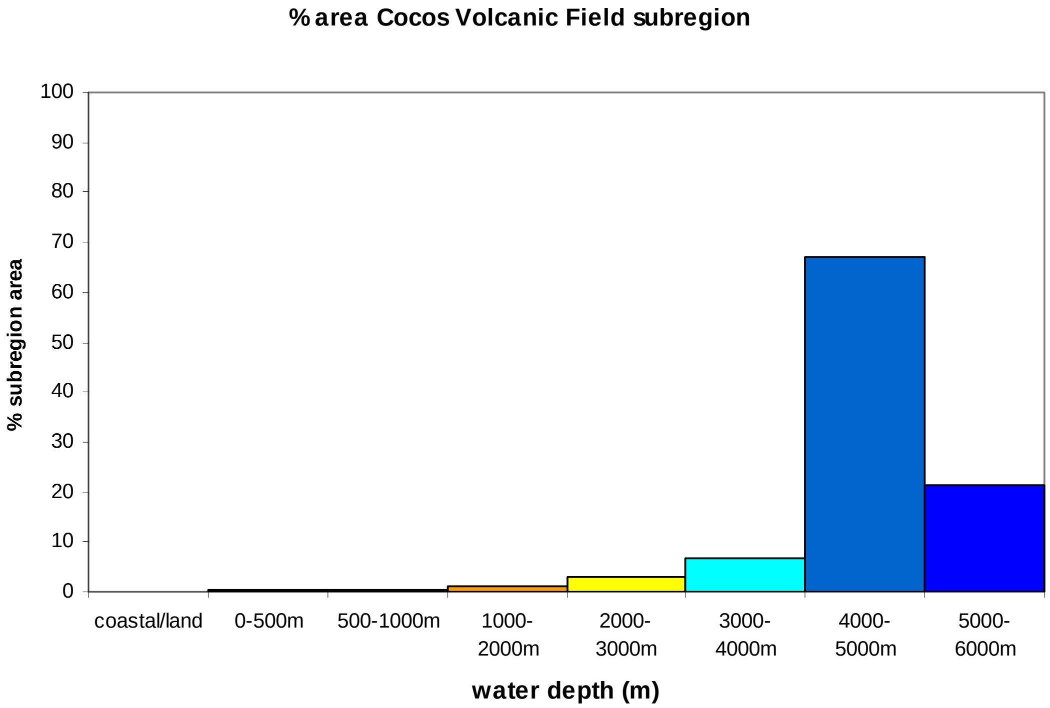


Figure 4-72. Bathymetry characterisation of the Cocos Volcanic Field subregion, showing percentage breakdown of the subregion by the area covered for each bathymetry class.

Samples collected from abyssal plain/deep ocean floor and seamount peaks and seamount slope/plateaus in the north of the subregion suggest that these features have a relatively homogeneous sedimentology dominated by mud, with variable sand content and rare occurrences of gravel. It is likely that these areas contain areas of hard substrate and gravels resulting from erosion of these may occur locally on the slope and base of slope but are expected to be far less abundant than in the area around Christmas Island.

Coarse sediments are more abundant in the south of the subregion. No samples were collected from southern seamounts or their slopes. However, gravels are common on the abyssal plain in the south of the subregion with coral gravel dominating sediment at one location on the abyssal plain near some low abyssal hills. Pumice pebbles are present at one site. In general, abyssal plain sediments tend to be dominated by mud with minor sand, as in the north. No samples were collected from low relief topography such as knolls/abyssal hills/hills/mountains/peaks or basins.

Table 4-37. Water depth within geomorphic features in the Cocos Volcanic Field subregion.

Feature	Maximum depth	Minimum depth	Mean depth	STD
Abyssal-plain/deep ocean floor	5670	3130	4870	257
Ridge	5180	4980	5090	50
Knoll/abyssal-hills/hills/mountains/peak	5230	3620	4380	255
Seamount slope/plateau	5330	2140	4180	412
Terrace	4920	2560	4360	273
Seamount/guyot	4670	0	2500	939
Shelf	2350	0	90	160
Basin	5800	5580	5650	34

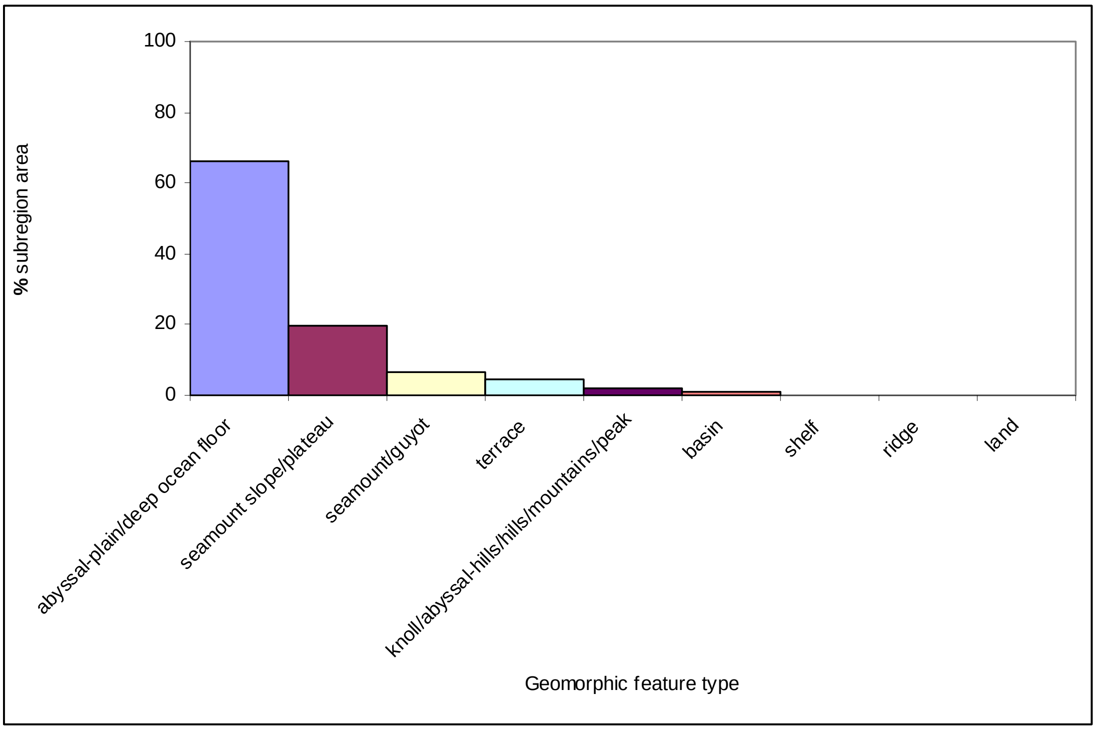


Figure 4-73. Geomorphology of the Cocos Volcanic Field subregion.

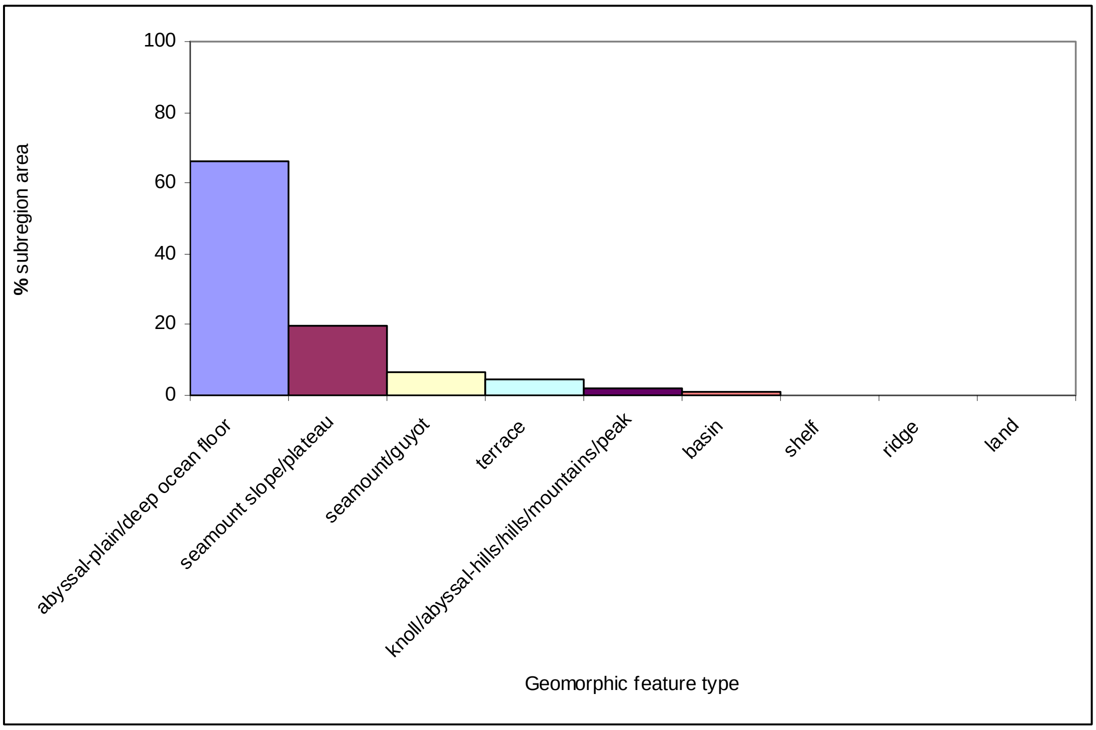


Figure 4-74. Geomorphology of the Cocos Volcanic Field subregion, showing percent total subregion area for each geomorphic feature type present.

Ecological processes, habitats and biodiversity

The pelagic environment in Cocos Volcanic Field subregion is subject to the same general seasonal drivers as described above. The oligotrophic waters of the Indonesian Throughflow dominate for most of the year, although variable levels of higher productivity water from upwelling along the Java coast can reach into the north of this subregion. The shallower seamounts in the region also interact with surface and sub-surface currents to drive eddies that produce relatively local mixing and higher productivity cells. This pelagic biomass delivers particulate organic matter or detrital rain into the deeper waters and benthic habitats, thereby driving increased species richness in the subregion.

The shallower seamounts (Cocos and Murefield) have extensive areas of habitat in the surface waters and support highly diverse reef systems. The Cocos (Keeling) Islands themselves contain an even wider range of habitat types including reefs, sandy beaches, mangroves, seagrass beds etc (see 4.3.9).

The deeper habitats are poorly known although large areas of abyssal plain/deep ocean floor extend through the subregion. The range of sediment types described above suggests a relatively broad range of benthic communities occurs in these habitats.

Assessment of Conservation values

One of the most striking features in this subregion is the extensive areas of shallow seamount habitat of the Cocos and Murefield Seamounts. These provide unique areas of highly diverse reef and other shallow water communities, representing the only extensive shallow reef features for about 1000 km. In an Australian context they are unique when compared to other shallow reef systems in Australia’s western regions.

The Cocos (Keeling) Islands are an internationally recognised seabird rookery and is one of the major seabird breeding grounds in the Indian Ocean. Seabirds occur in large numbers on North Keeling Island, in particular, with about 24 bird species currently found on the island, and 15 of these breeding in the Park. Pulu Keeling National Park houses the world's largest breeding population of red foot booby (*Sula sula*) colonies. It also has the second largest lesser frigate bird (*Fregata ariel*) nesting population in Australia and possibly the Indian Ocean (DEH 2004b). The island habitats also appear to be an important staging point for a range of migratory birds (see 4.1.5).

The reefs in the Central Ridge subregion also provide habitat for one species of endemic fish, Cocos pygmy angelfish (*Centropyge joculator*), and two species of corals. Nine of the 99 species of shallow reef corals have not been recorded anywhere else in the eastern Indian Ocean.

Little is also known about the other environments within this subregion, but like other subregions described above, their unique geographic location and subsequent influence of biophysical drivers, in conjunction with their own unique combination of geomorphic features, sediment characteristics and connectivity to other habitats indicates that unique ecological communities are probable in most depth zones, warranting further investigation.

Threats

Productivity in the subregion is dependent on the climate and current patterns in the region and the extensive shallow reef environments may also be highly vulnerable to rising sea temperatures. Cyclones have also been known to destroy seabird breeding habitat and increased intensity through climate change may reduce seabird populations over time. Outbreaks of crown of thorns starfish (*Acanthaster planci)* are known to occur and may be severely impacting local corals. These outbreaks have been linked to both natural and anthropogenic changes to reef dynamics.

Other natural processes have recently altered the southern lagoon habitat through its closure from the open sea. Water temperature increase and deoxygenation can affect water quality and impact a range of habitat types, species richness and diversity.

Human occupation of the south islands pose a threat to shallow habitats and the natural resources they support. The Southern atoll has already been cleared to make way for a coconut plantation. Poaching of seabirds is also an ongoing problem with potentially major impacts on the internationally significant rookeries. Illegal fishing, marine pollution and debris from commercial shipping can also impact marine habitats and communities. Foreign fishing vessels also have the potential to introduce pests and diseases.

Given the unique nature of these environments careful control of human activity is warranted.

Table 4-38. Geomorphological characterisation of the Cocos Volcanic Field (CVF) subregion, and comparisons with (i) the total subregion area and (ii) combined Christmas & Cocos (Keeling) Islands (CI & CKI) territory areas.

Feature	CFV subregion areas (km^2)	Percent total CFV subregion area	Percent total area of feature type in CI & CKI territories
Abyssal-plain/deep ocean floor	110411	66.1	24.2
Seamount slope/plateau	33193	19.9	30.9
Seamount/guyot	10836	6.5	26.4
Terrace	7373	4.4	32.5
Knoll/abyssal-hills/hills/mountains/peak	3619	2.2	34.2
Basin	1430	0.86	2.3
Shelf	218	0.1	87.3
Land	14.1	0.008	8.3
Ridge	7.9	0.005	0.04
Total	**167102**	**100**	**n/a**

Table 4-39. Representation of geomorphic features within the Cocos Volcanic Field subregion as a percentage of the total number and area of these features within the entire AEEZ.

Feature	Percentage (number) of feature in AEEZ	Percentage (area) of feature in AEEZ
Abyssal-plain/deep ocean floor	5.88	4.74
Seamount slope/plateau	17.4	30.87
Seamount/guyot	9.62	10.78
Terrace	4.55	1.29
Knoll/abyssal-hills/hills/mountains/peak	10.1	3.22
Basin	2.13	0.20
Shelf	3.36	0.02
Ridge	1.01	0.01
Land	0.16	0.0001

4.3.7 Cocos (Keeling) – West Cocos Abyssal Plain

The West Cocos Abyssal Plain covers an area of approximately 145,251 km² (20% of the Christmas and Cocos (Keeling) Islands territories) and is the most western of the Christmas and Cocos (Keeling) Islands territories subregions. It is composed of the southern part of the broader Cocos Basin that extends to the northwest to the Ninetyeast ridge and characterised by a deep abyssal region with several low relief knoll/abyssal hills/hills/mountains/peaks (Figure 4-75, Figure 4-76).

Geological and biophysical drivers

This subregion shows little variation in topography across its area. Water depths range from 4,013-6,104 m, with >80% of subregion is in depths of 5,000-6,000 m (Table 4-40) which represents 30% of the total area of the Christmas and Cocos (Keeling) Islands territories where water depths exceed 5,000 m. However, very little of the subregion exceeds 6,000 m (400 km, <1% subregion area).

The majority of the subregion comprises abyssal plain (105,108 km^2, 72% of the subregion area) and numerous broad low relief basins (38,843 km^2, 27% of the subregion area). Individual basins cover up to 16,700 km, and generally extend beyond the territory boundary. Basin depths generally do not exceed 500 m below the surrounding abyssal plain and generally water depths in basins do not exceed 6,000 m. One exception is the southernmost basin (10,700 km area) that is 870 m deep and contains the only areas of the subregion with water depths >6,000 m. Basins in this subregion represent 62% of the total area of basins in the Christmas and Cocos (Keeling) Islands territories although they represent only a minor portion of the total area of basins in the Australian EEZ (5.4%).

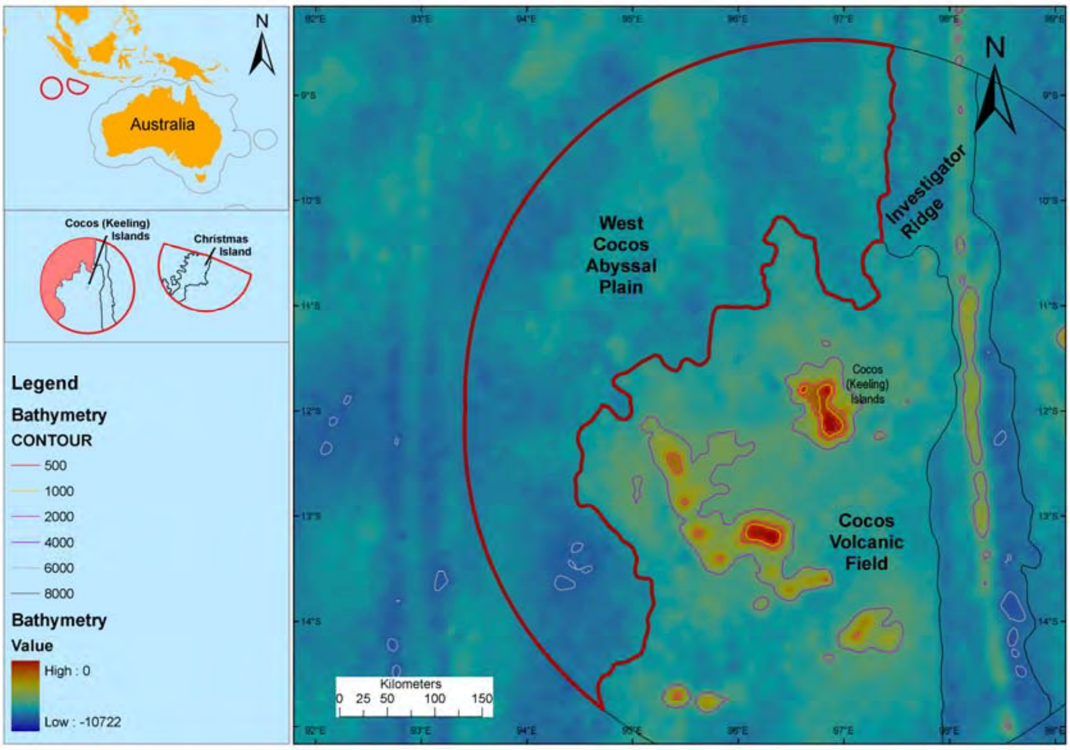


Figure 4-75. Bathymetry of the West Cocos Abyssal Plain subregion.

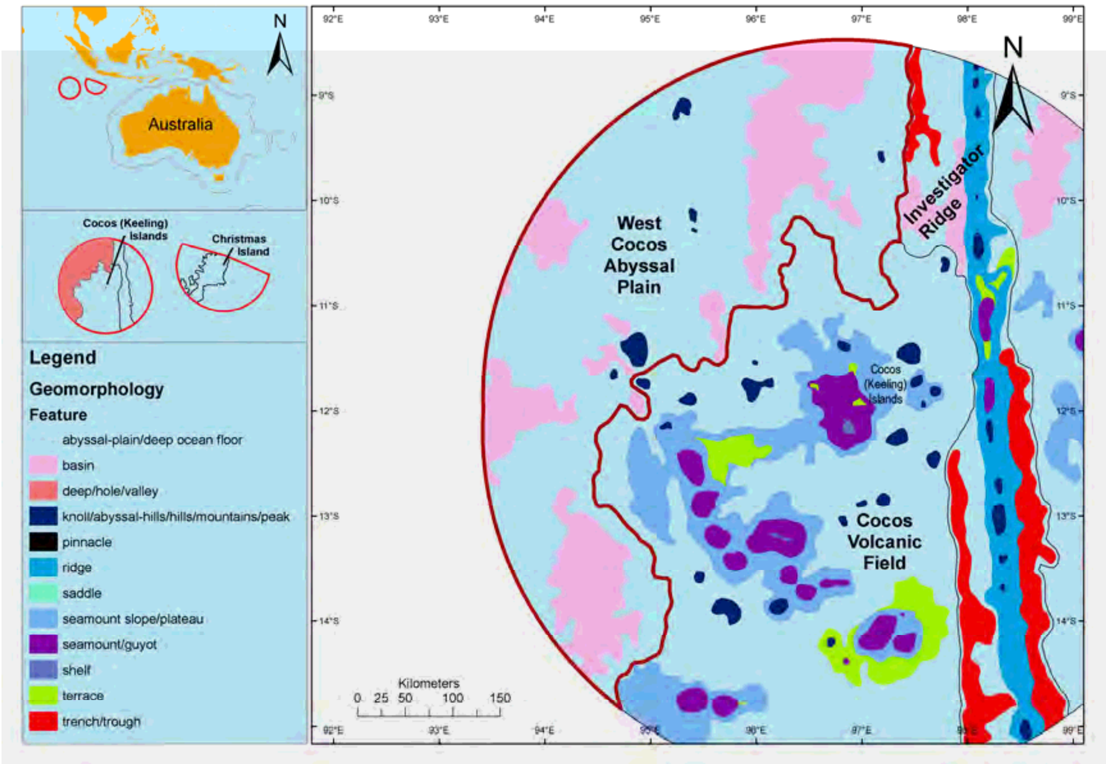


Figure 4-76. Geomorphology of the West Cocos Abyssal Plain subregion.

A total of 6 knoll/abyssal hills/hills/mountains/peaks (1,300 km^2, 0.9% of the subregion) occur across the northern half of the region (Figure 4-76). Elevation of individual features ranges from approximately 100 m for smaller features (width 10-20 km) to 700 m for a large feature adjacent to the main ridge (width ~30 km). Water depth on these features ranges from 4,200 - 5,800 m.

A total of sediment 5 samples have been taken in the region in water depths ranging from 5,000 to 5,600 m (Figure 4-31). These provide coverage of abyssal plain (2 samples) and basins (3 samples). No samples occur on knolls/abyssal hills. Sediments across the region are relatively homogeneous with all locations dominated by mud, with lesser sand. The exception is a sample from the floor of a basin which contains mud with low concentrations of manganese micronodules.

Table 4-40. Bathymetry characterisation of the West Cocos Abyssal Plain subregion. Bathymetry range for the entire subregion is 4,013-6,104 m (mean 5,280, stdev 290).

Water Depth (m)	Area (km^2)	Percentage area of subregion
4000-5000 m	23415	16.1
5000-6000 m	121446	83.6
>6000 m	389	0.3

Table 3-36. Water depth within geomorphic features in the West Cocos Abyssal Plain subregion

Feature	Maximum depth	Minimum depth	Mean depth	STD
Basin	5780	5210	5460	87
Abyssal-plain/deep ocean floor	5530	4380	5090	197
Knoll/abyssal-hills/hills/mountains/peak	4700	4420	4530	79

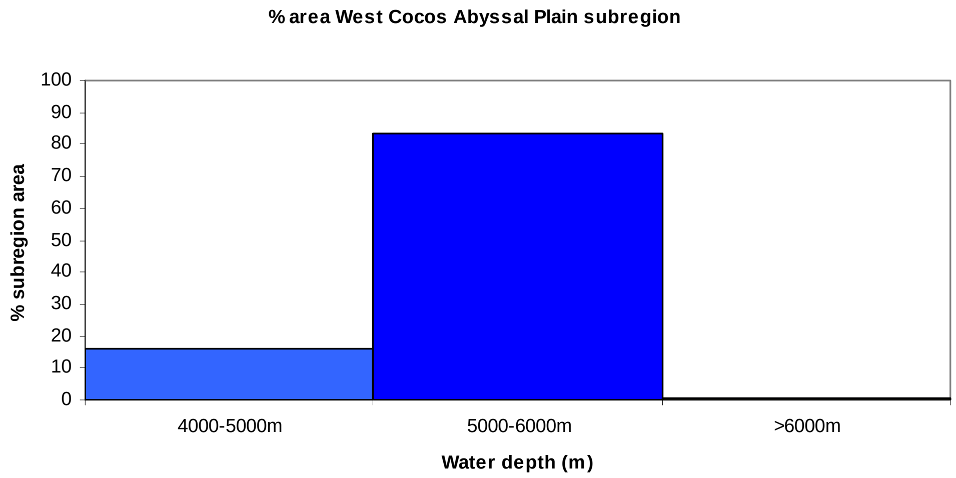


Figure 4-77. Bathymetry characterisation of the West Cocos Abyssal Plain subregion, showing percentage breakdown of the subregion by the area covered for each bathymetry class.

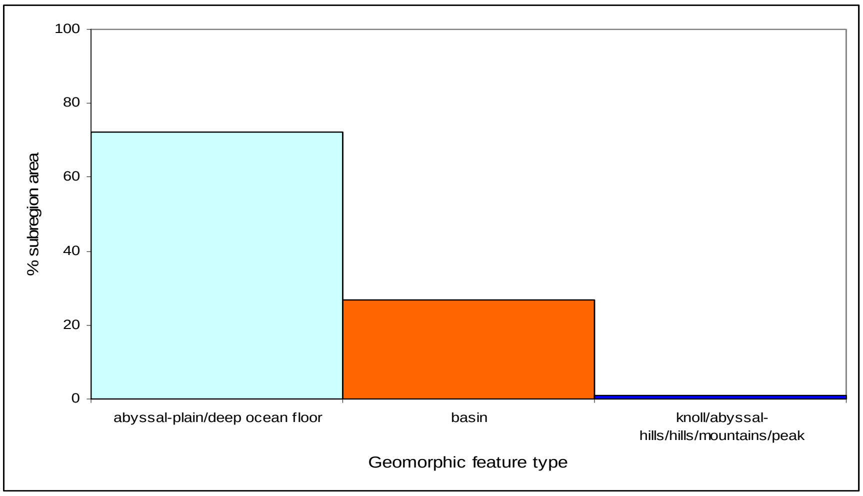


Figure 4-78. Geomorphology of the West Cocos Abyssal Plain subregion, showing percentage breakdown of the subregion by the area covered for each geomorphic feature type present.

Table 4-41. Geomorphological characterisation of the West Cocos Abyssal Plain (WCAP) subregion, and comparisons with (i) the total subregion area and (ii) combined Christmas & Cocos (Keeling) Islands (CI & CKI) territory areas.

Feature	WCAP subregion areas (km^2)	Percent total WCAP subregion area	Percent total area of feature type in CI & CKI territories
Abyssal-plain/deep ocean floor	105108	72.4	23.0
Basin	38843	26.7	62.3
Knoll/abyssal-hills/hills/mountains/peak	1300	0.9	12.3
Total	**145251**	**100**	**n/a**

Table 4-42. Representation of geomorphic features within the West Cocos Abyssal Plain subregion as a percentage of the total number and area of these features within the entire AEEZ.

Feature	Percentage (number) of feature in AEEZ	Percentage (area) of feature in AEEZ
Abyssal-plain/deep ocean floor	17.6	4.5
Basin	19.1	5.4
Knoll/abyssal-hills/hills/mountains/peak	3.0	1.2

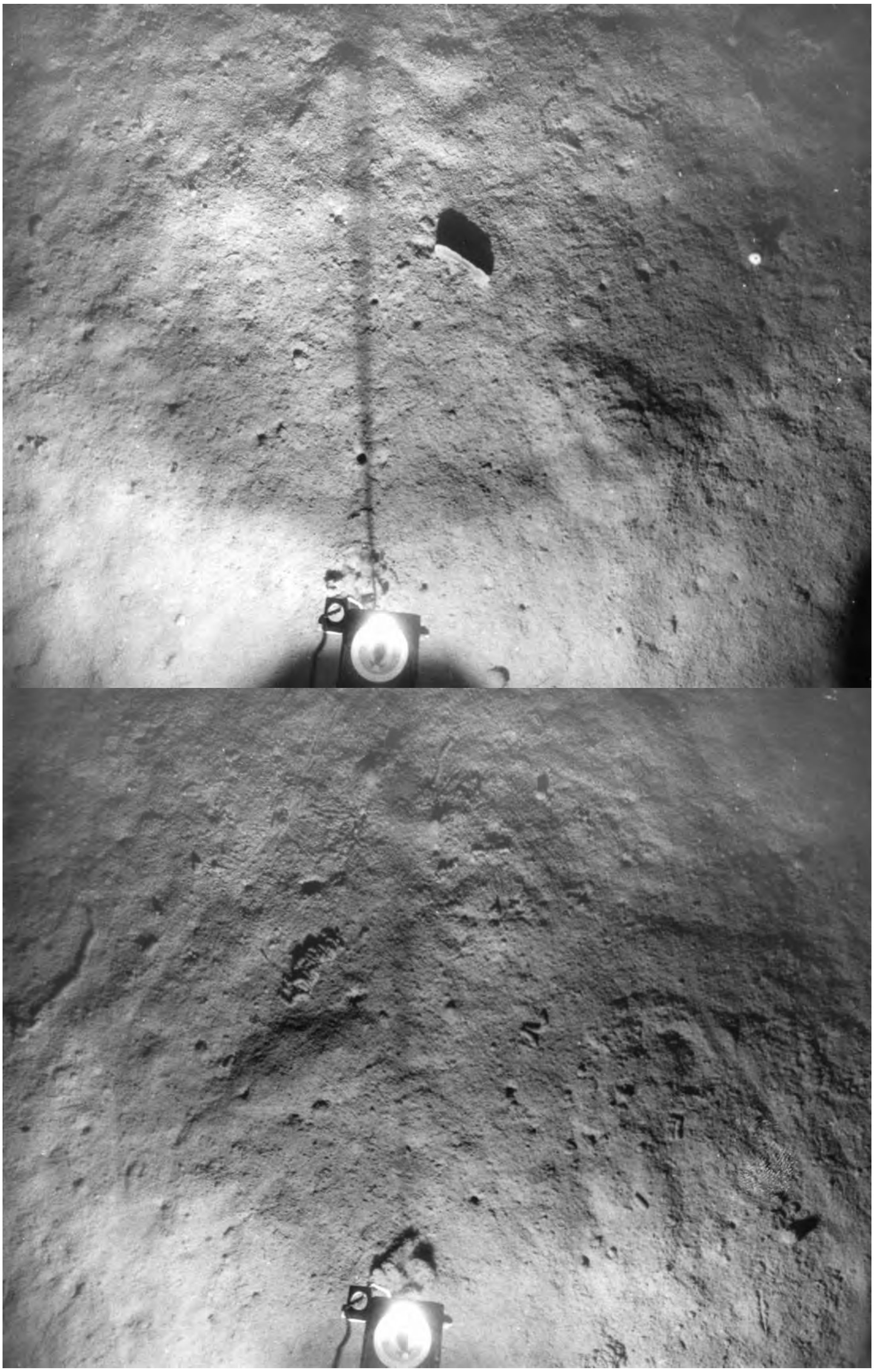


Figure 4-79. Photographs of the benthic habitat at location VM28-245 (just outside the northern extent of the subregion, showing soft sediments (depth 2800 m).

Ecological processes, habitats and biodiversity

The subregion has the lowest level of primary productivity of all the subregions (Figure 4-14, Figure 4-15 and Figure 4-16) due to the low relief of the bottom topography and distance from upwelling events such as those associated with the Java coast. Most of the seamounts within the subregion are relatively deep (>4000 m) and would not produce significant upwelling or associated productivity associated with them. This subregion falls under the influence of the Indonesian Throughflow waters which generally leads oligotrophic conditions with the suppression of the thermocline and deep ChlA maxima.

However, the surface waters in the northern part of the subsystem does have some enhanced productivity probably during spring related to the dynamics of the ITF and associated eddies (Figure 4-39), resulting in some enhanced productivity during that time. These northern waters are known to contain populations of Bigeye (*Thunnus obesus*) and Yellowfin tuna (*T. albacares*) (Figure 4-13).

The deep demersal environment is reliant for its energy input on falling detritus or particulate organic matter (marine snow) and the occasional large carcass directly supplied by the pelagic environment. In this instance, the generally low productivity of the surface waters in the subregion would result in a low productivity in the benthic system.

Any hard substrate on the tops of the small numbers of knoll/abyssal hills/hills/mountains/ peaks may have very sparse epibenthic communities from a variety of animal groups, including deep sea corals. These epi-benthic communities may in turn support a very sparse population of bentho-pelagic fish and cephalopods.

Given the area is influenced by the South Java Current and other dynamic oceanographic conditions, we would expect a high level of connectivity with other areas within the Christmas and Cocos (Keeling) Islands territories, and the neighbouring slopes of the Australasian continental slopes.

Assessment of Conservation values

The West Cocos Abyssal Plain subregion is relatively remote and has had little human disturbance with the exception of variable levels of pelagic fishing effort over recent decades. However, little fishing effort or illegal, unregulated and unreported (IUU) fishing is reported to currently occur in this subregion. The benthic environments are largely undisturbed. None of the subregion is currently protected other than through fishing effort regulation.

The surface waters of the subregion are mostly oligotrophic, with sporadic interannual variability in productivity during autumn and due to seasonal upwelling forced by the local climate and oceanographic conditions.

This subregion is has large expanses of abyssal plain (72% of the subregion area and 23% of the Christmas and Cocos (Keeling) Islands territories) and basin environments (27% of the subregion area and 62% of the Christmas and Cocos (Keeling) Islands territories) that are likely to have sparse, but potentially unique community types associated with them.

There are a range of species that are listed (under the EPBC Act) that may either use the East Cocos Abyssal Plain subregion as a foraging ground or other habitat (see 4.1.5). However, there has been little scientific study of species such as whales, dolphins, seabirds and turtles in the subregion so the importance of this subregion for these species is largely unknown.

Threats

Changes in climate and ocean acidification are likely to influence the pelagic and lesser known benthic dynamics and productivity in this region in the same way as described for other subregions.

Physical disturbance such as new mining ventures may cause significant habitat and community degradation. Such impacts in these deeper environments are likely to result in long-term change.

Information gaps

- Knowledge of the distribution and life history of pelagic communities and their use of the different current systems, eddy habitats, water masses and interaction with benthic communities and habitats;
- Dependence on and/or links between pelagic communities associated with seamount communities (both territories) and the general overlap interaction of the pelagic system with seafloor habitats at various depth levels;
- Dependence of cetacean, seabird and turtle species on habitats (both territories), including ranges, feeding/breeding use of spatial and temporal productivity episodes and adaptions (such as specialised feeding of Abbot’s Booby bird on flying fish);
- Knowledge of communities on benthic habitats within differing water mass layers, including seamounts, slopes, terraces, abyssal plain habitats, including seasonal and spatial dynamics (both territories), and how that dependence is conditional upon the system and subsystem context;
- Effect of Investigator Ridge and volcanic province on current and water mass dynamics;
- Knowledge of phyto and zooplankton communities, including seasonal other temporal and spatial dynamics (both territories) ;

Monitoring

- Potential impacts of climate change in altering monsoonal patterns of wind and air-sea fluxes that may change productivity, seasonal currents, heat stress, water mass formation/layering, subduction and deep currents. Interactions between the pelagic and demersal systems also need to be understood;
- Annual variability and trends in current patterns including links to productivity levels;
- Fishery catch and effort in the broader region and its impact on pelagic species abundances, and sources of larvae, in both territories;
- Impacts of IUU fishing in the territories and broader region;
- Health of shallow reef communities that may be highly vulnerable to climate change, including bleaching;
- Potential impacts of climate change and other stressors on Christmas Island affecting availability and distribution of crab larvae to marine species such as the whale sharks.
- Shallow reef island habitats

4.3.8 Christmas Island reef

Island + slope less than 500 m

The Christmas Island (CI) coastline is predominantly cliff with few breaks for beaches and some lower terraces. The underwater topology varies according to the exposure and aspect of the coast but within a couple of kilometres of the island the water depth drops to over 5000 m. Even within 500 m of the coastline the water depth can be greater than 1000 m.

Prevailing weather

The South East trade winds are prevalent in the dry, SE monsoon season (May to September). Heavy swells usually impact the east and south coasts at this time. The wet, erratic North West Monsoon usually brings more rainfall and large swells to the north coast around December, continuing until March / April. Although it has suffered from severe winds and heavy swells from cyclones close by, there has never been a direct hit. The island is located at 10^{o}S which is at the northern edge of the cyclone belt.

Exposure and aspect

The south coast is considered the most exposed and inaccessible coast. It is pounded by swells for most of the year and the coastline is rough cliffs with many blowholes and fallen boulders close to shore. The east coast is also exposed to the prevailing weather. Underwater the reef slopes gently on this side without the reef drop offs common around the rest of the island. The east coast is accessible through Ethel Beach boat ramp during the NW monsoon. During the SE monsoon access to the ocean is restricted to the boat ramp at Flying Fish Cove on the North Coast. Hence, very little fishing occurs on the east or south coasts at this time. These coasts vary from the north and west coasts which are sheltered from the SE trade winds. The cliffs along these coasts are known to contain many caves and crevices.

There is no information of the local current regimes.

There are 7 main beaches on Christmas Island with a total length of 1380 m. Some other sandy gullies are exposed at low tides. The beaches are mostly coral rubble with some coarse sand. Dolly (90 m long) and Greta (50 m long) are the only sandy beaches.

Marine environment

The coastal marine zone has a limited range of habitats. There is little soft bottom, shallow waters, sheltered habitats or level deep water (<15 m) and therefore species diversity is limited. The isolation of the island also limits diversity as shallow marine species need long pelagic larval stages to be recruited to the island.

The South Equatorial Current is thought to be the main mechanism bringing nutrients to the island (Meyers *et al.,* 1984). This is at its strongest at the end of the SE trade winds season (Donguy & Meyers 1994). Much of the larval recruitment is reliant on this current system. The island is only a small land mass in the middle of the open ocean so the coastal waters are well mixed with almost constant wind generated waves and large swells from the prevailing weather.

The fish fauna is described as slightly impoverished Indo-Malayan belonging to the Western Pacific province of the Indo-west Pacific faunal region (Allen *et al.*, 2007, Hobbs *et al* 2008). The reef ecosystem has low endemism and diversity (Allen *et al.,* 2007). Surveys of the fish fauna have identified 607 fish species, including 4 endemics and 2 near endemics. Of these 50 species are not found in other Australian waters, 28 are found in extraordinary abundance and 8 are hybrid species. Many species show Indian Ocean and Pacific species hybridisation offering a unique opportunity to study preferences of species that hybridise. Indian Ocean species have been seen living alongside their Pacific Ocean counterparts (Hobbs *et al.,* 2008). There are also some notable absences in the fish fauna. A range of species are abundant in other Indo Pacific locations but absent from Christmas Island. These include coral trout (genus Plectropomus), emperors of the genus Lethrinus, the Humbug damselfish (*Dascykkus aruanus*), dragonettes (Callionymidae) and rabbitfish (Siganidae) (Allen *et al.,* 2007). Although Allen *et al.,* (2007) state that stingrays are absent, they are seen infrequently.

The majority of the shallow sea bed substrate is rock, rubble or coral (Wells 2000). Hard coral cover on the north and west coasts are high, reaching up to 75% at Flying Fish Cove and 65% at Chicken Farm (unpublished Reef Check data). The coral composition is not diverse compared to species rich reefs of Indonesian, but it is abundant. The composition of the corals on Christmas Island is uncertain as the WA Museum survey was undertaken after a massive coral die off (Done & Marsh 2000). During the survey many corals, especially *Acropora* spp. were colonising but were still small. Coral species then, and still are, dominated by the families Acroporidae, Agariciidae and Faviidae. Additional to these families Pocilloporidae and Poritidae are particularly abundant on the reef.

The most abundant octocoral on the reef is the blue coral, *Heliopora coerulea* (Done & Marsh 2000). The soft corals are the typical alcyonacean of the genera Lobophytum, Sarcophyton and Sinularia. These occur in many locations but were not abundant. The soft corals are more abundant on the East Coast than any other area.

The benthic marine invertebrates tend to be found in small numbers, are patchily distributed and are of small size (Marsh 2000, Wells & Slack Smith 2000). The presence and absence of species is determined and understood from the available habitats and the larval cycles of species. Mollusc diversity was low as there is little sandy or muddy habitat and the island is too isolated for the levels of larvae recruitment seen on mainland reef systems (Wells 2000). Gastropods make up 80% and bivalves 20% of the mollusc fauna. This composition is similar to the NW shelf-edge atoll of Western Australia. The decapod crustacean fauna is typical of a topical, oceanic Indo West Pacific Island dominated by coral and coral rubble habitats (Morgan 2000). Common genera are xanthoid, grapsid and majid crabs and 3 species of rock lobster.

Christmas Island is also unique in that it is home to 3 species of true land crab. These crabs inhabit the whole island and spawn along the whole coastline. They are dependent on the ocean for the development of the larval phases. It is understood that the zoea are dispersed from the island by currents and are returned to the island by currents (Davies 2006). Recruitment success is patchy, with about 1-2 in ten years, as they are vulnerable to changing ocean conditions such as temperature and currents (Clark 1994).

The subterranean environment is diverse and includes freshwater, marine, anchialine and terrestrial habitats. The cave fauna is poorly known yet is a significant component of the islands biodiversity (DEH 2002). These systems are very vulnerable and are the subject of global conservation assessment.

Commercial fishing

There are currently no commercial fishers based on the island. For the period when the resort and casino were operating, approximately 1994 to 1998, there was one commercial fisher. The Island Lady fished to supply the resort and for local markets. The low levels of infrastructure and transport make it difficult for a commercial operator to survive.

Recreational fishing

Recreational fishing is popular and people travel to Christmas Island from all over Australia and the world. The fishing season currently runs from May to November allowing tourists to co-incide with the better weather. The main recreational fishing charter, *Shorefire*, targets the following fish:

- S Popper casting – Giant trevally (*Caranx ignobilis*), Yellow fin and Dogtooth tuna (*Gymnosarda unicolor*)
- Jigging – anyway on steep drop offs, Giant trevally, Dogtooth tuna
- Trolling – fast pelagics, Yellow fin tuna (*Thunnus albacares*), Sail fish (*Istiophorus platypterus*), Wahoo (*Acanthocybium solandri*)

The Giant Trevally is a dominant sport fishing species popular with recreational fishermen on the island. Wahoo is caught with consistently good numbers all around the island. The yellow fin tuna is targeted as it migrates through when the waters are cooler.

Many locals fish all through the year when the weather is conducive. Access to the water is normally from Flying Fish Cove on the north side restricting small fishing boats to the north and west coasts and the northern end of the east coast. During the NW monsoon period heavy NW swells may prevent access from Flying Fish Cove and the Ethel beach boat ramp is used on the East coast. Some of the more commonly caught fish are Red Bass (*Lutjanus bohar*), Bluefin trevally (*Caranx melampygus*), Big Eye trevally (*Caranx sexfasciatus*), Black Trevally (*Caranx lugubris*), Jobfish (*Aprion virescens*), Amberjack, Dolphinfish (*Coryphaena hipprus*), Barracuda (*Sphyraena barracuda*) and Rainbow runner (*Elagatis bipinnulata*). Some Malay fishermen target the smaller reef fish such as Long tom (*Platybelone argalus*) and the Black triggerfish (*Melichthys niger*) in great numbers as they are extremely abundant. Squid and flying fish (*Cypselurus poecilopterus*) are also targeted as bait. The flying fish are also popular on the island for making fish crackers. Most reef fish are not heavily targeted as the proximity to deep water makes it easy for people to catch more ‘exciting’ fish and many local fishing boats have electric reels that can fish to hundreds of meters.

Terrestrial adjacencies

Many fauna on Christmas Island rely on the ocean as a spawning ground or feeding area. The Christmas Island marine area may be impacted by the following terrestrial adjacencies.

- The state of the beaches for nesting turtles. Turtles only try to nest on Dolly beach (DEH 2002) and also occasionally on Greta beach. The area of sand above the high tide level on Dolly beach is small and is used as a camp site by locals. The eggs are also poached by locals. The available sand on Greta beach is minimal and successful hatching is extremely unlikely.

- The destruction of primary rainforest trees where the endemic Abbots booby nest. Abbots booby's only nest in the very tall trees on the central plateau. These trees are under threat from future mining operations. Without these trees the Abbots booby will be without the only nesting area it has in the world. Other species of seabird including the endemic Christmas Island frigate bird and the red foot booby also use the rainforest trees for nesting.
- The maintenance of a healthy rainforest cover for migrating crabs. The land crabs migrate in daylight hours and need a healthy forest to reduce the dehydrating effect of the sun. Deaths of crabs migrating across open minefields are commonplace.
- Twenty species of native land and shoreline crabs inhabit the Island and depend on the terrestrial and marine zones for survival.
- The Yellow crazy ants are killing the crabs (and other invertebrates). These ants have formed supercolonies in the rainforest and have caused the deaths of many millions of the endemic red land crab and other invertebrates (PANCI 2005).
- Run off and sedimentation is minimal in most places. Blocked drainage channels and earthworks close to the coast can cause temporary run off problems. There are no rivers on the island and the rain soaks into the land quickly and disappears into the freshwater lens.
- The tanker loading operations from the phosphate mine allow phosphate rich dust to blow across the ocean from the port in Flying Fish Cove. This may have an impact with excess nutrients on the reef.

Island coast subregions

N&W coastal reefs (~10 m deep)

The majority of the coastline on the north and western coast is cliff. The main port and recreational areas are located at Flying Fish Cove on the North Coast. There are also a couple of beaches and many cave systems on this coast line. West white beach is the longest beach on the island and is in the centre of the North coast. Winifred beach, on the west coast, is small and infrequently visited. None of these beaches have turtles nesting but Flying Fish Cove and West white beach are important recreationally especially as snorkelling areas. They are shallow reef areas with good hard coral growth and fish life.

Some of the sea caves along the northern coast can be accessed by SCUBA and snorkel. These cave systems can be followed for several kilometres in some cases and many have air domes. These form very interesting and unexplored habitats for freshwater, marine and anchialine ecosystems. These represent important ecosystems as they are uncommon and poorly understood.

The North coast is sheltered from the SE trade winds for most of the year and is relatively calm. Severe swells can hammer the shallow reef and the cliffs during the NW monsoon. The monsoon varies in strength and duration from year to year but can have a destructive effect on the corals. The bay inlet along the central part of the north coast is also sheltered from major current action, this being mostly confined to the points. The west coast is less accessible due to the distance from the boat ramp and is often rougher than the North Coast. This coast has a less dramatic cliff line but underwater the reef slopes steeply away.

The indented bays of the north and west coasts have reef flat between 10 and 100 m wide with good hard coral cover. The reef flat sits at about 10 – 15 m deep. In most areas this reef flat has a steep slope down to what appears a second plateau at around 40 – 60 m, although this is not evident at all places (Wells & Berry 2000). The drop off, 30 m from the coastline, at the mid point of this bay descends vertically to over 1000 m. The indented bay on the north coast supports a population of perhaps 200 resident spinner dolphins, *Stenella longirostris*. This is also an area where whale sharks are frequented in the season.

These corals are often partially devastated by storm surges during the NW monsoon which can topple huge massive corals and dislodge boulders. The resilience of the system is shown in its ability to recover. In 1987 when WA museum completed the marine survey they reported that coral die off must have been almost total to 10 m (Wells & Berry 2000). Recent Reef Check surveys 15 years later shows up to 75% coral cover at this depth in those same areas.

The steep walls on the north east and north west tips of the island support huge gorgonians (including large *Subergorgia* sp.), antipatharians and large numbers of crinoids and other hydrozoan corals that thrive feeding in the currents (Marsh 2000). In these areas it is common to see more pelagic fish and sharks.

Eastern coastal reefs (~15 m deep, more gentle topography)

This coast gets pounded by heavy swell for most of the year from the SE trade winds. The majority of this coastline is high cliff with some breaks for small beaches.

On this coast much of the underwater topology is less dramatic and the reef slopes are more gentle. There is a good covering of soft corals, sponges and low lying encrusting corals which are rarely seen on the north and west coasts. The acropora table corals and staghorns which grow on this coast are of small size, as are the massive corals. There are also more areas of coral rubble and bare rock substrate, probably from the constant wave and swell action.

Dolly beach, 90 m of sand is the only successful turtle nesting beach on the island (DEH 2002). Although there is very little sand available above the high tide level, turtles continually try to nest here with some success. They also try and nest on Greta Beach, 50 m of sand but virtually none is above the high tide level and nests here are rarely successful. It is mostly green turtles that nest on Christmas although hawksbills are also common in the area.

Southern coastal reefs (~10 m deep)

Very little is known about the southern coast as it is difficult to access. It is only accessible during the doldrums for the islander's small boats. It is unlikely that much coral survives there due to the rough conditions. Reports are of lots of rocky boulders and soft corals, Alcyonacea, in the narrow shallow areas (Wells 2000). In the central area the terrestrial flat dips quite close to the ocean level and the cliffs are low. There are some impressive blowholes in the cliffs along this coastline, showing the presence of underwater caverns and crevices.

Schools of pelagic fish and turtles are frequently seen from the coast. A pod of common dolphins, *Delphinus delphis*, are occasionally seen around the south eastern corner of the island.

Coastal waters, extending off the reef out to sea (to about 500 m depth)

The water surrounding Christmas Island is unusually clear and the visibility and light penetration is high. The water is generally low in productivity with very little surface plankton throughout most of the year, <0.1 ml plankton /m^3 (Davies 2006). The plankton density rises when the South Equatorial Current is flowing strongest at the end of the SE trade winds, 1.9 ml plankton / m^3. This productivity peak is normally seen around September or October. The sea surface temperature normally ranges from 25 – 30^{o}C.

Christmas Island is surrounded by very deep water which is an important habitat for whale sharks. Whale sharks are known to dive to over 1000 m regularly. Whale sharks are seen at Christmas Island predominantly from December to April, but have been spotted all year round (DEH 2002). The sharks are planktonic filter feeders and are thought to arrive at the island in time to feast on the red crab larvae. Whale shark poo has been found to contain high levels of red crab matter (Meekan pers comm.). At this time manta rays, *Manta birostris*, are also frequently seen.

Thousands of seabirds nest on the island. Many of the seabirds fly 100's of kilometres to their feeding grounds but the waters surrounding the islands are also used.

Freshwater seeps are common around the island. Some are strong such as the 'gusher' out of Daniel Roux cave on the north coast (DEH 2002).

Information gaps

- Cave fauna and the habitats that exist within the cave structures are poorly known. The extent and effect of the freshwater seeps around the island are unknown.
- The importance of the shoreline rock platforms is also unknown.
- Current systems on a local scale are unknown.
- The south coast is relatively unexplored
- Only one comprehensive marine study completed for the island by WA museum in 1987.

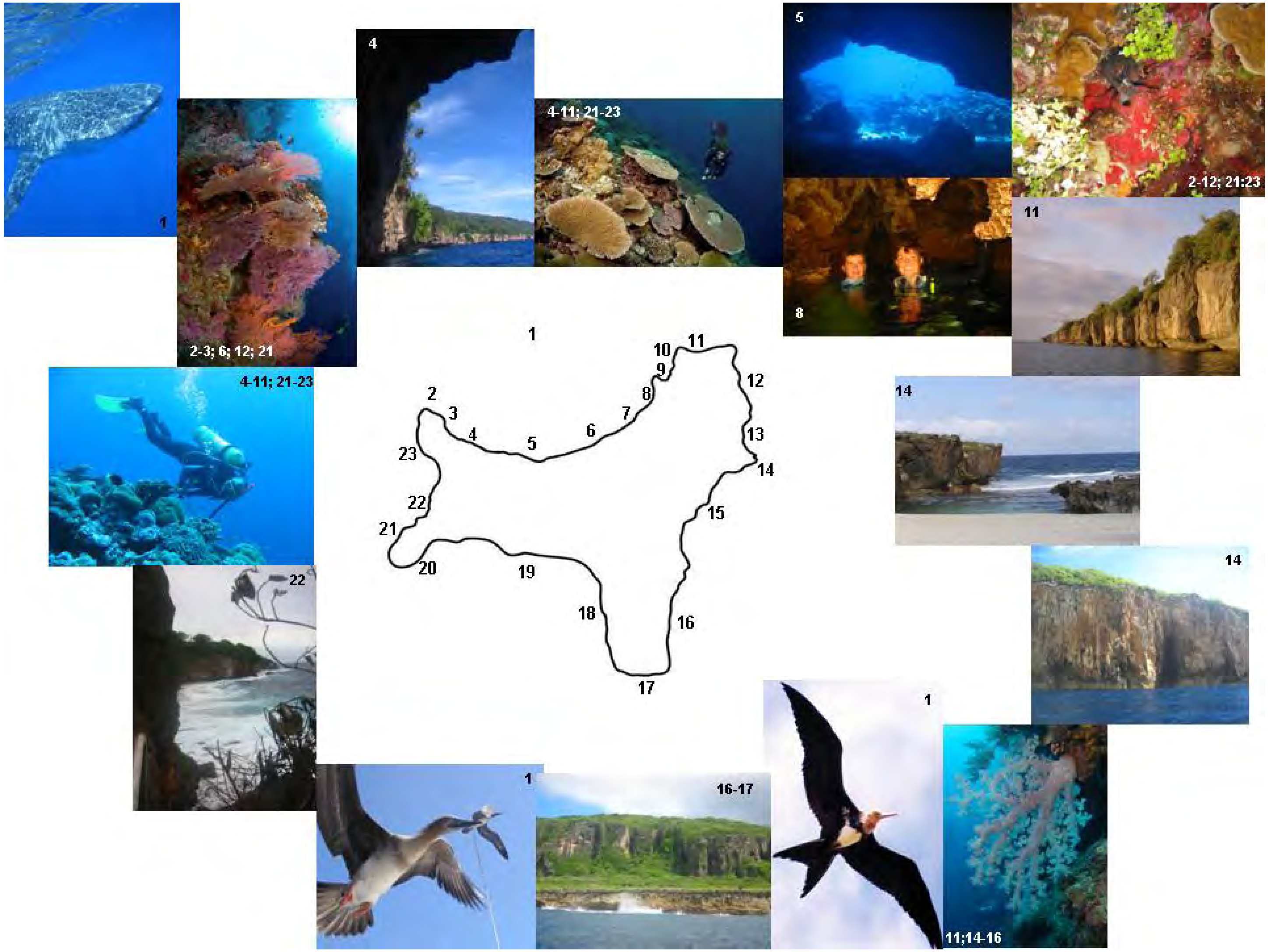


Figure 4-80. Island scale subsystems for Christmas Island, with examples of habitat (Numbers relate to island sub systems) (photos: Claire Davies, Udo Van Dongen, Justin Giligan)

<u>Island scale subregions</u>

Table 4-43. Christmas Island coastline island scale subsystems. The numbering of these subsystems match the numbering on Figure 4-80.

Island scale subsystem	**Coastal subtidal description**	**Feature (space or key species)**
1. Whole coast line	Coastal waters around Christmas Island	Coastal waters as spawning area for the land crabs. Area for the juveniles to return to land. Coastal waters as seasonal habitat for whale sharks / mantas and resident spinner dolphins, *Stenalla longirostris* Coastal waters for large pelagics Coastal waters as feeding grounds for seabirds
2. NW pt to Perpendicular Wall (1 km, straight coastline) – tail tip Station 13 WA Museum Report (100 m east of NW point) Station 2 WA Museum report	200 m wide fringing reef at NW point reducing to 60 m wide at Perpendicular Wall. Terraced rock pools up to 1.2 m deep with raised algal rims. Shallow gentle flat at 4 – 6 m for 40 m with good hard coral cover. Steep drop off to 50 m, high current area, lots of sharks, big fish, schooling reef fish, gorgonians and coral. Intertidal wall cave at perpendicular wall with encrusting corallines and vermetids. *Distichophora violacea* is conspicuous (1988 and to date). Near vertical drop off within 10 m of cliff to greater than 70 m. Good live cover on wall, gorgonians and anitpatharians conspicuous (1988 and to date)	Coral reef flat ecosystem and many pelagic fish Shoreline rock platform

Island scale subsystem	Coastal subtidal description	Feature (space or key species)
3. Perpendicular Wall to McPherson pt (1.6 km, concave)	Embayment with steep cliffs with fallen rock, underhangs and caves.	Deep water bay, steep walls with high gorgonian growth
4. 'Boat cave' thru McPherson pt to west of West White Beach (~1.2 km, convex)	90 m wide shelf/reef; 1:1 slope	Coral reef ecosystem (hard coral dominates)
5. West White Beach (0.34 km, concave) Station 11 WA Museum Report (West white beach)	Coral sand and rubble beach (~5 m; weather dependent), ~40 m fringing reef. Cliff face contains many caves along this point. Shallow wave scrubbed pavement about 3 m deep for 30 m. Drops off to about 6 m for 20 m. This area has good hard coral growth on boulders, sand inbetween. Steep drop off to ~40 m, good live cover, sand at bottom, gutters down slope.	25% of the islands beaches Cave habitat Coral reef ecosystem (hard coral dominates)
6. West White Beach east to west of Rhoda beaches I, via Lost Lake Cave (4.2 km, concave)	Cliffs with very narrow fringing reef, underhangs with caves. Cliff face contains many caves along this point.	Caves habitat, entrance to Lost Lake Cave, second biggest cavern in Southern Hemisphere Coral reef ecosystem (hard coral dominates)
7. Rhoda and Margaret Beaches to Daniel Roux Cave (5.4 km, concave)	Scalloped/fractal coastline, whisps of sand pockets, ~100-170 m of fringing reef, fresh water seepage and vents. Cliff face contains many caves along this point.	Coral reef ecosystem (hard coral dominates) cave habitat
8. Daniel Roux Cave to Smith Pt (2.4 km, concave)	Highly fractal coastline, cliffs and caves with narrow rocky shelf, little reef, protected from SE. Cliff face contains many caves along this point	Cave habitat

Island scale subsystem	Coastal subtidal description	Feature (space or key species)
9. Flying fish Cove (Smith Pt to phosphate loading terminal), (1.2 km wide, 0.5 km radius, concave) Station 1 WA Museum report	Narrow (10 m) sand / rubble beach. Sheltered embayment. Small limestone flat on western side at 3-4 m with good hard coral cover on rocky substrate. This drops to 6 m about 20 m offshore. Gently sloping flat to 10 m. Substrate varies from sand, rubble and rock boulders, good hard coral cover. Drop off to 30 m deep at variable inclination (steep at western edge to moderate to gentle slope from centre of cove to eastern edge), good live cover on wall. drying reef to 60 m, intertidal reef further 200 m. Some degraded reef in intertidal. Some anchor damage. *Echinothrix diadema* and *Diadema savignyi* very abundant in 1988 and to date. 68% of all mollusc species collected in the WA museum survey were found in Flying Fish Cove. Reef Check 2003-2007 66 ± 0.05% mean hard coral cover	Coral reef ecosystem (hard coral dominates). Recreational beach. Commercial port area.
10. Port to Rocky Pt. Straight section, 1.1 km.	Moderately fractal. Freshwater seeps. Reef, bouldery – degraded reef. 50 m wide reef.	Coral reef ecosystem (hard coral dominates)
11. Rocky Pt to NE Point. Concave section, 2.8 km (3.2 km concave).	No beaches. Cliff faces. Some intertidal habitat – rock pools etc. Reef healthy and lots of fish. limestone pavement with gutters close to shore with sand bottoms. 100 m wide reef with gentle slope to 10 m, steep drop off to 50 m. Good hard coral cover and lots of alcyonacera. 200 m to 100 m isobath. Caves at NE Pt. Reef Check 2003-2007 64 ±0.05% mean hard coral cover	Coral reef ecosystem (hard coral dominates)

Island scale subsystem	Coastal subtidal description	Feature (space or key species)
12. NE Pt to Low Pt/New port. Cliffs with boulders (3.6 km to Norris Pt, or 5.6 to new port; variable stretch, but mainly with 2 concave sections).	Fractal coastline with fields of boulders.	Coastal pelagics
Station 6 WA Museum Report (off the golf course)	Narrow fringing reef with steep slope, wave swept pavement dissected by deep gutters. Lots of big boulders, gorgonians, rugose with lots fish action. Sounds like a high energy environment. Lots of fish, sharks etc. High currents	
13. New port to low point includes Waterfall and Ethel Beach (1.2 km concave beach section)	This is an area of low cliffs in a concave coastline. It has been altered by man, with a new boat ramp at Ethel Beach and a lagoon created just south of the casino at the waterfall.	Coral reef ecosystems (soft corals and encrusting corals dominate)
Station 5 WA Museum report (Waterfall)	Rubble and boulder beach, man made lagoon since 1988. Outside the lagoon the wall drops off to 30 m almost immediately, low levels of coral cover and life. Mostly rubble, wall slopes more gently as you go south towards Ethel beach.	
Station 3 WA Museum report (Ethel Beach)	Ethel Beach is south of the waterfall area and just north of Lily beach. It is 600 m of shallow sand and rubble covered limestone pavement. The reef slopes out gently from the beach to 6 m after about 30 m. The shore side is rubble and dead coral on a limestone pavement, turning into high relief with gutters and caves. *Galaxae* dominates (1988 to date). Steep drop off to about 40 m where there is a sandy flat.	17% of beach. high recreational use

Island scale subsystem	Coastal subtidal description	Feature (space or key species)
14. Low Pt (Lily beach) to Allen Pt (1.3 km, straight section) Station 4 WA Museum Report (Lily beach to steep point)	Just south of Lily beach there is a series of intertidal terraced rock pools up to 1.5 m high (3-6 m above sea level). High pools are high temperature with low water exchange. Lots of blennies. Lower pools have better water exchange and some coral growth. Pools have raised rims due to vermetid tubes concreted by corallines. The rest of the coast is steep, high, perpendicular cliffs, little fringing reef, some boulders, fractal, rugose, high currents and lots of fish	Shoreline rock platforms
15. Allen Pt to John D Pt/Dolly beach (3 concave sections), includes Greta Beach (6.7 km) – dogs chest Station 8 WA Museum Report Greta Beach Station 15 WA Museum Report (Dolly beach)	Steep cliffs, boulders, sandy patches; encrusting species and soft coral dominated; moderate to gently sloping habitat Greta beach is sand and coral rubble. very small, 10 m wide by 50 long. Limestone platform around beach area about 2m deep. Drops off to 6 m about 15 m from beach and slopes to 30 m deep over 40 m. lots of alcyonacea, encrusting corals. Small sand pockets close to shore, sand increases with depth. Coral sand rubble beach, 90 m long. High surf zone with lots of big boulders off beach for 30 m. slopes from 10 – 30 m over 40 m, lots of boulders, good hard coral cover (encrusting species), galaxea and alcyonaceans.	90 m, 7 % of islands beaches. Green turtles nest above high tide level at Dolly beach Coral reef ecosystem (encrusting hard and soft coral) Coastal pelagics
16. John D Pt to South Pt (dogs front leg, anterior), (5.8 km, straight) –	Steep cliff; reef with more sand and less coral; rubble and dead coral; gently sloping subtidal habitat	Sand area popular with turtles coral reef ecosystem (encrusting hard and soft coral)

Island scale subsystem	**Coastal subtidal description**	**Feature (space or key species)**
17. South Pt to Stubbings Pt (dogs paw), (2.8 km, convex), Station 7 WA Museum Report (between Tait and Andrews pt)	Steep cliffs, narrow sandy subtidal & boulders, little reef, poorly known, Douglas Point is a good spot for pelagics Moderate slope from 3 m to 30 m depth over 50 m. wave swept pavement dissected by deep gutters filled with sand and rubble. Slope mostly low relief of rubble and limestone slabs, some high relief at 15 – 20 m, alcyonacea dominates.	Coastal pelagics
18. Stubbings Pt to Middle Pt (10 km, concave) – dogs chest	Steep cliffs, little reef, rough water, poorly known	Coastal pelagics
19. Middle Pt to Jones Pt (6.7 km, concave) – dogs underbelly	Steep cliffs, little reef, rough water, poorly known. Schools of pelagic fish seen from shore, esp at Douglas Pt	Coastal pelagics
20. Jones Pt to Egeria Pt (dogs paw), (1.1 km, convex)	Low coastal cliffs, Sloping reef, with sand patches, doesn't follow shape of coast – very wide and shallow on western point (up to ~400 m), strong currents	Coastal pelagics
21. Egeria Pt to Toms Pt (2.0 km, straight) – posterior dogs back leg Station 12 WA Museum Report (Egieria point dive site not geographic location on map)	Moderate height cliffs, boulders in shallows, moderately fractal coastline; dense hard coral cover for last 1500 m (~ 100 m wide, 10 m deep, then steep drop off), high current area. First 500 m is limestone swept pavement in shallows, large limestone boulders off cliff in amongst sand and rubble. Steep drop off 20 m off cliff.	Coral reef ecosystem (hard coral dominates)

Island scale subsystem	Coastal subtidal description	Feature (space or key species)
22. Toms Pt to Martin Pt (5.5 km, concave) – upper hind leg and bum	Sandy with boulders and gently sloping reef/hard coral (100 to 300 m wide) then steep drop off, large and small scale fractal coastline	Coral reef ecosystem (hard coral dominates)
Station 9 WA Museum Report (Winifred beach)	Coral sand and rubble beach in onshore cave, small 30 m long. Wave swept pavement dissected by deep gutters close to shore and sand and rubble with boulders in wider bay area. Moderate slope to 30 m over 50 m.	50 m of beach, intertidal area in front of beach
Station 10 WA Museum Report (Merial Beach)	Not really a beach, a narrow canyon caused by a dale. About 5 m wide. Slopes down to 20 m over 50 m. Wave scrubbed pavement cut by deep gutters with rubble bottoms. Lots of boulders.	
23. Martin Pt to NW pt (2.3 km, convex) – back of tail	Irregularly fractal coastline, low terrace rather than cliffs; ~170 m wide of subtidal reef, poorly known; NW pt = high current area	Coral reef ecosystem (hard coral dominates)

Table 4-44. Christmas Island coastal island scale assets and threat analysis

Habitat / Feature	Attribute	Surrogate	Comments/Description and significance	Threats
Deep coastal waters	Access to the ocean for 13 species of land crab and return of the juvenile crabs to the land	~20 million red crabs, *Gecarcoidia natalis*, of juvenile crabs + robber crabs + 11 other land crab species – spawning + return	Crab larvae is thought to be dependent on favourable winds and currents to bring the megalope back to the island after spawning.	Terrestrial clearing removing shade areas and increasing run off. Yellow crazy ant. Changing ocean conditions preventing return / development of megalope.
	Suitable habitat / feeding area for juvenile whale sharks / mantas in season and resident for spinner dolphins	No. of whale sharks / mantas / dolphins present in season	Area of deep water, whale sharks dive greater than 1000 m regularly. Whales sharks and mantas predominantly seen on North and West coasts from December to April. This may be due to these being the most accessible areas. Resident population of spinner dolphins and frequently sighted common dolphins use the coastal area.	Illegal fishers Boat strike. Tourism Changing ocean conditions effecting habitat, food sources etc marine debris
	Habitat of 3 endemics plus 5 other seabird		Abbotts booby, Christmas Island frigate, White tailed tropic bird	Loss of rainforest habitat Changing ocean conditions effecting location of food sources

Habitat / Feature	Attribute	Surrogate	Comments/Description and significance	Threats
Caves	habitat for subterranean fauna, troglofauna (air filled voids) and stygofauna (water filled voids), includes freshwater, marine, anchialine and terrestrial habitats	Poorly known habitat and fauna	poorly known but a significant part of the islands biodiversity, notable is the presence of procardid, alpheid, hippolytid and atyid shrimps in the anchialine systems. Anchialine waters are near coastal groundwater systems with no surface connection to the ocean but are influenced by marine tides. These are poorly studied areas of the island. At least 12 endemics have been found from terrestrial / aquatic systems.	Lack of knowledge of system Limited habitat Changing ocean conditions meaning a loss of freshwater to system.
Beaches	Mostly coarse coral and shell rubble, some sand on north and east coast beaches Turtle nesting beaches Dolly and Greta	Green turtles, and rarely hawksbill turtles nest on Dolly Beach and attempt to nest on Greta Beach.	Turtles nest above the high tide mark and this habitat is limited on Christmas. Dolly beach has a dense coverage of coconut trees close to the tide line and locals camp on the beach regularly. Greta beach is very small and tides may cover the whole beach, therefore nesting here is frequently unsuccessful.	Locals are known to poach turtle eggs. Changing ocean conditions reducing the amount of sand available for nesting. Temperature increase of sand where eggs are maturing favouring male turtles.
Coral Reef ecosystem	Reef fish and marine invertebrates coral ecosystems	Reef Check surveys recreational fishing	North & West coasts - Many small reef fish and invertebrates, good hard coral cover, rubble, few soft coral or sponges East coast – soft corals, sponges, encrusting hard corals, more pelagics.	Development of coastal region Port operations Yacht anchors Overfishing of reef fish Changing ocean conditions leading to bleaching, acanthaster explosions, etc
Coastal pelagics	Many species of large pelagic fish inhabit the waters	Recreational fishing reports	Most fishing on north and west coasts as sheltered from SE trades. Access to other coasts restricted to NW monsoon times and doldrums.	Illegal fishers Overfishing Changing ocean conditions effecting current patterns, food sources etc.

Habitat / Feature	Attribute	Surrogate	Comments/Description and significance	Threats
Shoreline rock platforms				Limited habitat Changing ocean conditions reducing habitat, increasing temperatures

4.3.9 Cocos Island reef

Island + lagoon + slope less than 500 m

The Cocos (Keeling) Islands consist of North Keeling Island and the South Keeling Islands. These oceanic coral atolls are connected by a submerged ridge and are separated by about 28 km. North Keeling Island is an atoll with an opening to a central lagoon. The South Keeling Islands sit on a coral atoll, comprise 26 separate islands and are inhabited by about 500 residents.

The Cocos (Keeling) Islands have been an Australian External Territory since 1955 and on the 12th of December 1995, the Pulu Keeling National Park was proclaimed and is now managed under the EPBC Act.

Prevailing weather

At the Cocos (Keeling) Islands relatively strong, constant SE trades winds prevail all year, during and outside of the monsoon season. From January to May the islands are affected by the NW monsoon bringing heavy swells, rain and potential cyclones. The islands are buffeted by wind generated wave action all year and heavy swells from the direction of the prevailing weather. These swells can be devastating to the coral reef systems and can cause severe erosion on low lying land.

Cyclones are a major threat to the Cocos (Keeling) Islands and frequently pass close to the island. At 12^{o}S the islands are within the cyclone belt. In April 2001 Cyclone Walter destroyed 61% of the canopy and 14% of the trees on North Keeling. Approximately 30 cyclones have passed with 100 m of the island since 1961.

Exposure and Aspect

The islands are low lying with the highest point on the southern atoll being 8 m above sea level and only 5 m on North Keeling (DEH 2004b). As the islands are low lying there is rarely any sheltered areas outside of the lagoon.

There is no information of the local current regimes.

Marine Environment

Table 4-45. Number of species at Christmas and Cocos (Keeling) Islands (from Woodroffe & Berry 1994). * from Hobbs *et al.,* 2008

Group	Cocos (Keeling) Islands	Christmas Island
Reef building corals	99	85
Decapod crustaceans	198	204
Molluscs	c. 610	c. 490
Echinoderms	88	90
Fishes	c. 550	607*
Native Birds	38	88
Plants	130	386

The Cocos atolls represent the western boundary for many species of the Western Pacific biogeographic province and taxa from the Indo West Pacific dominate (Woodroffe & Berry 1994). For many species these islands are the western limit of their distribution. As at Christmas Island, endemism and diversity are low due to the island's isolation and small size. The most likely source of recruitment of marine biota is from the Indonesian and Eastern Indian Ocean region. Marine taxa would require to be pelagic as adults or to have a long lived larvae or juvenile stage to reach Cocos (Keeling) Islands (Woodroffe & Berry 1994).

The Western Australian Museum marine fauna survey recorded 533 fish species at the Cocos (Keeling) Islands. Of these 22% were at the edge of their range and across a range of taxa Pacific and Indian Ocean species were found to be cohabiting (Allen & Smith-Vaniz 1994). Endemism is low with only the angelfish, *Centropyge joculator*, having been identified as endemic, although it also occurs on Christmas Island. There are healthy populations of shark (black tip, white tip, grey reef) around the atolls and a substantial population of butterfly fish. It is to be noted that both the humphead wrasse (*Cheilinus undulates*) and bumphead parrotfish (*Bolbometapon muricatum*) are common in the island waters and that benthic skates and rays are absent.

The coral fauna is typical of Western Australia although some common Indo Pacific species are missing (Veron 1994). Of the 99 species of reef building coral found here, 12 are not found anywhere else in Australia and 9 are not present anywhere else in the eastern Indian Ocean. Conversely, 70% of the coral species known from mainland Australia are missing from Cocos (Keeling) Islands (Veron 1994). The reef is predominantly rock with soft and hard coral cover present in most areas. Pocillopora spp. and Montipora spp. corals are common in most areas on Cocos with Montipora spp. noticeably much more common than at Christmas Island (Veron 1994). A distinctive feature of the reef is the low diversity and low abundance of Acropora spp. corals on Cocos Island with only a few stands of Acropora spp. occur on the reef flats. Oculinidae and Caryophylliidae are also absent. The Pectiniidae, Mussidae and hermatypic dendrophylilidae are each represented by only one species. The following genera are also missing Stylophora, Goniopora, Alveopora, Coscinaraea, Cycloseris, Polyphyllia, Lithophyllon, Podabacia, Goniastrea, Platygyra (Veron 1994).

Reef Check surveys have measured 50-75% live (hard and soft) coral cover on 10 sites distributed around the Southern Atoll and 1 on North Keeling. Reef check studies have shown little change in reef 'health', live coral cover or indicator species abundance, over the years of the survey (1997-2005) (DEH 2005b).

The mollusc fauna is diverse and numerous, 610 species compared to 490 at Christmas Island (Wells 1994). The molluscs of Cocos (Keeling) Islands are closely linked to those of Christmas Island and Western Australia. The largest of the giant clam species, *Tridacna gigas*, was not recorded during the WA museum survey on Cocos (Keeling), however large numbers of long dead shells were seen on the shoreline of Home Island. Wells (1994) suggests that *T.gigas* occurred on the atoll when it was first inhabited but became locally extinct as it was collected by Cocos Malays for food. There is currently a clam farm on the island which collects clams from the lagoon area and grows them. Most of these are exported for the aquarium trade and to replenish local stocks. The two species grown are *Tridacna maxima* and *T. derasa*. The maxima are the smaller size clam and the derasa tends to grow much larger. Primarily, the maxima are being bred and farmed for the aquarium market, while the derasa are being farmed for a meat market.

The spider shell *Lambis lambis* occurs in large numbers in shallow water in the southern part of the lagoon at Cocos (Wells 1994). It is easily collected and is regarded as a delicacy by the Cocos Malays. The same species is also collected for food in many other areas of the Indo-Pacific but little is known of the fishery biology of any species of *L. Lambis.* Being a relatively large species that occurs in shallow water L. *lambis* could be easily fished out. A study of the population biology of *Lambis lambis,* to determine effective management strategies for the species, is in its 3rd and final year (Evans, S. WA fisheries, pers comm.).

Most of the Echinoderm species found at Cocos (Keeling) Islands are widespread, Indo west Pacific varieties but some of them are at the western edge of their range, extended from Christmas Island or Indonesia and one species at its eastward boundary extended from Sri Lanka (Marsh 1994). Holothurian fauna is especially rich, including most of the species known as trepang or beche-de-mer.

The lagoon of the southern atoll has been well studied and a variety of habitats has been described (Figs 3.28 & 3.29). The lagoon is ecologically important as it provides a sheltered area to act as a nursery to fish, seagrass beds that provide habitat for invertebrates, small fish and feeding area for turtles and the dugong. Cyclones, deoxygenation of lagoon waters and *Acanthaster planci* outbreaks are all known to have reduced coral cover in the past (DEH 2004b). The shallow, lagoonal waters can get very warm especially in the doldrums when water movement is low and the air temperature is typically high, this has resulted in coral death due to bleaching in the past.

Commercial fishing

There are no commercial fishing operations on Cocos (Keeling) Islands.

Recreational fishing

Recreational fishing is restricted to trolling by permit only at North Keeling and is restricted to fine weather. Targeted species are Wahoo, barracuda, mahi mahi (Dolphin fish), yellow fin and dog tooth tuna, GT and the Indo Pacific sailfish.

Within the lagoon of the southern atoll (southern half) and pretty much throughout the year most fishers tend target snappers (Lutjanus spp.), sweetlips (Lethrinus spp.), trevally (Caranx spp.), silver biddy (*Gerres subfasciatus)*, mullets (*Liza vaigiensis*, *Mugil cephalus*), rabbitfish (Siganus spp.), Bonefish (*Albula glossodonta*), milkfish (*Chanos chanos*) and darts (Trachinotus spp.). Sometimes it would also depend on the species that is active (taking baits). At the lagoon edge and in the vicinity of West, Horsbrugh and Direction Islands when the weather is favourable for smaller vessels, usually late November to March, trout (*Variola louti* and *Plectropomus areolatus*), green fish (*Cheilinus undulates*), snappers (including *Lutjanus gibbus* and *L. fulviflamma*) and a number of cod species (including *Epinephelus quoyanus* and *E. merra*) would be targeted. Gong gong (Lambis lambis), rock lobsters (*Panulirus sp.*), Mud crabs (Scylla sp.) and possibly the giant clams (Tridacna sp.) are also targeted in the lagoon.

In recent years WA fisheries have begun the process of introducing bag and size limits to the recreational fishing on Cocos (Keeling) Islands (DOF 2006). They have run education programs on the islands and released booklets to explain catch limits, legal fishing gear and marine conservation areas to the locals. This process will take time as the Cocos Malay population are unused to fishing restrictions and have been fishing in and around the atolls for many years to supplement their diets. It is estimated that the Cocos Malsy subsistence fishery was 52 - 77 tonnes in 1992 and that 15 - 30 tonnes of fish products is exported from the island each year (Alder *et al.,* 2000). This does not include the fish products caught by West Islanders, recreational tourists or those used in the restaurants.

<u>Terrestrial Adjacencies</u>

Development of new jetty and port at Rumah Baru on the lagoon side of West Island is due to begin shortly.

Sedimentation from the land or run off is not a major concern for Cocos (Keeling) Islands. There are no rivers and the rain soaks into the land quickly. The continuous wave action on the land, however, is creating many erosion problems around the atoll (Figure 4-81). With the predicted rise in sea levels and increase in severity of storms this problem will only increase. The runway is situated just above the current water level in the lagoon. The land at the end of the runway is eroding and the runway may flood if sea levels rise (causing higher tide levels) or king tides occur.

Figure 4-81. Sea reinforcement and the runway at and lagoon at low tide in the background (Photos Claire Davies and www.earthrounders.com)

The forest of Pulu-Keeling National Park (PKNP) supports many thousands of nesting seabirds. The atoll is the only seabird breeding colony within a 975 km radius (DEH 2004b). It is among the world's most important and largest red foot booby (*Sula sula*) colony in the world. It also has the second largest lesser frigate bird (F*regata ariel*) nesting population in Australia and possibly the Indian Ocean (DEH 2004b). The Cocos buff banded rail, *Gallirallus philippensis andrewsi*, is the only endemic bird in the territory and feeds on crustaceans living in the seagrass on the lagoon shore. Migratory birds are also thought to use the island as a staging point. There are no significant seabirds on the Southern Atoll as it was cleared to become a coconut plantation.

Island coast subregions

<u>North Keeling</u>

Broken, irregular reef crest is found all the way around North Keeling, except at the north west corner (Woodroffe & McLean 1994). The reef is narrower on sheltered side (north and west coasts) and broader on the exposed sides (south and east coast). The reef is continuous across the mouth of the lagoon. Surrounding the Island are reef flats including sandy and rocky shores, which are intertidal habitats. A broad platform of coral conglomerate extends out over the reef flat on the eastern and the south western shores. The northern shore is predominantly a sandy beach. The sand mixes with coarser coral rubble to the south and some rocky outcrops and erosional cliff are visible on the south coast.

The lagoon has one entrance to the ocean on the southeastern corner of the island but this is currently closed at the moment. The opening has no channel through the reef but is a shallow conduit that drains almost totally at low tide (Woodroffe & McLean 1994). The lagoon has been open to the ocean within the last 10 years and is known to temporarily close. The lagoon is a maximum of 2.5 m deep, mostly muddy sand but there is some seagrass. The lagoon acts as a fish nursery when open to the ocean.

The historic shipwreck, SMS Emden and graves of German soldiers are on North Keeling.

<u>Southern Atoll</u>

The reef front, the reef seaward of the breaking waves, slopes gently down to 15 – 18 m and then more steeply to about 50 m. Above the abyssal slope there is a gentle terrace of about 50 m to 2 km width, rising gradually to the reef crest (Williams 1994). The most abundant and diverse coral growth occurs on this reef terrace although much of it is rock and sand slopes. Sand deposits are more common on the leeward side.

The reef crest around the southern atoll is continuous apart from at the major entrances to lagoon. The width of the reef crest varies from about 50 to 400 m from the shore line. The reef flat has four main types of habitat (Williams 1994):

- areas of platform rock, beach rock and beaches along the coastal region of most of the islands
- small massive corals dominate between the islands on the eastern side
- seagrass beds off the south western corner
- and branched hard corals dominate in small patches off West Island and Horsburgh.

There are surge channels, breaking the reef, in the exposed areas of South Island and the southern end of West Island.

Inside the southern atoll lagoon there is a variety of marine habitats of importance. The lagoon is mostly shallow but at the blue holes, fields of collapse, in the centre of the lagoon, the depth can reach 30 m. There are extensive seagrass beds (*Thalassia hemprichii*) on the lagoon side of West Island, South Island and the eastern islands all the way up to Home Island. These are the feeding grounds for the green turtles that nest on North Keeling. They are also habitat for the common Portunid crab, *Thalamita crenata*, and the less common mud crab, *Scylla serrata*. The seagrass is also a feeding area for a dugong which has taken up residency in the lagoon and has now been there for over 10 years. Further seagrass is found under Direction Island (*Syringodium isoetifolium*) and amongst the coral outcrops in the central northern area of the lagoon (*Thalassodendron cillatum*). The central area of the lagoon has coral outcrops, deep depressions and sandy areas scattered throughout. Much of this is algal covered staghorn rubble. Other major habitats are:

- sand sheets which are almost devoid of surface life when active. When active they support algal growth, sea cucumbers and *Lambis lambis*.
- mud and sand flats, habitat for the fiddler crab, *Uca chlorpphthalmus* and *Macrophthalmus verrauxi.*
- sand flats and shoals where sand accumulates on the leeward side of the lagoon margin and where is may eventually be carried offshore.
- corals flats and patch reefs are mostly found in the vicinity of the blue holes. These are made up of foliose hard corals and staghorn rubble. Away from the holes the reef areas are made up of branching acropora and outcrops of massive corals such as porites. Bivalve molluscs and holothurians are abundant in these areas (Williams 1994).

Coastal waters

Many species of whale have been seen migrating through the coastal waters of Cocos (Keeling) Islands. Two species of dolphin are frequently seen and may be resident in the lagoon, *Delphinus delphis* and *Tursiops truncates* (DEH 2004b). A manta ray cleaning station has been observed by scuba divers on the southern edge of the ocean side of West Island. Manta rays can be seen all year round in the lagoon and in the coastal waters. Many thousands of seabirds nest on PKNP and use the surrounding waters as feeding grounds (DEH 2004b).

Information gaps

North Keeling is still a relatively unknown area since weather constraints have resulted in limited time for underwater exploration. Other gaps include:

- Only one comprehensive marine survey carried out by WA museum in 1989.
- Local current regimes are unknown.
- Impacts of the new port facility at Rumah Baru on the marine characterisation of the lagoon.

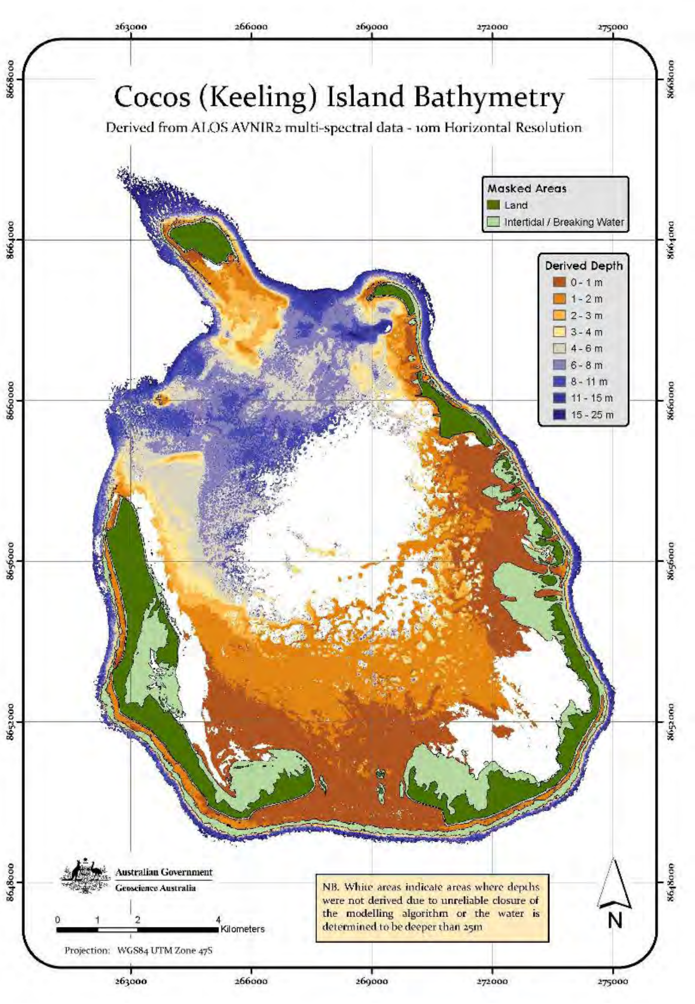


Figure 4-82. Cocos bathymetry

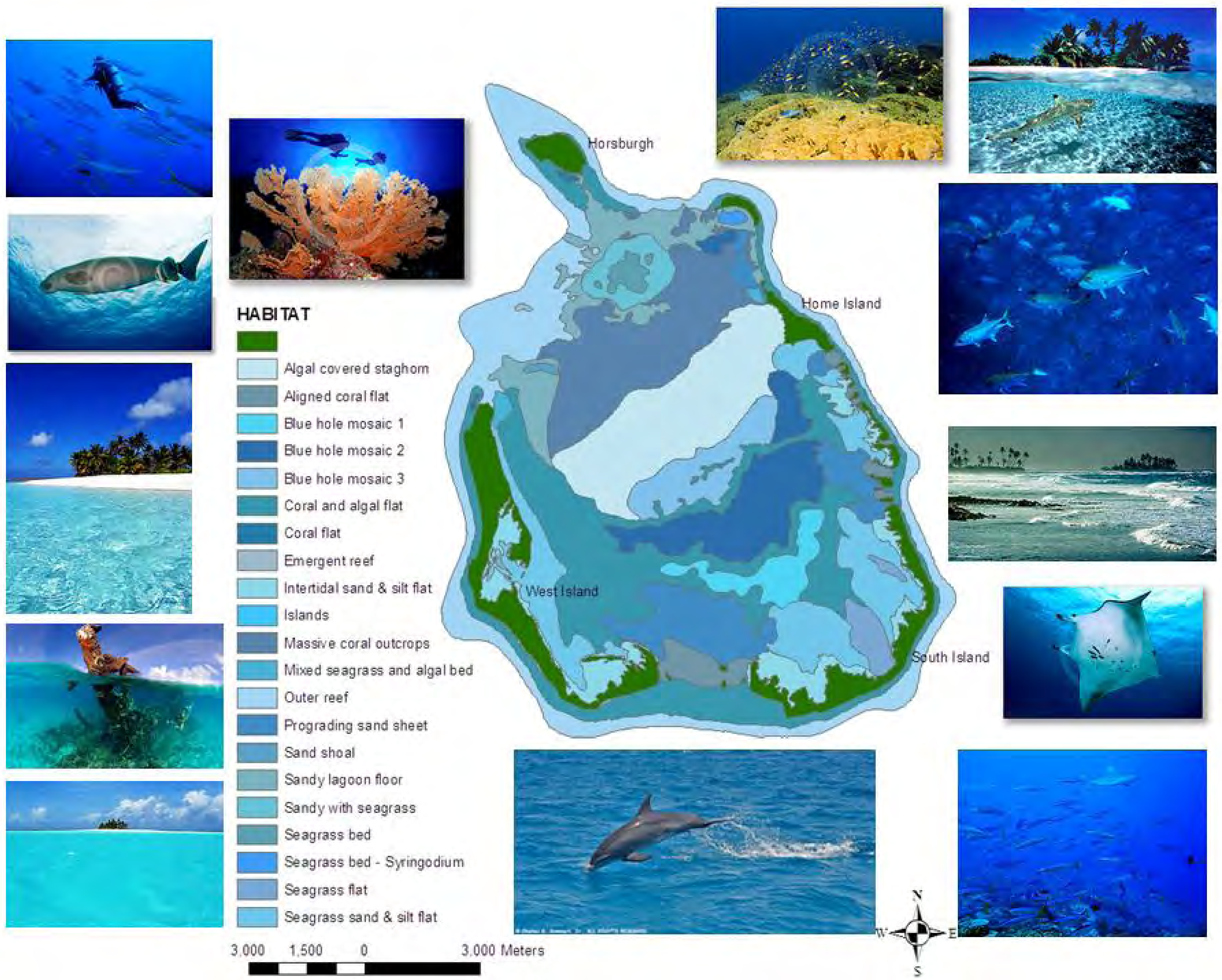


Figure 4-83. Cocos Island Map with examples of habitats and species (photos: Karen Willshaw, Image oasis, Justin Giligan, Wildimages, Parks Australia)

Table 4-28. Island scale subregions of the Northern Atoll

Island scale subsystem	Coastal subtidal description	Asset (space or key species)
1. Coastal waters	Open ocean surrounds the northern atoll, mantas / dolphins / whales are all seen here. feeding areas for many thousands of seabirds	Coastal waters for large pelagics / mantas / dolphins / migrating whales spawning area for land crabs, inc Birgus Lat seabird feeding
2. North Keeling Coast	Shallow water between 100 – 200 m from shore. Coral reef crest surrounding the lagoon except the northwest corner. Reef narrower on north and west sides where it is more sheltered. Much of the reef is exposed at low tides Outer reef slope (subtidal) Reef flats including sandy and rocky shores (intertidal) Rocky south western corner	beaches coral reef ecosystem SMS Emden wreck, protected under the historic shipwrecks act 1976
3. North Keeling Lagoon	Shallow, brackish water, lagoon entrance opens and closes over long periods, currently closed since about 5 years ago. Can act as fish nursery and sea grass habitat when open.	lagoon

Table 4-46. Island scale subsystems of the Southern Atoll

Stretch of coast	**Coastal subtidal description**	**Feature (space or key species)**
1. Coastal waters	open ocean waters around islands, mantas / dolphins / whales are all seen here. feeding areas for many thousands of seabirds	Coastal waters for large pelagics / mantas / dolphins / migrating whales
2. Lagoon	Seagrass beds on the west and southern sides of the lagoon Coral reefs in the central and north western sides of the lagoon. Close to Prison Island 50% rock/rubble and 40% live coral cover. West side of the lagoon by passage is up to 70% live coral cover in the middle of the northern part of the lagoon there is about 55% live coral cover at 10 m reducing to ~30% at 3 m	seagrass beds as food source and habitat coral reef ecosystem reef fish habitat and nursery for other fish nursery for significant reef shark population Black tips / White tips *Lambis lambis* habitat
3. West Island	barrier of reef on lagoon entrance, 50 m to 10 m depth south of south island, reef check shows 60% soft coral., 40% rock. western shore of south island is 55% rock and 45% live coral cover north of the island is 50% rock and 45% live coral cover	coral reef ecosystem on ocean side manta ray cleaning station purple land crab habitat and spawning area
4. South Passage	shallow sandy area with reef break on coastal side, high water flow area as tides change	
5. South Island	east and southern sides have 100-300 m of shallow reef / rubble north west area has large mud / sand flats on low tide	coral reef ecosystem on ocean side mud flats on low tide, wading, migratory birds
6. Pulu Ampang to Pulu Labu	east sides have 100-300 m of shallow reef / rubble eastern reef is up to 70% live coral cover	coral reef ecosystem on ocean side
7. Home Island	East coast about 300 m of shallow reef / rubble	coral reef ecosystem on ocean side
8. Prison Island	between Direction island and Home island is shallow reef / rubble break The coastal side of prison island is 70% rock, 30% live coral cover	coral reef ecosystem on ocean side

Stretch of coast	Coastal subtidal description	Feature (space or key species)
9. Direction Island	north and eastern sides are shallow reef / rubble for 300 – 500 m west side is very shallow rubble for 300 m, drops off in another 200 m south side is sandy bay area	coral reef ecosystem on ocean side
10. Port Refuge	sandy area, high water flow area as tides change	
11. Horsburgh	north side up to 1 km shallow rubble / reef. Reef check here shows mostly rock substrate with about 20 – 30% live coral cover (soft and hard coral). east and west sides 400 – 500 m of shallow reef / rubble on the south east side, shallow sandy substrate extends into lagoon	coral reef ecosystem on ocean side
12. Western Entrance	reef crest dropping off to deep water on ocean side.	coral reef ecosystem on ocean side

Table 4-47. Cocos (Keeling) Islands coastal island scale assets and threat analysis

Habitat / Feature	Attribute	Surrogate / Indicator	Comments	Threats
Beaches	nesting areas for turtles	No. of green turtles nesting on North Keeling and feeding in southern atoll. Tagging program Scott Whiting.	Beaches on the north, west and south coasts of North Keeling are used by green turtles for nesting. Green turtles are a non migratory population which is unique, adds conservation value as can maintain a population at one place. NK beaches are quite mobile. Hawksbill turtles feed in same area Shallow waters used for mating.	sea level rise and temperature rise poaching of eggs and turtles marine debris boat strike
Mud flats	migratory wading birds large fiddler crab population		stop off point for many migratory bird species feeding and habitat for fiddler crabs	sea level rise

Habitat / Feature	**Attribute**	**Surrogate / Indicator**	**Comments**	**Threats**
Seagrass beds	food for turtles and habitat	No of turtles in lagoon	Food for turtles (green and hawksbill) and the dugong Provides shelter for juveniles and benthics	Development in the lagoon, new jetty. locals drag nets across some areas of the lagoon disturbing the sea bed.
Coral Reef ecosystem	reef fish and marine invertebrates coral ecosystems	Reef check and other marine studies	Western limit for many species of the Western Pacific biogeographic province. Faunal composition is typical of Indo West Pacific coral reefs (Allen 1994) a study on *Lambis lambis* biology or ecology is underway, it is heavily predated here. Harvesting of giant clams, there is a facility on the island to grow clams from those taken in the wild.	coral bleaching, acanthaster invasions, over fishing, netting across lagoon entrances, cyclones, pollution from vessels and the aquarium fishing industry
Coastal pelagics	Suitable habitat / feeding area for species,	Recreational fishing reports	Many species of large pelagic fish inhabit the waters	over fishing,
Coastal waters	feeding area for seabirds Mantas/ dolphins habitat	no of breeding pairs	North Keeling is the only seabird nesting area within a radius of 975 km (red-foot booby, lesser frigate, greater frigate, fairy terns in large numbers). Manta cleaning station and year round presence Dolphins may be resident.	hunting, cyclones
Historic ship wreck	cultural site and graves of soldiers		MS Emden grounded and sunk on North Keeling. Soldiers that perished were buried there.	
lagoons	fish nursery area	maintenance of reef fish numbers	NK lagoon needs to be open to the sea to be a nursery.	North Keeling lagoon naturally closes periodically, fish die, it goes saline etc

5. ASSESSMENT OF CONSERVATION VALUES AGAINST KEY NRSMPA CRITERIA

5.1 Wharton Basin subregion

Table 5-1. Table summarising the assessment of conservation values against five of the NRSMPA criteria for the Wharton Basin subregion. CI = Christmas Island; CKI – Cocos (Keeling) Islands; SBT – Southern Bluefin Tuna; POM - particulate organic matter

Conservation values	**Assessment against NRSMPA criteria 1-5 (Wharton Basin subregion)**				
	Naturalness	**Biogeographic importance**	**International and national importance**	**Representativeness**	**Comprehensiveness**
1. Protected species	All species appear to be under minor or no short-term threat within the subregion		Likely to be part of the migration route and foraging grounds for a range of protected sea birds, turtles and cetaceans	Many protected species (turtles, birds, cetaceans) are widespread	Several bird species are largely restricted to CI and surrounding waters
2. Protected places					
3. Key ecological features					
Pelagic communities	Limited fishing activity	Some species (e.g. Blue fin tuna – SBT) appear to use this region to spawn – recruits form the basis of pelagic communities and fisheries	May be part of an important feeding and breeding region for large pelagic fish, some form part of an international fishery	Unclear	SBT most likely to spawn in this subregion and eastward
Seamount	Largely unimpacted	Unclear	Unclear	Most other deep seamounts are in the	Contains about half of the deep water

communities				Aust. Eastern Marine Region	seamounts in the AEEZ
Abyssal plain communities	Largely unimpacted	Unclear	Unclear	Unclear	Contains 43% of the abyssal plain and 72% of deep/hole/valley environs in the two territories

Table 5-2. Table summarising the assessment of conservation values against four of the NRSMPA criteria for the Wharton Basin subregion. CI = Christmas Island; CKI – Cocos (Keeling) Islands; SBT – Southern Bluefin Tuna; POM - particulate organic matter

Conservation values	**Assessment against NRSMPA criteria 6-9 (Wharton Basin subregion)**			
	Ecological importance	**Productivity**	**Uniqueness**	**Vulnerability assessment**
1. Protected species	Unclear	High productivity of the region likely to support a range of protected species including whale sharks, sea birds and cetaceans	One of a few regions in the AEEZ that may be supporting feeding Whale sharks	Changes to productivity dynamics may be the most likely threat to the ability of this region to support protected species using this subregion
2. Protected places				
3. Key ecological features				
Pelagic communities	High local productivity likely to be supporting species rich and diverse pelagic communities; Part of only spawning region for SBT and likely important nursery ground for larvae and juveniles of SBT and other	Subregion appears to be most strongly influenced by upwelling and seamount-induced productivity; Supports aggregation of large pelagic fish and likely to be similar for small pelagics and meso-pelagics	SBT and probably other pelagic species likely to occur in this subregion only due to it's high relative productivity, and remote location compared to other AEEZs	Can be heavily altered by increased commercial and/or IUU fishing activity

Conservation values	Assessment against NRSMPA criteria 6-9 (Wharton Basin subregion)			
	Ecological importance	**Productivity**	**Uniqueness**	**Vulnerability assessment**
	pelagic species			
Seamount communities	Likely to have unique and relatively diverse benthic and demersal communities, including endemics; These may be self sustaining given the rarity of other deep seamounts in the broader region	High pelagic productivity is likely to support high demersal productivity in this region via falling POM	Deep water seamounts will have unique benthic and demersal communities within an AEEZ context.	Climate change may alter productivity patterns; Fishing effort controls needed to maintain pelagic productivity which link to demersal productivity; Demersal fishing should be assessed with great caution given the unique characteristics of the subregion
Abyssal plain communities	Potential for endemism in deep hole and valley habitats	As for seamount communities in the subregion (above)	Deep abyssal plain communities also unique in an AEEZ context.	Seafloor mining should be assessed with great caution in this unique region

5.2 Central Ridge subregion

Table 5-3. Table summarising the assessment of conservation values against five of the NRSMPA criteria for the Cocos Basin subregion. CI = Christmas Island; CKI – Cocos (Keeling) Islands; POM - particulate organic matter; SBT = Southern bluefin tuna.

Conservation values	**Assessment against NRSMPA criteria 1-5 (Central Ridge subregion)**				
	Naturalness	**Biogeographic importance**	**International and national importance**	**Representativeness**	**Comprehensiveness**
1. Protected species	Most TEP species appear to be undisturbed within the subregion; CI red crabs (which spawn in the sea) are substantially affected by introduced crazy ant species	Supports wide range of resident and migrating seabird species; May provide genetic diversity for seabirds breeding on both CI and elsewhere (e.g. on CKI); Green turtles nest and form a unique genetic stock	Nesting ground for range of seabirds; Stopover habitat for a range of migrating seabirds; Important juvenile and adult whale shark habitat	Abbotts Booby, CI red crabs largely restricted to this subregion; Yellow-headed angelfish restricted to CI and CKI reefs	Ranges widely from species that occur fully within the subregion (red crabs) to species ranging globally (e.g. turtle and seabird species)
2. Protected places					
3. Key ecological features					
Pelagic communities	Limited recreational and charter fishing; Many pelagic communities will extend beyond the subregion boundaries so will be exploited by high seas fisheries	May be an important source for CKI species;	May be part of an important feeding and breeding region for large pelagic fish, some form part of an international fishery; Appears to be an important stopover and	Most pelagic species appear to be wide ranging	May be part of the spawning region for SBT, and possibly other pelagic species

			juvenile habitat for wide-ranging whale sharks		
Seamount communities	Largely unimpacted; Some recreational fish and boating on CI reefs	May be a source for benthic and demersal species for CKI territory seamount communities	Unclear	Few similar seamount features in AEEZ	Contains about 1/3 seamounts in CI and CKI territories and about 12% of seamounts in AEEZ; Also relatively large proportions of saddles and slope/plateaus
Abyssal plain communities	Largely unimpacted	Unclear	Unclear	Abyssal plain features widespread, but these habitats may be unique in having close association with productive seamounts	<1% of Abyssal plain in AEEZ and <3% of CI and CKI territories;

Table 5-4. Table summarising the assessment of conservation values against four of the NRSMPA criteria for the Cocos Basin subregion. CI = Christmas Island; CKI – Cocos (Keeling) Islands; SBT – Southern bluefin tuna; POM - particulate organic matter

Conservation values	**Assessment against NRSMPA criteria 6-9 (Central Ridge subregion)**			
	Ecological importance	**Productivity**	**Uniqueness**	**Vulnerability assessment**
1. Protected species	Pelagic environment supports the endemic Abbotts Booby and CI Frigatebird; Likely nursery for juvenile whale sharks; Green turtles nest and forage; Reef habitats support six pipefish species; Staging point for many migratory bird species	Appears to be an important stopover for migrating whale sharks, whales and birds;	Only remaining habitat for Abbotts Booby; One of a few habitats in AEEZ that supports whale sharks; Marine environment supports the endemic Christmas Island Frigatebird	Mining and land clearing can have direct and indirect effects on bird nesting success and reef quality; Many introduced terrestrial species impacting endemic species; Marine pollution and debris impacts crab and turtle habitat
2. Protected places	Wetlands listed under RAMSAR convention			
3. Key ecological features				
Pelagic communities	Appears to support rich and diverse pelagic communities; Subregion generates eddies that support high productivity	Supports productive pelagic commercial, game and recreational fisheries due to proximity to seasonal upwelling and eddy systems	Eddies unique to this region develop in associated with the combination shallow seamounts and opposing currents, to produce highly productive cells	Pelagic productivity dynamics may be vulnerable to climate change; Overfishing (including IUU)
Seamount communities	Shallow and deep seamount communities likely to be relatively diverse and abundant;	Shallow seamount environments likely to benefit from high pelagic productivity;	Shallow seamount habitats rare in the west AEEZ outside this subregion; Reef habitat with low diversity of coral species but many	Shallow reefs have been severely impacted by bleaching;

Conservation values	Assessment against NRSMPA criteria 6-9 (Central Ridge subregion)			
	Ecological importance	Productivity	Uniqueness	Vulnerability assessment
			hundreds of Indo-west Pacific fish and invertebrate species; Shallow reef surrounding Christmas I considered to be very high quality in relative terms	
Abyssal plain communities	Unclear	Likely to be relatively productive based on pelagic productivity and habitats created by close proximity to seamounts	Unclear	Few threats currently; Non-resilient habitat

5.3 Cocos Basin subregion

Table 5-5. Table summarising the assessment of conservation values against five of the NRSMPA criteria for the Cocos Basin subregion. CI = Christmas Island; CKI – Cocos (Keeling) Islands; POM - particulate organic matter

Conservation values	**Assessment against NRSMPA criteria 1-5 (Cocos Basin subregion)**				
	Naturalness	**Biogeographic importance**	**International and national importance**	**Representativeness**	**Comprehensiveness**
1. Protected species	All TEP species appear to be undisturbed within the subregion, however, most that occur within this subregion will have a broad distribution		May to be part of the migration route and foraging grounds for a range of protected sea birds, turtles and cetaceans	Many protected species (turtles, birds, cetaceans) are likely to be found within this region, though it does not appears to be critical habitat for any	Only a small proportion of the population of protected species is likely to be found within this region
2. Protected places					
3. Key ecological features					
Pelagic communities	Limited fishing activity has occurred in this subregion since closure of Japanese longlining in 1998. Many pelagic communities will extend beyond the subregion boundaries so will be exploited by high seas fisheries.		May be part of an important feeding and breeding region for large pelagic fish, some form part of an international fishery	This subregion is likely to contain a broad range of pelagic species.	Most east Indian Ocean pelagic species will be found in here at some density or time, apart form SBT which are more likely to be found in the eastern subregion (Wharton Basin).
Seamount	Largely unimpacted	Unclear	Contains small number	The seamounts of this	The seamounts of this

communities			of seamounts compared to the region and AEEZ.	subregion are mostly deep and somewhat separated from the main seamount chain, therefore only represent a small subset of seamount types in the volcanic province.	subregion are only a small proportion of this seamount type in the volcanic province that runs through these external territories.
Abyssal plain communities	Largely unimpacted	Unclear	Contains relatively small section of the Cocos basin.	The abyssal regions are relatively flat and featureless. There is some harder substrate and manganese nodules but these are associated with the seamounts in the south of the subregion.	Contains relatively small section of the broader Cocos basin together with two other subregions of the Cocos territory

Table 5-6. Table summarising the assessment of conservation values against four of the NRSMPA criteria for the Cocos Basin subregion. CI = Christmas Island; CKI – Cocos (Keeling) Islands; SBT – Southern Bluefin Tuna; POM - particulate organic matter

Conservation values	**Assessment against NRSMPA criteria 6-9 (Cocos Basin subregion)**			
	Ecological importance	**Productivity**	**Uniqueness**	**Vulnerability assessment**
1. Protected species	Probably forms part of a larger feeding ground for a range of TEP species such as sea birds, turtles and cetaceans.	The relative productivity of the subregion is likely to support the necessary trophic system suitable to support TEP species populations.		Changes to productivity dynamics may be the most likely threat to the ability of this region to support protected species using this subregion
2. Protected places				
3. Key ecological features				

Conservation values	**Assessment against NRSMPA criteria 6-9 (Cocos Basin subregion)**			
	Ecological importance	**Productivity**	**Uniqueness**	**Vulnerability assessment**
Pelagic communities	High local productivity likely to be supporting species rich and diverse pelagic communities; probably forms part of a larger feeding ground for a range of pelagic species.	Subregion appears to be most influenced by upwelling and other dynamic eddies and current features, which in turn is likely to support the necessary trophic system suitable to support pelagic species populations.	This subregion is likely to contain a broad range of pelagic species found in the East Indian Ocean	Can be heavily altered by increased commercial and/or IUU fishing activity
Seamount communities	Contains a small number of seamounts that are likely to contain significant populations of demersal communities. Likely to be a high connectivity to neighbouring seamounts due to high currents.	Pelagic productivity is likely to support demersal seamount populations via falling POM	Contains a small number of seamounts that are likely to contain communities similar to neighbouring seamounts due to high currents and resultant connectivity. Overall, deep water seamounts within the region will have unique benthic and demersal communities within an AEEZ context.	Climate change may alter productivity patterns; this will potentially affect productivity and connectivity of seamount communities. Demersal fishing should be assessed with great caution given the fragile nature of seamount communities.
Abyssal plain communities	The abyssal plain of this subregion forms a small part of the broader Cocos Basin.	Pelagic productivity is likely to support demersal abyssal communities via falling POM	Probably contains fauna common to the broader Cocos Basin. These abyssal plain communities are probably unique in an AEEZ context.	This subregion contains small areas of manganese nodules. Seafloor mining should be assessed with great caution in this subregion.

5.4 East Cocos Abyssal Plain

Table 5-7. Table summarising the assessment of conservation values against five of the NRSMPA criteria for the East Cocos Abyssal Plain subregion.
CI = Christmas Island; CKI – Cocos (Keeling) Islands; POM - particulate organic matter

Conservation values	**Assessment against NRSMPA criteria 1-5 (East Cocos Abyssal Plain subregion)**				
	Naturalness	**Biogeographic importance**	**International and national importance**	**Representativeness**	**Comprehensiveness**
1. Protected species	All TEP species appear to be undisturbed within the subregion, however, most that occur within this subregion will have a broad distribution		May to be part of the migration route and foraging grounds for a range of protected sea birds, turtles and cetaceans	Many protected species (turtles, birds, cetaceans) are likely to be found within this region, though it does not appears to be critical habitat for any	Only a small proportion of the population of protected species is likely to be found within this region
2. Protected places					
3. Key ecological features					
Pelagic communities	Limited fishing activity has occurred in this subregion since closure of Japanese longlining in 1998. Many pelagic communities will extend beyond the subregion boundaries so will be exploited by high seas fisheries.		May be part of an important feeding and breeding region for large pelagic fish, some form part of an international fishery	This subregion is likely to contain a broad range of pelagic species representative of those generally associated with the waters of the Indo-Pacific Throughflow.	Most east Indian Ocean pelagic species will be found in here at some density or time, apart especially those species associated with the Indo-Pacific Throughflow
Seamount	Largely unimpacted	The seamounts in this	Contains small number	The seamounts of this	Only a small proportion

communities		subregion are isolated major and shallow and probably represent important ecological communities in the context of the region.	of significant seamounts	subregion are small in number and have the unusual combination of being somewhat separated from the main seamount chain, shallow (<1000 m) and mostly large therefore represent a unique subset of seamount types in the volcanic province.	of the seamounts in the region are contained within this subregion, however, these probably have a unique set of physical drivers that sets them apart in the regional and national context.
Abyssal plain communities	Largely unimpacted	The abyssal plains are unique, being among the deepest in the region and influenced by the adjacent investigator Ridge.	Contains relatively small section of the broader Cocos Basin.	The abyssal regions within the subsystem contain a broad range of habitat types, from deep basins, featureless abyssal plain and abyssal plain adjacent to major ridge systems. This will likely produce a wide variety of benthic communities in the abyssal plains of this subregion.	Contains relatively small section of the broader Cocos basin together with two other subregions of the Cocos territory. Likely to be a unique combination of abyssal communities due to interaction with Investigator Ridge.

Table 5-8. Table summarising the assessment of conservation values against four of the NRSMPA criteria for the East Cocos Abyssal Plain subregion. CI = Christmas Island; CKI – Cocos (Keeling) Islands; SBT – Southern Bluefin Tuna; POM - particulate organic matter

Conservation values	**Assessment against NRSMPA criteria 6-9 (East Cocos Abyssal Plain subregion)**			
	Ecological importance	**Productivity**	**Uniqueness**	**Vulnerability assessment**
1. Protected species	Probably forms part of a larger feeding ground for a range of TEP species such as sea birds, turtles and cetaceans.	Productivity from seasonal upwelling and dynamics associate with seamount and ridge features is likely to support the necessary trophic system suitable to support TEP species populations.		Changes to productivity dynamics may be the most likely threat to the ability of this region to support protected species using this subregion
2. Protected places				
3. Key ecological features				
Pelagic communities	Local productivity likely to be supporting species rich and diverse pelagic communities; probably forms part of a larger feeding ground for a range of pelagic species.	Subregion appears to be most influenced by upwelling and dynamic eddies associated with seamounts and ridge features, which in turn is likely to support the necessary trophic system suitable to support pelagic species populations.	This subregion is likely to contain a broad range of pelagic species found in the East Indian Ocean	Can be heavily altered by increased commercial and/or IUU fishing activity
Seamount communities	Contains a small number of seamounts that are likely to contain significant populations of demersal communities. Likely to be some connectivity with neighbouring seamounts due	Pelagic productivity is likely to support demersal seamount populations via falling POM	Contains a small number of significant seamounts that probably have a unique set of physical drivers that would indicate the likelihood of a unique fauna in the regional and national context.	Climate change may alter productivity patterns; this will potentially affect productivity and connectivity of seamount communities. Demersal fishing should be

Conservation values	**Assessment against NRSMPA criteria 6-9 (East Cocos Abyssal Plain subregion)**			
	Ecological importance	**Productivity**	**Uniqueness**	**Vulnerability assessment**
	to directional currents.			assessed with great caution given the fragile nature of seamount communities.
Abyssal plain communities	Potential for endemism in the deeper basins.	Pelagic productivity is likely to support demersal abyssal communities via falling POM	The abyssal plain of this subregion forms a small part of the broader Cocos Basin, however, the adjacency to the Investigator Ridge and its divers range of abyssal habitats make it potentially diverse and probably unique system.	Seafloor mining should be assessed with great caution in this subregion.

5.5 Investigator Ridge subregion

Table 5-9. Table summarising the assessment of conservation values against five of the NRSMPA criteria for the Investigator Ridge subregion. CI = Christmas Island; CKI – Cocos (Keeling) Islands; SBT – Southern Bluefin Tuna; POM - particulate organic matter

Conservation values	**Assessment against NRSMPA criteria 1-5 (Investigator Ridge subregion)**				
	Naturalness	**Biogeographic importance**	**International and national importance**	**Representativeness**	**Comprehensiveness**
1. Protected species	All species appear to be under minor or no short-term threat within the subregion	Lack of land mass in the subregion restricts its services to food provision to birds and pelagic species. At depth, unique habitats may offer other services to demersal species	Likely to be part of the migration route and foraging grounds for a range of protected sea birds, turtles and cetaceans due to potential enhancement of productivity from currents interacting with the Ridge system	Many protected species (turtles, birds, cetaceans) are widespread;	Lack of service provision restricts access to adult species but long duration drifting larvae of many species may transit through the region
2. Protected places					
3. Key ecological features					
Pelagic communities	Limited fishing activity – mostly concentrated in the northern half of this subregion	Many larvae from pelagic species such as Southern Bluefin Tuna (SBT) may transit through this region in the South Equatorial Current or eddies spawned from the	May be part of an important feeding, and possibly breeding region for large pelagic fish.	Being in the path of the South Equatorial Current, species transiting through the region are likely to be representative of those generally associated with the waters of the	Likely to contain a relatively comprehensive suite of larval species associated with the Indo-Pacific Throughflow but lack of land mass restricts

Conservation values	Assessment against NRSMPA criteria 1-5 (Investigator Ridge subregion)				
	Naturalness	Biogeographic importance	International and national importance	Representativeness	Comprehensiveness
		South Java Current. Species transiting from the east through to CKI must pass through this subregion		Indo-Pacific Throughflow	value of region to those species which require land (e.g turtles requiring nesting sites)
Ridge/Seamount communities	Largely unimpacted apart from any debris from passing traffic (such as dead sheep – C. Davies, pers. comm.)	This subregion represents a major geophysical divide that may well have separated communities at depth, and offered others a set of unique habitats	The Ridge system represents a substantial proportion (>15%) of ridges within Australia's EEZ and it's the only example in the CI/CKI territories.	While other such communities may exist in Australia's EEZ, the communities in this subregion may be unique due to their location within a unique Sub-Province (the striation region) and a unique subregion (there are no other such subregions)	Uncertain as the subregion contains only a segment (but a significant one at that) of the entire Investigator Ridge which traverses an extensive latitude range
Deep Trench and Abyssal Plain communities	Largely unimpacted (apart from those dead carcasses from above)	As above	As above, but represents only 7.5% of such geological units in Australia's EEZ. 100% in CI/CKI territories.	As above. Also, being below the Calcite Compensation Depth implies that communities at these depths must be highly adapted to live in such extreme conditions. We have very little idea what's down there in those deep trenches – a fascinating area for future research voyages	As above

Table 5-10. Table summarising the assessment of conservation values against four of the NRSMPA criteria for the Investigator Ridge subregion. CI = Christmas Island; CKI – Cocos (Keeling) Islands; SBT – Southern Bluefin Tuna; POM - particulate organic matter.

Conservation values	**Assessment against NRSMPA criteria 6-9 (Investigator Ridge subregion)**			
	Ecological importance	**Productivity**	**Uniqueness**	**Vulnerability assessment**
1. Protected species		Productivity is in general higher to the north, as is the supply of sedimentary material to the deep. The Ridge is likely to interact with current systems to cause local uplift of water masses and downstream enhancement by mixing, nutrient supply and productivity. Catches of commercial fish are higher in the north so abundances of protected species may also be higher in that region	A very unique geophysical environment that we know very little about so unique species may exist that are not on the list of protected species	Changes to productivity dynamics and the flow of the various intermediate and deep water masses may be the most likely threat to the ability of this region to support protected species using this subregion. Flow path changes may alter the delivery of larvae to environments that may reduce the changes of recruitment
2. Protected places				
3. Key ecological features				
Pelagic communities	High local and downstream productivity likely to be supporting species richness and diverse pelagic communities; Many larvae are likely to be transiting through this subregion as for example SBT larvae	Subregion, particularly the northern half, appears to be most strongly influenced by upwelling and seamount-induced productivity; appears to support aggregation of large pelagic fish and likely to be similar for small pelagics and meso-pelagics	This is a unique subregion where the South Equatorial Current flows across the Ridge system. As such the environment is unique and may translate to unique or unusual collections of pelagic and mid-water communities	Can be heavily altered by increased commercial and/or IUU fishing activity. Climate Change likely to alter productivity, water masses and currents

Conservation values	Assessment against NRSMPA criteria 6-9 (Investigator Ridge subregion)			
	Ecological importance	**Productivity**	**Uniqueness**	**Vulnerability assessment**
Ridge/Seamount communities	Likely to have unique and relatively diverse benthic and demersal communities, including endemics; particularly the rare Ridge habitats. These may be self sustaining given the rarity of other deep such environments in the broader region and in the Australian EEZ	High pelagic productivity is likely to support high demersal productivity in this region via falling POM	As for Pelagic communities, deep water ridge and seamounts will have unique benthic and demersal communities within an AEEZ context	Climate change may alter productivity, water masses and current patterns; Fishing effort controls needed to maintain pelagic productivity which link to demersal productivity; Demersal fishing should be assessed with great caution given the unique characteristics of the subregion
Abyssal plain communities	Potential for endemism in deep hole and the very deep trenches below the Calcite Compensation Depth	As for seamount communities in the subregion (above).	Deep abyssal plain communities also unique in an AEEZ context especially those in the deep trenches below the Calcite Compensation Depth may await new discoveries	Seafloor mining should be assessed with great caution in this unique region given the slow water mass circulations and very slow natural accumulations of sediment

5.6 Cocos Volcanic Field subregion

Table 5-11. Table summarising the assessment of conservation values against five of the NRSMPA criteria for the Cocos Volcanic Field subregion. CI = Christmas Island; CKI – Cocos (Keeling) Islands; POM - particulate organic matter.

Conservation values	Assessment against NRSMPA criteria 1-5 (Cocos Volcanic Field subregion)				
	Naturalness	**Biogeographic importance**	**International and national importance**	**Representativeness**	**Comprehensiveness**
1. Protected species	Important seabird rookeries impacted by human settlements	Only Australian marine region with stronger biogeographic affinities to Indian ocean communities than elsewhere; Green turtles are a unique genetic stock	Nesting ground for range of seabirds; stopover habitat for a range of migrating seabirds	Seabirds, whales, dolphins and turtles not restricted to CKI; Only dugong for >1000 km!	Some seabirds found only in the Central Ridge and Cocos Volcanic Field subregions
2. Protected places	Pulu Keeling National Park – naturalness unclear	See above	Among the worlds most important and largest red foot booby colony in the world; Second largest lesser frigate bird nesting population in Australia and possibly the Indian Ocean	No other national park with this combination of features in the broader region	See 'International and national importance'
3. Key ecological features					
Pelagic	Some local recreational fishing	Unclear	Unclear	May be similar to other	Unclear, but may be

communities	activity			oceanic communities in NE Indian Ocean	similar pelagic communities at CI territory and other Australian marine regions
Seamount communities	Largely unimpacted	Shallow seamount communities with strong Indian ocean affinities	Unclear	Shallow reef communities on seamount peaks with at least 10 species of marine endemic animals	Contains significant proportion of seamounts AEEZ
Abyssal plain communities	Largely unimpacted	Unclear	Unclear	Unclear	Unclear

Table 5-12. Table summarising the assessment of conservation values against four of the NRSMPA criteria for the Cocos Volcanic Field subregion. CI = Christmas Island; CKI – Cocos (Keeling) Islands; POM - particulate organic matter.

Conservation values	**Assessment against NRSMPA criteria 6-9 (Cocos Volcanic Field subregion)**			
	Ecological importance	**Productivity**	**Uniqueness**	**Vulnerability assessment**
1. Protected species	Large number of seabirds may have important role in structuring pelagic communities; May be an important staging point for many migrating seabirds	Relatively high productivity of the region likely to support a range of protected species including sea birds and cetaceans; Reef habitats support range of diverse communities	Wide variety of breeding, resident and migrating seabirds;	Vulnerable to changes in productivity dynamics as well as human impacts, including egg collection and habitat destruction; Southern atoll already cleared for a coconut plantation
2. Protected places	Pulu Keeling National Park protects large seabird breeding colonies	See 'International and national importance'	Only seabird colony for almost 1000 km	See above
3. Key ecological features				

Conservation values	**Assessment against NRSMPA criteria 6-9 (Cocos Volcanic Field subregion)**			
	Ecological importance	**Productivity**	**Uniqueness**	**Vulnerability assessment**
Pelagic communities	Unclear	Some seasonal and seamount-induced productivity blooms; Supports aggregations of large pelagic fish; likely to be similar for small and meso-pelagics	May be similar to other Indo-west Pacific pelagic communities	Can be heavily altered by increased commercial and/or IUU fishing activity
Seamount communities	These may be self sustaining given the rarity of other shallow seamount communities in the region	Highly productive reef habitats on shallow seamounts; Relatively high pelagic productivity is likely to support high demersal productivity on slopes in this region via falling POM	Extensive shallow and highly diverse habitats on Cocos and Murefield seamounts	Climate change may alter productivity patterns and impact coral reefs; Fishing effort controls needed to maintain pelagic productivity
Abyssal plain communities	Potential for endemism (see ‘Uniqueness’)	As for seamount communities in the subregion (above)	May support unique communities in a regional and AEEZ context, due in part to segregation by investigator ridge.	Seafloor mining should be assessed with great caution in this unique region

5.7 West Cocos Abyssal Plain subregion

Table 5-13. Table summarising the assessment of conservation values against five of the NRSMPA criteria for the Cocos Volcanic Field subregion. CI = Christmas Island; CKI – Cocos (Keeling) Islands; POM - particulate organic matter.

Conservation values	**Assessment against NRSMPA criteria 1-5 (West Cocos Abyssal Plain subregion)**				
	Naturalness	**Biogeographic importance**	**International and national importance**	**Representativeness**	**Comprehensiveness**
1. Protected species	All species appear to be under minor or no short-term threat within the subregion	Unclear	May to be part of the migration route and foraging grounds for a range of protected sea birds, turtles and cetaceans	Many protected species (turtles, birds, cetaceans) are likely to be found within this region, though it does not appears to be critical habitat for any	Only a small proportion of the population of protected species is likely to be found within this region
2. Protected places					
3. Key ecological features					
Pelagic communities	Limited fishing activity has occurred in this subregion since closure of Japanese longlining in 1998;	Unclear	May be part of an important feeding and breeding region for large pelagic fish - some may form part of an international fishery	This subregion is likely to contain a broad range of pelagic species representative of those generally associated with the waters of the Indo-Pacific Throughflow.	Likely to have low levels of representativeness for pelagic species
Abyssal plain communities	Largely unimpacted	Unclear	Contains relatively small section of the	The abyssal regions within the subsystem	Contains about 5% of basin and abyssal plain

			broader Cocos Basin.	contain basin and abyssal plain habitats that may be similar to others in the western AEEZ and internationally	environments in AEEZ

Table 5-14. Table summarising the assessment of conservation values against four of the NRSMPA criteria for the Cocos Volcanic Field subregion. CI = Christmas Island; CKI – Cocos (Keeling) Islands; POM - particulate organic matter.

Conservation values	**Assessment against NRSMPA criteria 6-9 (West Cocos Abyssal Plain subregion)**			
	Ecological importance	**Productivity**	**Uniqueness**	**Vulnerability assessment**
1. Protected species	Probably forms part of a larger feeding ground for a range of TEP species such as sea birds, turtles and cetaceans.	Influenced by relatively oligotrophic ITF water, with sporadic, interannual productivity blooms in Sring	Unclear	May be targeted for deep sea mining; Habitats here relatively fragile and vulnerable to moinor disturbance
2. Protected places				
3. Key ecological features				
Pelagic communities	Low compared to other subregions	Low compared to other subregions; Productivity blooms in spring in some years	This subregion is likely to contain a broad range of pelagic species found in the East Indian Ocean	Can be heavily altered by increased commercial and/or IUU fishing activity
Abyssal plain communities	Potential for endemism in the deeper basins.	Sporadic pelagic productivity is likely to support demersal abyssal communities via falling POM	Most westerly Abyssal plain and Basin environments in AEEZ	Seafloor mining should be assessed with great caution in this subregion

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7. APPENDICES

APPENDIX A – PHYSICAL DATA SUMMARIES

Bathymetry (m)

(m)	Mean	Min	Max	Range	Majority	Median
Wharton Basin	-5210	-6306	-1848	4458	-5499	-5422
Christmas Central Ridge	-4345	-5721	227	5948	-5001	-4607
Cocos Basin	-5287	-5715	-1696	4019	-5500	-5485
Cocos Volcanic Field	-4645	-5932	75	6007	-5000	-4899
East Cocos Abyssal Plain	-5250	-6072	-1797	4275	-5500	-5484
Investigator Ridge	-5140	-6123	-2838	3285	-5000	-5246
West Cocos Abyssal Plain	-5239	-6017	-3971	2046	-5500	-5198

Wharton Basin

Depth (m)	Nit (uM)	Oxy (mg/l)	Pho (uM)	Sal (ppt)	Sil (uM)	Temp (C°)
0		4.57	0.13	34.28	3.63	27.65
150	16.43	2.78	1.16	34.68	34.68	18.71
500	31.97	2.30	2.18	34.68	46.86	8.40
1000	37.31	2.10	37.31	34.62	96.91	5.08
2000	36.79	3.14	2.59	34.73	119.97	2.51
Bottom	34.47	4.41	2.33	34.71	129.71	1.21

Christmas Central Ridge

Depth (m)	Nit (uM)	Oxy (mg/l)	Pho (uM)	Sal (ppt)	Sil (uM)	Temp (C°)
0		4.52	0.14	34.26	3.42	27.45
150	17.55	2.68	1.23	34.65	34.65	17.89
500	32.69	2.15	2.19	34.69	47.03	8.46
1000	37.13	2.09	37.13	34.63	95.31	5.12
2000	36.65	3.12	2.61	34.74	117.01	2.53
Bottom	35.16	4.22	2.35	34.71	129.58	1.43

Cocos Basin

Depth (m)	Nit (uM)	Oxy (mg/l)	Pho (uM)	Sal (ppt)	Sil (uM)	Temp (C°)
0		4.47	0.15	34.24	3.48	27.43
150	17.96	2.63	1.34	34.61	34.61	17.42
500	32.68	2.02	2.21	34.72	46.90	8.61
1000	36.61	2.06	36.61	34.64	94.55	5.13
2000	35.86	3.09	2.63	34.74	114.34	2.53
Bottom	34.22	4.49	2.27	34.71	129.63	1.20

Cocos Volcanic Field

Depth (m)	Nit (uM)	Oxy (mg/l)	Pho (uM)	Sal (ppt)	Sil (uM)	Temp (C°)
0		4.56	0.16	34.33	4.41	26.89
150	10.94	3.04	0.96	34.89	34.89	19.47
500	27.05	3.15	1.90	34.71	30.75	8.65
1000	35.70	2.04	35.70	34.65	82.57	5.18
2000	35.14	3.14	2.63	34.74	88.09	2.57
Bottom	33.02	4.53	2.28	34.72	128.71	1.19

East Cocos Abyssal Plain

Depth (m)	Nit (uM)	Oxy (mg/l)	Pho (uM)	Sal (ppt)	Sil (uM)	Temp (C°)
0		4.51	0.12	34.29	2.17	27.29
150	14.42	2.76	1.13	34.76	34.76	18.36
500	29.39	2.50	2.07	34.71	36.71	8.49
1000	35.14	2.01	35.14	34.65	89.06	5.10
2000	34.51	3.07	2.63	34.74	97.91	2.57
Bottom	33.20	4.50	2.26	34.71	129.06	1.22

Investigator Ridge

Depth (m)	Nit (uM)	Oxy (mg/l)	Pho (uM)	Sal (ppt)	Sil (uM)	Temp (C°)
0		4.54	0.14	34.28	2.91	27.16
150	13.51	2.85	1.08	34.83	34.83	18.61
500	28.42	2.76	2.01	34.72	33.64	8.61
1000	35.18	2.00	35.18	34.65	85.92	5.14
2000	34.64	3.09	2.63	34.74	92.92	2.57
Bottom	32.80	4.57	2.27	34.71	129.02	1.17

West Cocos Abyssal Plain

Depth (m)	Nit (uM)	Oxy (mg/l)	Pho (uM)	Sal (ppt)	Sil (uM)	Temp (C°)
0		4.53	0.14	34.20	5.42	27.45
150	15.49	2.55	1.21	34.71	34.71	17.82
500	30.43	2.36	2.08	34.74	38.60	8.66
1000	35.58	1.97	35.58	34.67	82.26	5.24
2000	34.67	3.11	2.57	34.74	87.54	2.58
Bottom	33.12	4.57	2.27	34.71	129.34	1.19

Mean All Regions (Project Area Mean)

Depth (m)	Nit (uM)	Oxy (mg/l)	Pho (uM)	Sal (ppt)	Sil (uM)	Temp (C°)
0		4.53	0.14	34.27	3.64	27.33
150	15.19	2.75	1.16	34.73	34.73	18.33
500	30.38	2.46	2.09	34.71	40.07	8.55
1000	36.09	2.04	36.09	34.64	89.51	5.14
2000	35.47	3.11	2.61	34.74	102.54	2.55
Bottom	33.71	4.47	2.29	34.71	129.29	1.23

APPENDIX B – RUSSIAN PHOTO INVENTORY

Column Identifiers - Photo Descriptors

A - fe_mn
B – tracks&trails
C – fish
D – sea_pens
E – echinoderms
F – mounds
G – sponges
H – scour
I – talus
J – sediment
K – substrate_outcrop

Photo Inventory

name	date	latitude	longitude	depth_m	A	B	C	D	E	F	G	H	I	J	K
VM28-242	19711030	-17.73	99.77	2830	1	1								1	
VM28-242	19711030	-17.73	99.77	2830	1	1								1	
VM28-242	19711030	-17.73	99.77	2830	1	1								1	
VM28-242	19711030	-17.73	99.77	2830	1	1								1	
VM28-243	19711031	-17.75	96.90	2995		1				1				1	
VM28-243	19711031	-17.75	96.90	2995		1				1				1	
VM28-243	19711031	-17.75	96.90	2995		1				1				1	
VM28-243	19711031	-17.75	96.90	2995		1				1				1	
VM28-244	19710111	-15.15	96.83	2479	1	1				1				1	
VM28-244	19710111	-15.15	96.83	2479	1	1				1				1	
VM28-244	19710111	-15.15	96.83	2479	1	1				1				1	
VM28-244	19710111	-15.15	96.83	2479	1	1				1				1	
VM28-244	19710111	-15.15	96.83	2479	1	1				1				1	
VM28-244	19710111	-15.15	96.83	2479	1	1				1				1	
VM28-245	19710311	-8.28	97.13	2800		1				1				1	
VM28-245	19710311	-8.28	97.13	2800		1				1				1	
VM28-245	19710311	-8.28	97.13	2800		1				1				1	
VM28-245	19710311	-8.28	97.13	2800		1				1				1	
VM28-245	19710311	-8.28	97.13	2800		1				1				1	
VM28-245	19710311	-8.28	97.13	2800		1				1				1	
VM28-246	19711011	-8.00	102.40	2945		1				1				1	
VM28-246	19711011	-8.00	102.40	2945		1				1				1	
VM28-246	19711011	-8.00	102.40	2945		1				1				1	
VM33-003	19760407	-17.72	106.35	3083		1				1				1	
VM33-003	19760407	-17.72	106.35	3083		1				1				1	
VM33-003	19760407	-17.72	106.35	3083		1				1				1	
VM33-005	19761107	-12.93	106.18	2982	4	1				1	1		1	1	
VM33-005	19761107	-12.93	106.18	2982	4	1				1	1		1	1	
VM33-005	19761107	-12.93	106.18	2982	4	1				1	1		1	1	
VM33-005	19761107	-12.93	106.18	2982	4	1				1	1		1	1	
VM33-006	19761207	-10.13	106.67	3175		1				1				1	
VM33-006	19761207	-10.13	106.67	3175		1				1				1	
VM33-006	19761207	-10.13	106.67	3175		1				1				1	

APPENDIX C – LIST OF SPECIES CAUGHT BY CHARTER AND RECREATIONAL FISHERS AT CHRISTMAS ISLAND

Commercially and recreationally fished animals of the Christmas and Cocos (Keeling) Islands territories. A = Department of Fisheries Western Australia (2007; B = Department of Fisheries Western Australia (2005); C = Department of Fisheries Western Australia (2006).

Species Name	Common Name	Christmas Island	Cocos Island	Reference
FISH				
Albulinae				
Albula neoguinaica	Bone fish		✓	B
Albula vulpes	Bone fish		✓	C
Albula spp.	Bone fish		✓	B, C
Carangidae				
Carangoides orthogrammus	Island trevally	✓		A
Caranx lugubris	Blue trevally	✓		A
Caranx melampygus	Bluefin trevally	✓	✓	A, C
Caranx ignobolis	Giant trevally	✓	✓	A, C
Caranx spp.	Other trevallies	✓		A
Decapterus macarellus	Mackerel scad	✓		A
Elegatis bipinnulata	Rainbow runner	✓		A
Scomberoides lysan	Queenfish	✓		A
Trachinotus baillonii	Dart		✓	C
Trachinotus blochii	Snub-nosed dart		✓	B
Trachinotus spp.	Dart		✓	B, C
Carcharhinidae				
Carcharhinus spp.	Dusky & bronze whalers		✓	B
Chanidae				
Chanos chanos	Milk fish		✓	B
Coryphaenidae				
Coryphaena hippurus	Dolphinfish	✓	✓	A, B, C
Exocoetidae				
Cypselurus spp.	Flying fishes	✓		A
Gerreidae				
Gerres acinaces	Silveries		✓	B
Gerres longirostris	Silveries		✓	C
Gerres spp.	Silveries		✓	C
Haemulidae				
Plectorhinchus chaetodontoides	Sweetlip		✓	B
Plectorhinchus gibbosus	Oriental/dusky sweetlips	✓		A
Hemirhamphidae				C
Hyporhamphus melanochir	Garfish		✓	B
Holocentridae				
Myripristis spp.	Soldier fishes	✓		A
Plectrypops spp.	Soldier fishes	✓		A
Sargocentron spp.	Squirrel fishes	✓		A
Istiophoridae				
Istiophorus platypterus	Sailfish	✓	✓	A, B, C
Tetrapturus audax	Striped marlin	✓	✓	A, B, C
Makaira mazara	Blue marlin	✓	✓	A, B, C
Labridae	Wrasse	✓		A
Cheilinus undulatus	Humphead maori wrasse	✓	✓	A, B, C

Species Name	Common Name	Christmas Island	Cocos Island	Reference
Lethrinidae				
Lethrinus miniatus	Redthroat emperor		✓	B, C
Lethrinus xanthocheilus	Yellowlip emperor (sweetlip)		✓	B, C
Monotaxis grandoculis	Large-eyed seabream	✓		A
Lutjanidae				
Aphareus rutilans	Small-toothed jobfish	✓		A
Aprion virescens	Green jobfish	✓		A
Etelis carbunculus	Ruby snapper	✓	✓	A, B
Etelis coruscans	Ruby snapper	✓		A
Etelis radiosus	Pale snapper	✓		A
Lipocheilus carnolabrum	Tang snapper		✓	B
Lutjanus bohar	Red bass	✓		A
Lutjanus fulviflamma	Blackspot smaller	✓	✓	A, C
Lutjanus fulvus	Yellow margined seaperch	✓		A
Lutjanus gibbus	Paddletail	✓	✓	A, B, C
Lutjanus kasmira	Blue stripe seaperch (Moses Perch)	✓	✓	A, B, C
Lutjanus rivulatus	Maori (blubberlip) seaperch	✓		A
Paracaesio sordidus	Blue snapper	✓		A
Pristipomoides auricilla	Goldflag jobfish	✓		A
Pristipomoides zonatus	Oblique banded snapper	✓		A
Pristipomoides auricilla	Rosy snapper	✓	✓	A, B
Pristipomoides filamentosus	Rosy snapper		✓	B
Mugilidae				
Liza vaigiensis	Diamond scale mullet		✓	B, C
Mugil cephalus	Sea mullet		✓	B, C
Mullidae	Goatfish		✓	B
Pempheridae				
Pempheris oualensis	Cave sweeper	✓		A
Priacanthidae				
Heteropriacanthus cruentatus	Glass big-eye	✓		A
Rhincodontidae				
Rhincodon typus	Whale shark			
Scaridae	Parrot fish		✓	B, C
Bolbometopon muricatum	Double-headed parrotfish		✓	B
Scomberesocidae				
Scomberesox saurus scombroides	Billfish	✓	✓	A, B, C
Scombridae				
Acanthocybium solandri	Wahoo	✓	✓	A, B, C
Gymnosarda unicolor	Dog-tooth tuna	✓	✓	A, B, C
Thunnus albacares	Yellowfin tuna	✓	✓	A, B, C
Thunnus obsesus	Big eye tuna	✓		A
Sarda australia	Bonito		✓	B, C
Serranidae				
Anyperodon leucogrammicus	White-lined cod	✓		A
Cephalopholis analis	Orange cod	✓		A
Cephalopholis argus	Peacock cod	✓		A
Cephalopholis miniatus	Coral cod	✓		A
Cephalopholis spiloparea	Strawberry cod	✓		A
Epinephelus fasciatus	Blacktipped cod	✓		A
Epinephelus hexagonatus	Wirenetting cod	✓		A

Species Name	Common Name	Christmas Island	Cocos Island	Reference
Epinephelus merra	Honeycomb cod	✓	✓	A, C
Epinephelus morrhua	Comet cod	✓		A
Epinephelus quoyanus	Long-finned rockcod		✓	C
Epinephelus retouti	Brownback cod	✓		A
Epinephelus sexmaculatus	Sixband cod	✓		A
Epinephelus spilotoceps	Spotty cod	✓		A
Epinephelus tauvina	Reef cod	✓		A
Plectropomus areolatus	Square-tail coral trout		✓	C
Plectropomus laevis	Chinese footballer cod		✓	B
Plectropomus maculatus.	Coral trout		✓	B, C
Saloptia powelli	Deepsea cod	✓		A
Variola louti	Lunar-tailed cod/Coronation trout	✓	✓	A, B, C
Siganidae				
Siganus argenteus	Rabbit fish		✓	B
Siganus spp.	Rabbit fish		✓	C
Sparidae				
Pagrus auratus	Pink snapper		✓	B
Sphyraenidae	Barracuda	✓		A
Sphyraena barracuda	Barracuda		✓	C
Tetradontidae				
Arothron hispidus	Stars & stripes toadfish		✓	B
Xiphiidae				
Xiphias gladius	Swordfish	✓	✓	A, B, C
CRUSTACEANS				
Diogenidae	Hermit crabs		✓	B, C
Palinuridae				
Panulirus ornatus	Ornate (‘leopard’) crayfish	✓		A
Panulirus pencillatus	Green crayfish	✓		A
Panulirus versicolor	Painted crayfish	✓		A
Panulirus spp.	Rock lobster	✓	✓	A, B, C
Portunidae	Sand crabs		✓	B, C
Scylla spp.	Mud crabs		✓	B, C
Ocypodidae	Ghost crabs		✓	B, C
Scyllaridae				
Parribacus antarcticus	Spanish lobster	✓		A
Scyllarides spp.	Slipper lobster		✓	B, C
MOLLUSCS				
Haliotidae	Abalone		✓	B
Strombidae				
Lambis lambis	Gong gong		✓	B
Tridacnidae				
Tridacna sp.	Clams		✓	B, C
Turninidae				
Turbo lajonkairii	Turban shell		✓	B, C
CEPHALOPODS				
Cephalopoda (Class)	Squid, cuttlefish, octopus			B, C

APPENDIX D – SUPPLEMENTARY MATERIAL

Table a). Definitions for sediment dataset.

Aggregated folk class value	Definition
M	Mud dominated with some sand and < 1% gravel
S	Sand dominated with some mud and < 1% gravel
gM	Mud dominated with gravel >1%, sand may also be present
gS	Sand dominated with gravel >1%, mud may also be present
G	Gravel dominated with lesser sand and/or mud

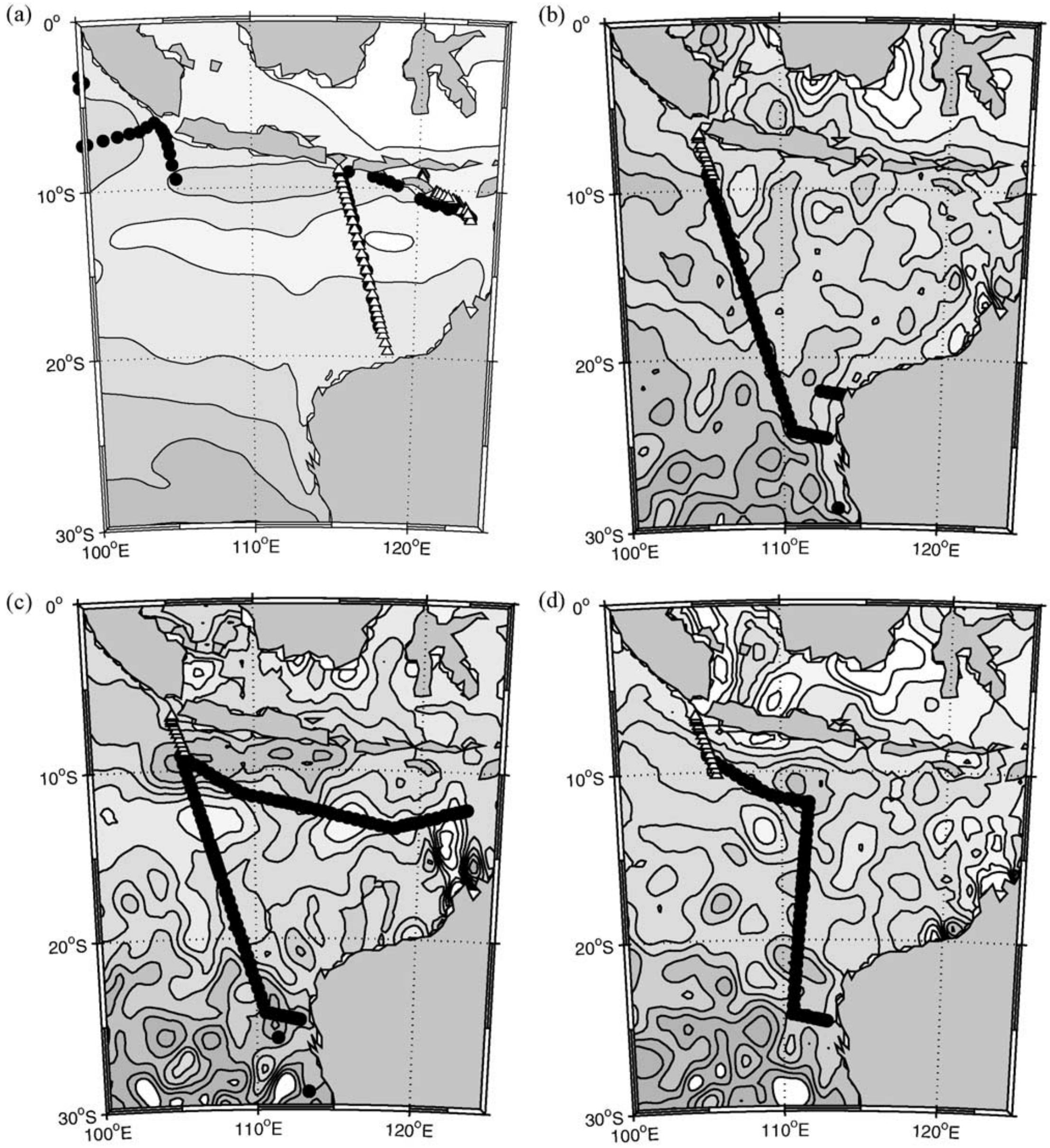

Figure a). Maps from Wijffles *et al.* (2002), showing the location of the hydrographic stations taken during the five cruises: (a) JADE August 1989 stations (b) WOCE IR6 April 1995, (c) and (d): as for (b) but for the WOCE September IR6 and November I10 cruises, respectively.

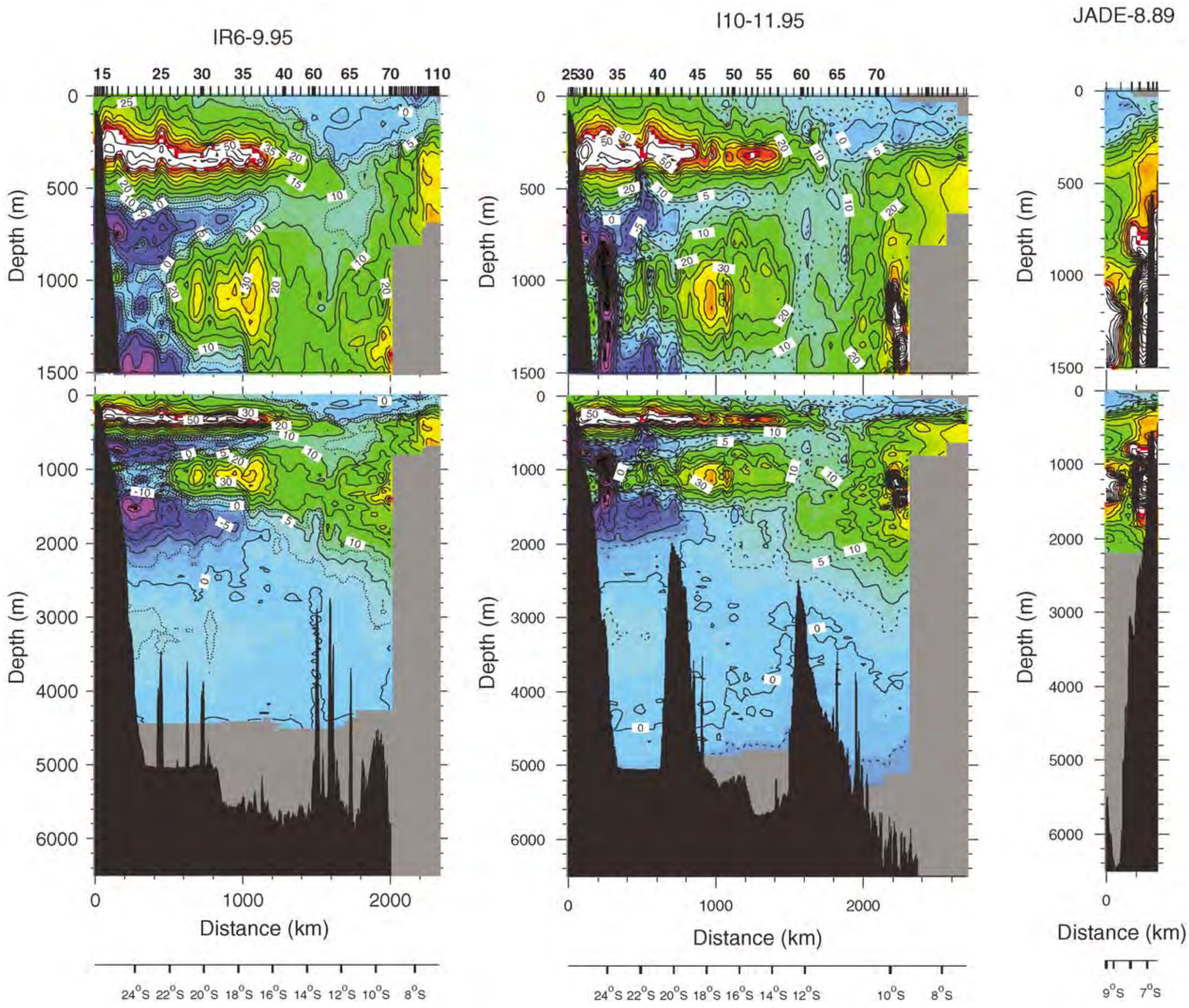

Figure b). Sections of normalised salinity anomaly from Wijffels *et al.,* (2002), along transects shown in Figure a).

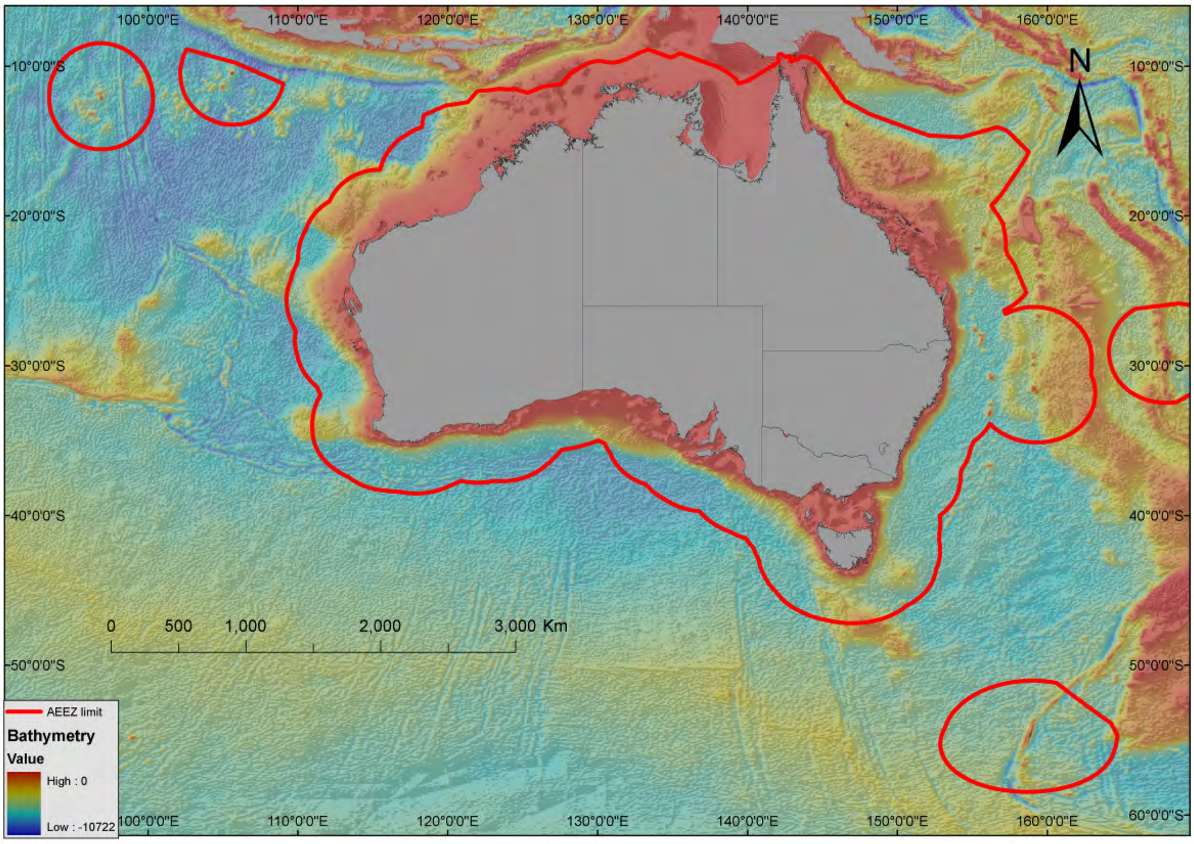

Figure c). Bathymetric profile of the entire AEEZ compared to Christmas and Cocos (Keeling) Islands territories. Note rich in deepwater areas.

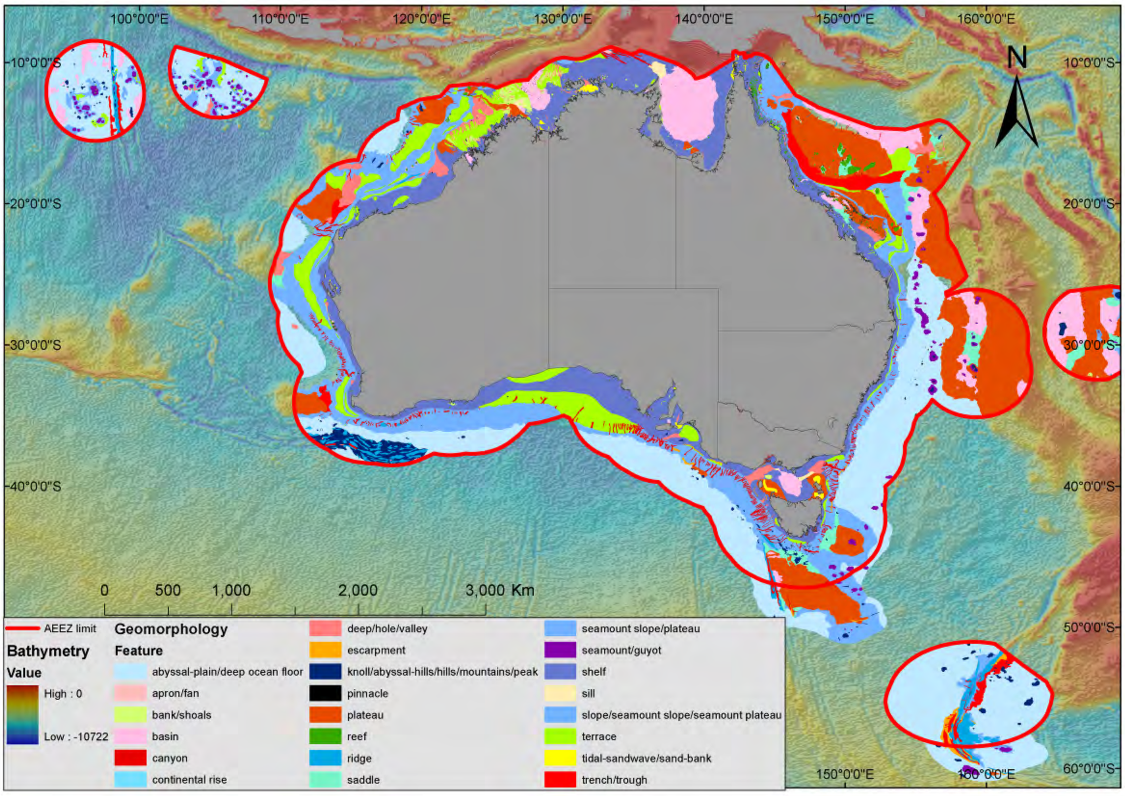

Figure d). Geomorphic profile of the entire AEEZ compared to Christmas and Cocos (Keeling) Islands territories. Note large % total AEEZ seamounts occur in this region. (graphs not final - suggest colouring match Geomorphology scheme)

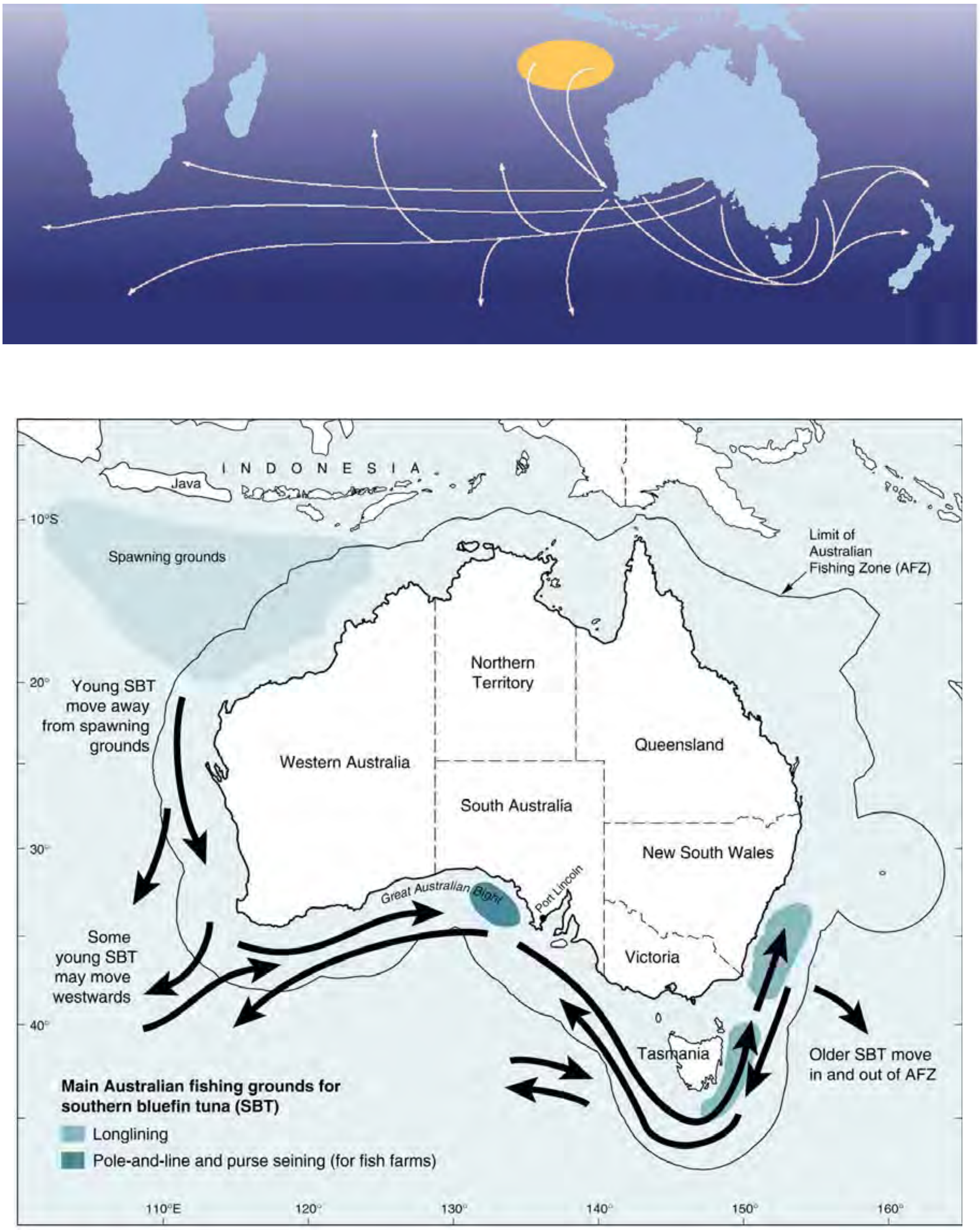

Figure 7-1. Southern bluefin tuna migration routes showing Australia's northern fishery and international migrations (above) and local migrations from the spawning grounds (below).

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