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Bioregions of the Indian Oceans

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CORDIO East Africa

GOBI Global Ocean Biodiversity Initiative www.gobi.org

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based on a decision of the German Bundestag

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Acknowledgments

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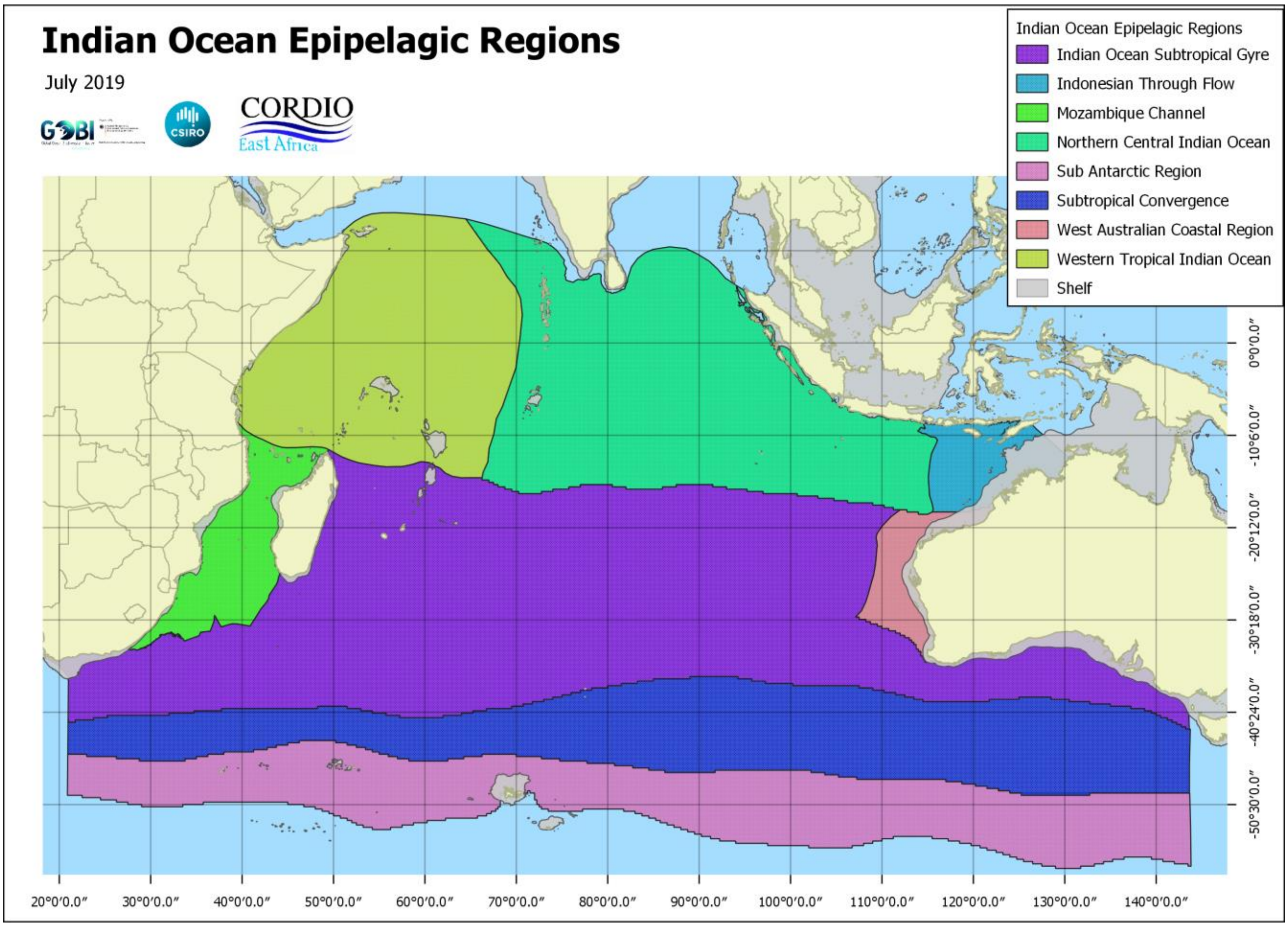
Bioregions of the Indian Ocean

This project has developed sub-regional bioregionalisations for the Indian Ocean. This combines approaches CSIRO developed in Australia, used in the Bay of Bengal (in collaboration with BOBLME) with similar approaches that have been used throughout the Indian and Pacific Oceans to derive a single combined bioregionalisation. The project has developed an expert derived bioregionalisation in the Indian and Pacific Oceans through expert workshops and novel statistical analysis of physical and biological data.

The project draws on experience in CSIRO, GOBI partners, and other collaborators, using approaches currently being trialled in Australia and around the Antarctic margins, and has collaborated with regional and national stakeholders to ensure a consistent approach. This Appendix contains the descriptions of each marine region and each province with the region. Where sufficient information exists it includes a description, a qualitative ecosystem model of the system and the pressures on it and a scenario analysis that explores the way the ecosystem changes with different pressures.

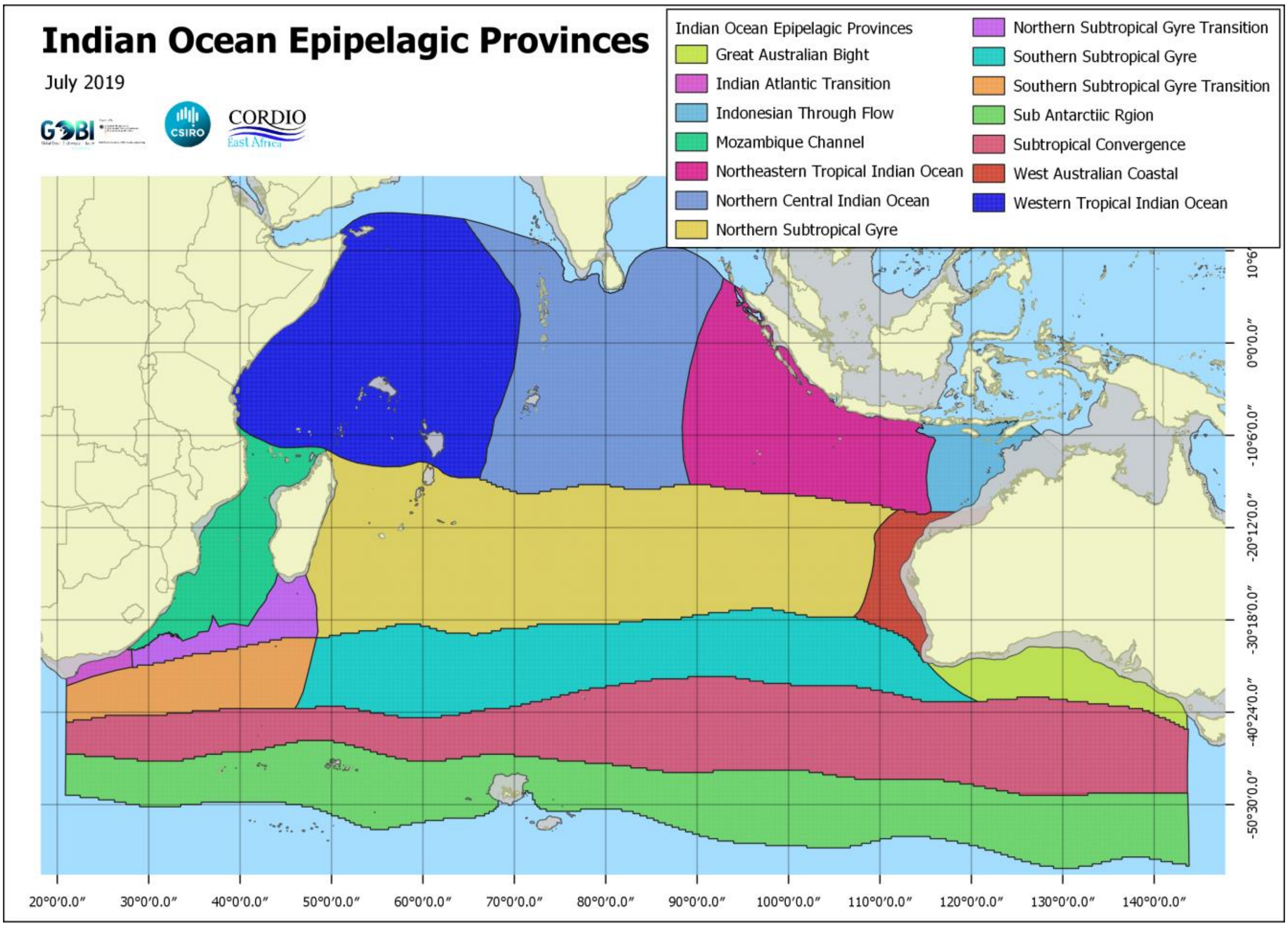
1 Pelagic Bioregions

The distribution of the Large Marine Areas – the highest level of classification for the Indian Ocean is shown below.



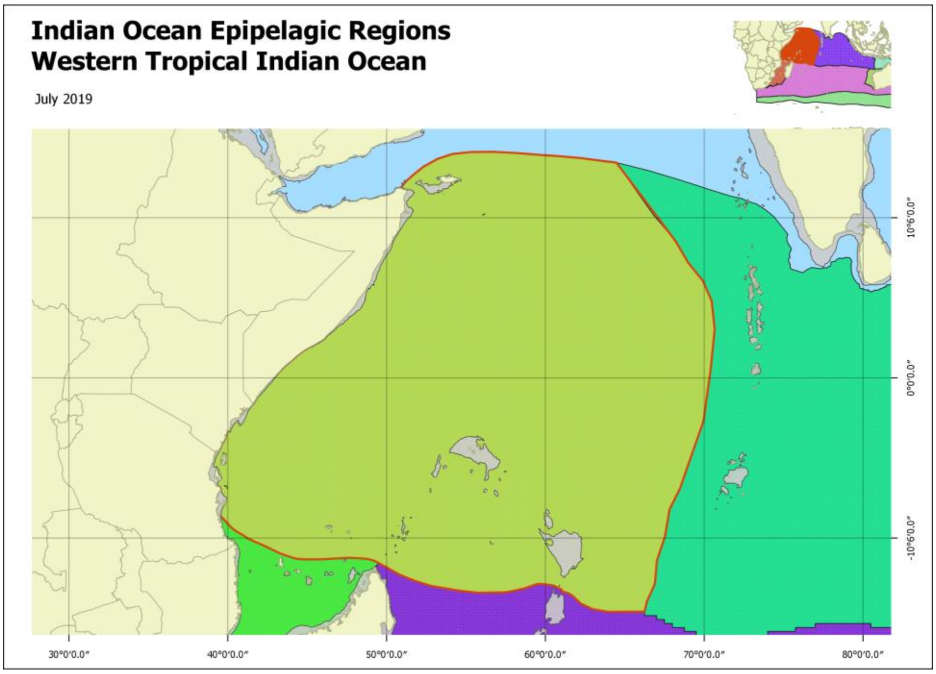
Map 1 Indian Ocean Epipelagic Regions

The distribution of the provinces within the Large Regions is shown below. More detailed descriptions of each of the provinces to given below.



Map 2 Indian Ocean Epipelagic Provinces.

1.1 Western Tropical Indian Ocean



One of the most biologically productive ecoregions of the world oceans characterized by a dominant seasonal cycle manifested as a unique western-boundary upwelling system supporting major pelagic fisheries. The region is bounded to the north by the northern limit of the North Equatorial Current (NEC) and the Southwest Monsoon Current (SMC), to the west by the east African coasts of Somalia and Kenya, in the south west by the Seychelles-Chagos thermocline ridge (SCTR), in the central and east South by the northern limit of South Equatorial Current (SEC) tipping towards 18°S of Australian Coast and to the east by the thermo-haline front of the western limit of the Indo-Pacific warm pool.

Main characteristics

- Strong seasonal upwelling of cold (22-26°C) and nutrient-rich waters (nitrate ~ 10-15 mmol), high Salinity (35.5-36 psu) linked to Arabian Sea high salinity water mass and high chlorophyll concentration (5-15 mg/mg3)

- Enrichment of surface waters results in high primary and secondary production with increased abundance of calanoid copepods species and occurrence of high density of myctophyds in the mesopelagic region (200-1000 m deep) (Catul et al. 2011, Vipin et al. 2012)

- Major fishing grounds for tropical tuna purse seine fisheries during July-Oct, medium-size pelagic fishes (e.g. horse-mackerel, small pelagics), and neritic tunas, and important grounds for skipjack fisheries in the Maldives.

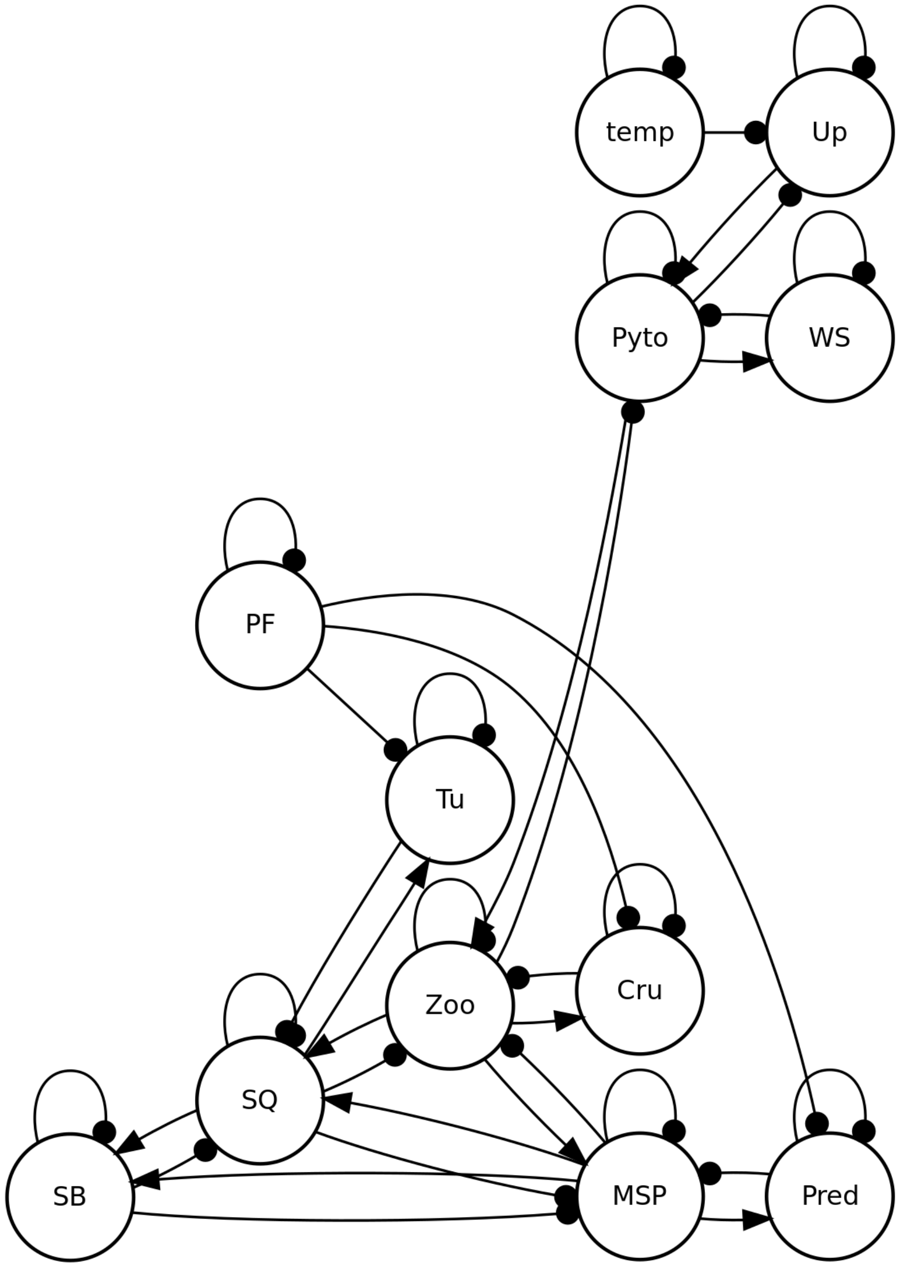


Figure 1: Qualitative model for the prominent ecosystem Western Tropical Indian Ocean and the associated pressures impact chart (PRESSURES :- PF – Pelagic Fisheries, Temp - Temperature ,; FUNCTIONAL GROUPS:- SQ – Squid, Pred – Predatory Fish, Tu – Turtle, WS – Whale Shark , BW – Blue Whale, ZP - Zooplankton, MSP – Medium Size Predator, UP – Upwelling, SB – Sea birds)

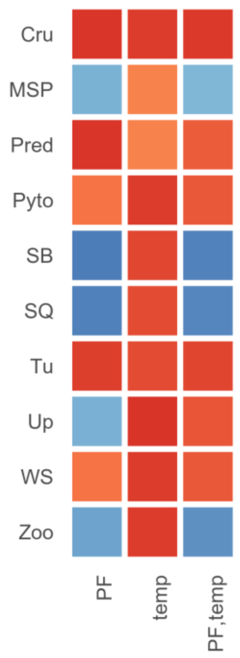
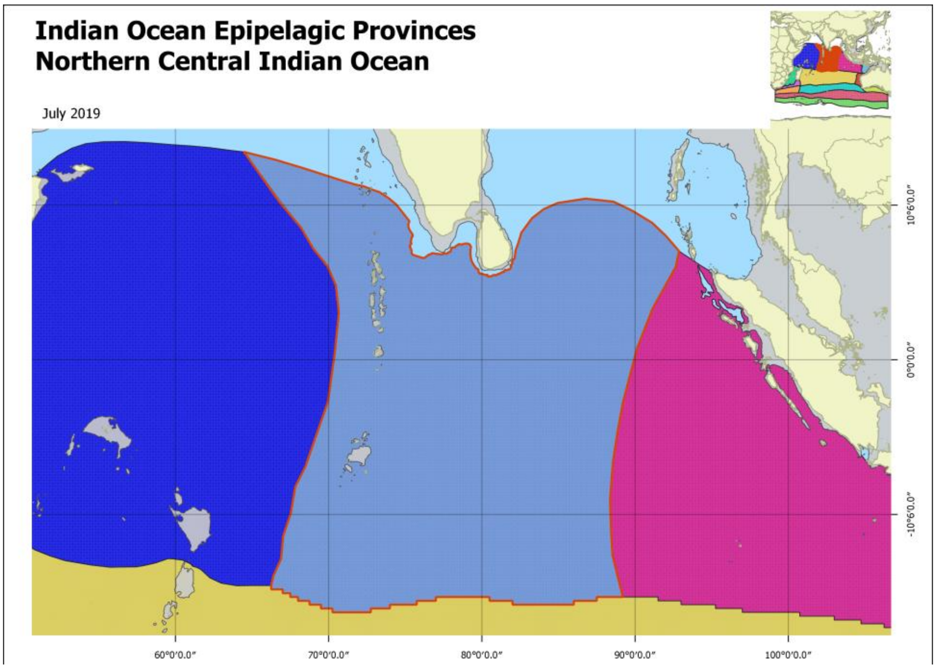


Figure 2: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

1.2 Northern Central Indian Ocean

The Central Eastern Tropical Indian Ocean region is influenced by the Indonesian Throughflow (ITF) and climate-mode Indian Ocean Dipole (IOD) described by strong inter-annual and seasonal signals that result in strong coastal upwellings and influence the productivity of the central and eastern equatorial Indian Ocean, supporting important pelagic fisheries. The region extends from southern Indian south to approximately 15 °Sand eastwards to the coasts of Indonesia and the core of the Indonesian Throughflow at approximately 115°E. Within this region are the Central Tropical and North eastern Indian Ocean Provinces.

1.2.1 Northern Central Indian Ocean Province



Within the Central Tropical Indian Ocean there are two sub regions defined. The western portion is defined by the western limit of the Indo-Pacific warm pool to the west (68°-80°E) and the most western region of influence of IOD-ITF (from tip of Sumatra peninsula bounded by 90°E south around 12°S) to the east. This sub region is characterised by the Indo-Sri Lankan seasonal upwelling region during June-September (de Vos et al, 2014), high temperature (>30°C) all through the year except during upwelling season, and low salinity waters (34-34.4 psu) influenced by the low-salinity water from the Bay of Bengal. The region supports important fisheries along the coasts of Indian and Sri Lanka (e.g. mackerel; BOBLME 2015).

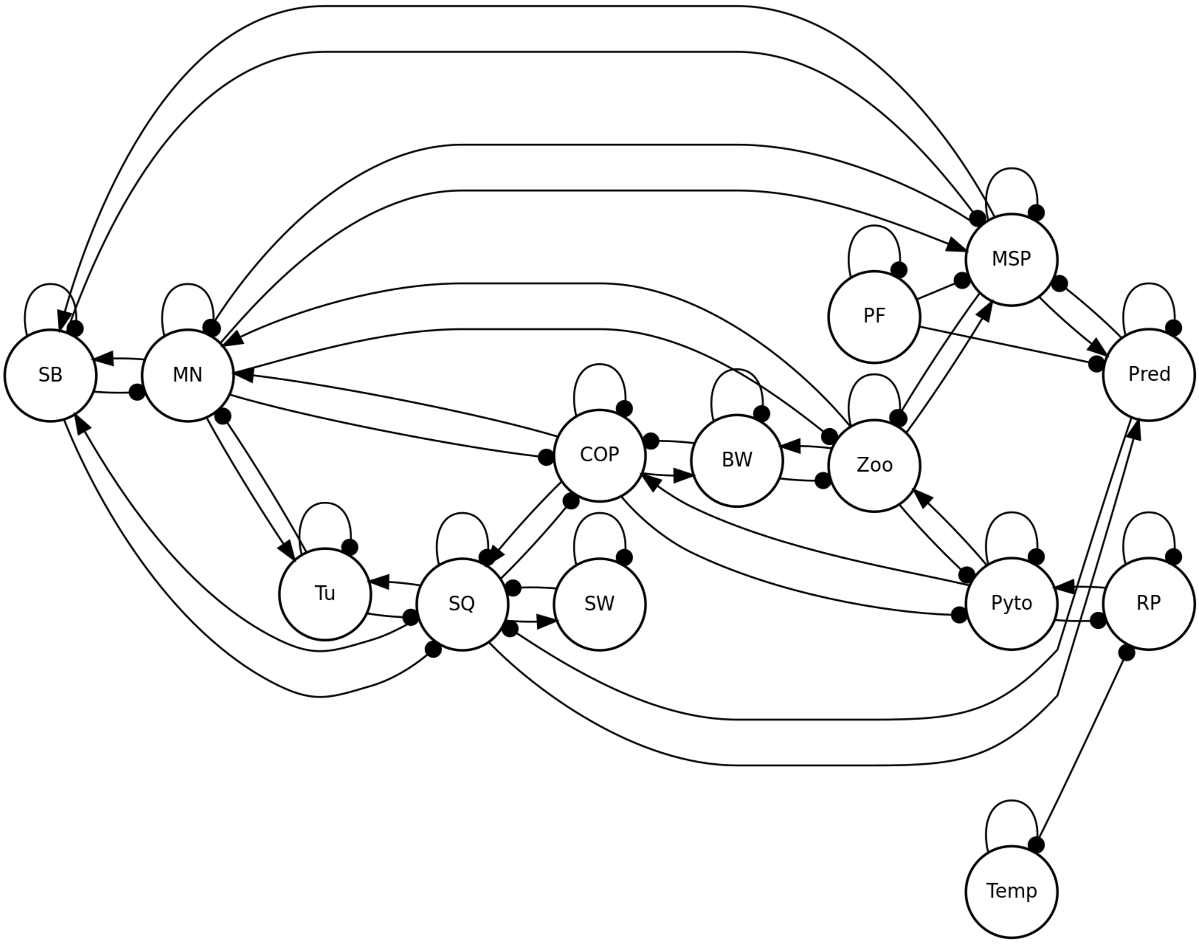
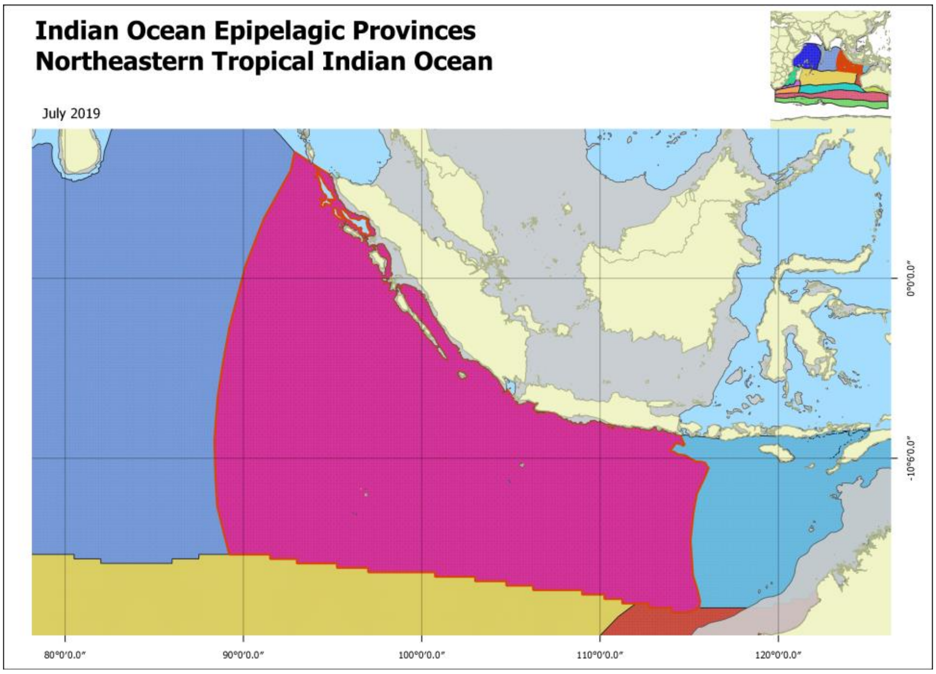


Figure 3: Ecosystem components in the qualitative model are: Seabirds (SB), Micro Nekton (MN), Predatory Fish (Pred), Squid (SQ), Copepods (COP), Regenerated Production (RP), Phytoplankton (Pyto), Zooplankton (Zoo), Medium Size Predators (MSP), Blue Whales (BW), Sperm Whales (SW), Turtles (Tu) . Pressures acting on the system are: Pelagic Fisheries (PF), Temperature (Temp)

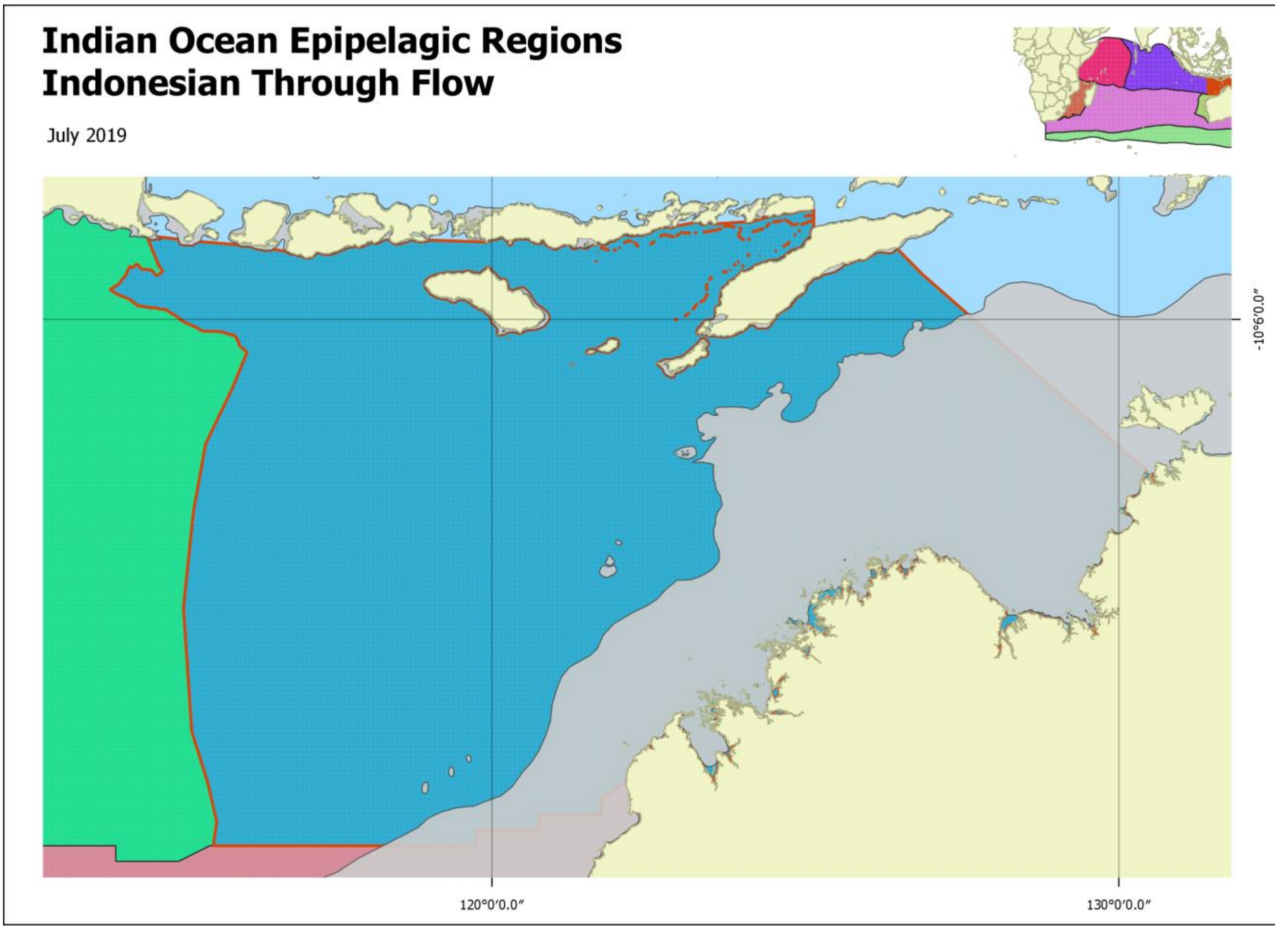
Figure 4: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

1.2.2 North-eastern Tropical Indian Ocean Province



The eastern portion of the Central Tropical Indian Ocean is defined by the influence of Indian Ocean Dipole (IOD) and Indonesian Throughflow (ITF). The boundary is the westernmost regional influence of IOD and ITF in term of sea surface temperature and chlorophyll-a extent. The westernmost limit of this region is 90°E. The El Nino Southern Oscillation (ENSO) influences west Sumatra due to the ITF transport and the influence of the ITF is strong in the area off south Java and off west Sumatra. The ocean temperature off Sumatra is warmer than at off South Java from the surface to at least 500m depth. Surface salinity ranges from 32 – 35 psu, from 200m – 500m depth the salinity near the tip of Sumatra is higher as a spread from the Persian Gulf water. Seasonal Upwelling (east monsoon) occurs along the South Java and West Sumatra coast with concentration of chlorophyll-a from July - August for south Java coast. Main catch is sardinella spp, tuna spp, marlin, skipjack, small Mackerel, scombroids (http://pipp.djpt.kkp.go.id/) and the main fishing gear actively operating are purse seine and gill net.

1.2.3 Indonesian Through Flow Region



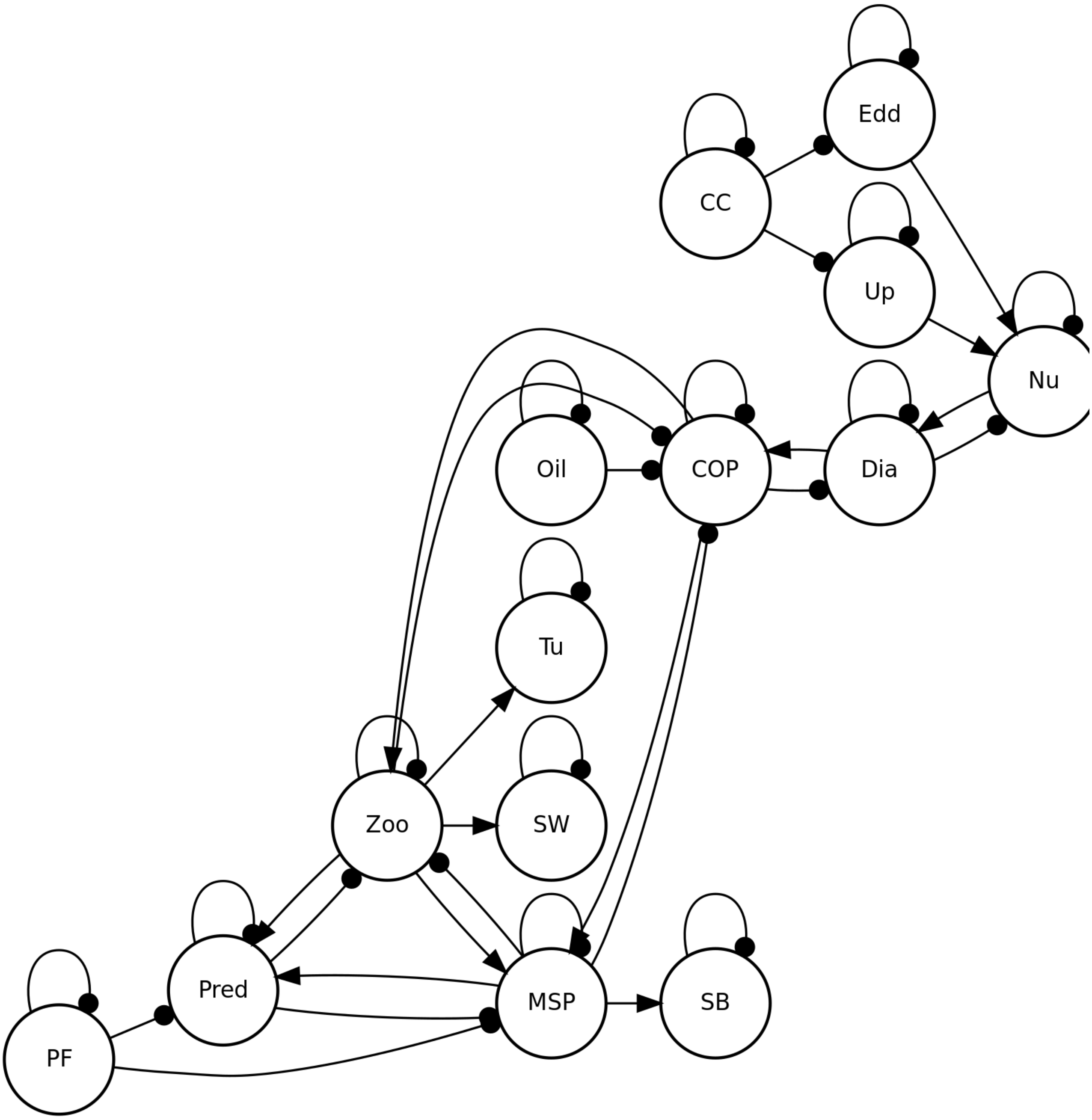


Figure 5: Ecosystem components in the qualitative model are: Predatory Fish (Pred), Sperm Whales (SW), Zooplankton (Zoo), Copepods (COP), Diatoms (Dia), Upwelling (Up), Nutrients (Nu), Eddies (Edd), Medium Size Predators (MSP), Seabirds (SB), Turtle (Tu) . Pressures acting on the system are: Climate Change (CC), Pelagic Fishing (PF), Oil Spills (Oil)

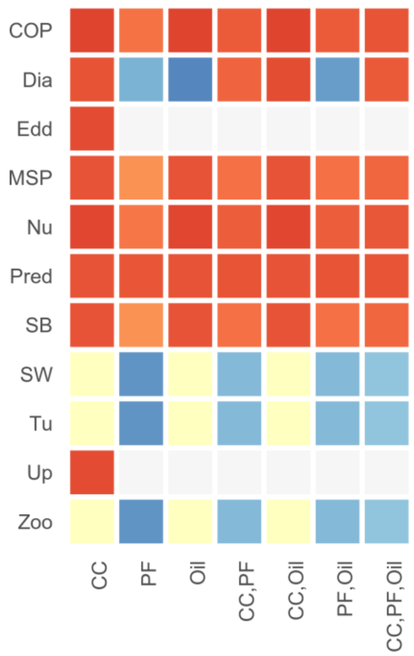
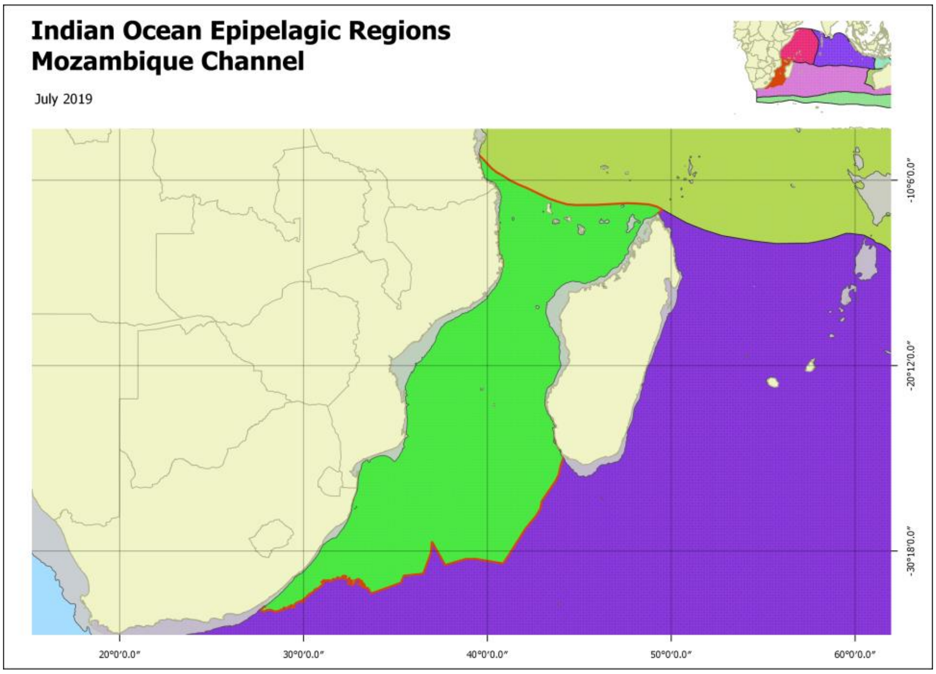


Figure 6: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

1.3 Mozambique Channel Region



Semi-closed region bounded by Madagascar to the east and Mozambique to the west, characterized by strong boundary current along with a large number of meso-scale eddies that drive short pelagic food-webs supporting seasonal tuna surface fisheries.

The Mozambique Channel is:

- bordered on the west side by Mozambique through a distance of 2,700 km is divided biogeographically in three regions, the North dominated by coral reefs and limestone, the centre estuarine region and the South soft with parabolic dunes (Massinga and Hatton 1996).

The Quirimbas Archipelago is part of the North biogeographic region comprising of a chain of 28 islands, housing complex habitats capable of supporting inter alia, some species of particular concern such as corals, sea turtles, dugongs, dolphins and some species of whales, sharks and molluscs (Ferreira et al., 2009).

The region is bounded by the northern boundary of the SEC which crosses the northern tip of Madagascar Island and meet the coast of Africa at 10°S (Tanzania) and runs from the northern tip of Madagascar Island through the Eastern coast down to the South-South East coast. The Eastern boundary continues downward parallel to the coast of South Africa to 30°E and 40°S. In the south the boundary is formed by the Subtropical convergence limit which is classified based on Chlorophyll-a concentration and Sea Level Anomaly and geostrophic circulation. The western boundary begins at the intersection between the Subtropical Convergence limit and the western boundary (the East coast of the African Continent) of the Study region. The western Boundary stops at the point where the Northern boundary meets Africa i.e. 10°S (Tanzania)

- The region is further characterised by eddies which seems to propagate from the center of the MC (15°S) towards the Agulhas retroflection region (35°S);

- The eddy paths are rather uniform, and follow the African coastal bathymetry (Schouten et al. 2003);
- Mesoscale Eddies in the MC range from 100 to 300 km in diameter, four to seven eddies per year are known to transit through the Channel, from North to South (Tew Kai et al. 2010);
- Various species of turtles breed along the coast and on islands along the Mozambique Channel;
- The potential for the commercial fisheries is estimated at about 391,000 tons, being the most important resource;
- Crustaceans (shallow and deep water shrimp, lobster and crabs) accounting for about 41,000 tons;
- Demersal and pelagic fishes accounting for about 325,000 tons; and
- Molluscs and seaweeds, accounting for about 5,500 tons. (Development and Protection of the Coastal and Marine Environment in Sub-Saharan Africa, Mozambique National Report Phase 1: Integrated Problem Analysis, GEF-2002).

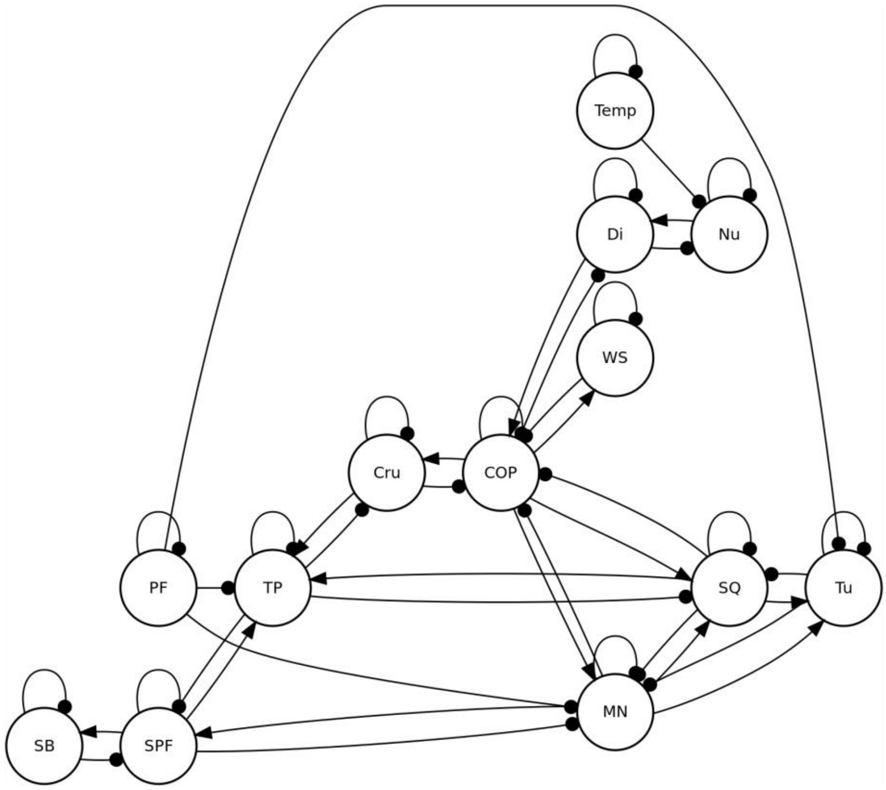


Figure 7 Ecosystem components in the qualitative model are: Seabirds (SB), Medium Sized Predators (MSP), Micro Nekton (MN), Predatory Fish (Pred), Turtles (Tu), Crusteceans (Cru), Squid (SQ), Whale Sharks (WS), Copepods (COP), Diatoms (Di), Nutrients (Nu) . Pressures acting on the system are: Pelagic Fisheries (PF), Temperature (Temp)

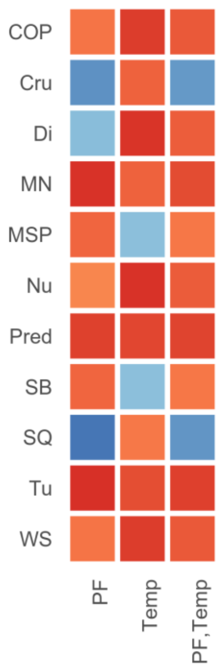
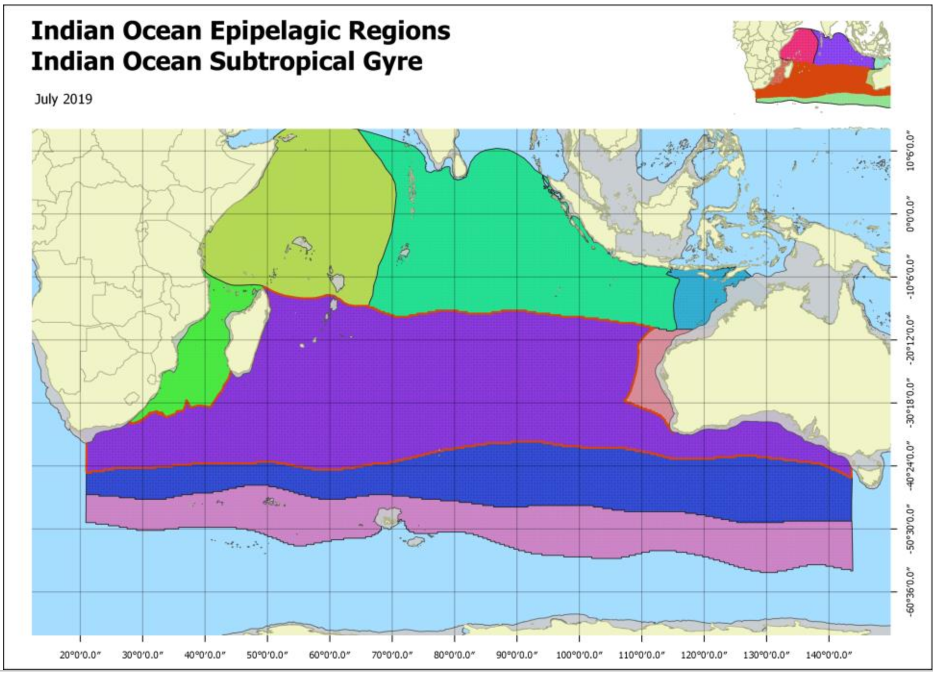


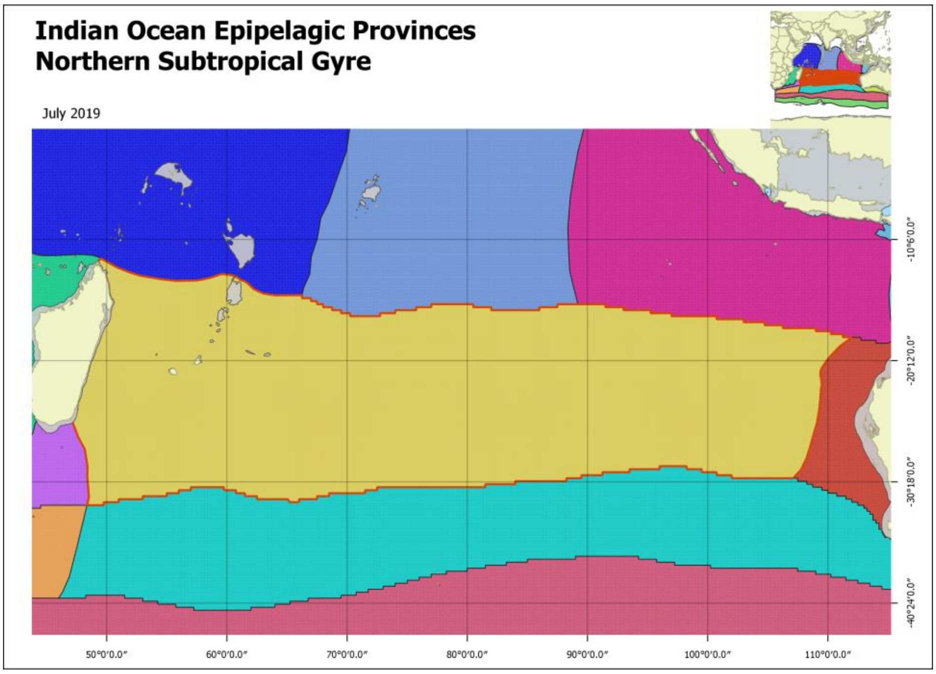
Figure 8: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

1.4 Indian Ocean Subtropical Gyre Region



The Southern Subtropical Indian Oceans is an oligotrophic, low-chlorophyll region characterized by strong western and eastern boundary currents and less pelagic fishing effort. The region is bounded in the north by the western portion of the northern limit defined by the SCTR and eastern part defined by the most northern limit of the Subtropical Equatorial current, in the south by the subtropical convergence, in the west by the eastern coast of Madagascar (Mozambique Current) and in the east by western and southern part of the Australian Coast bounded at 150°E.

1.4.1 Northern Subtropical Gyre



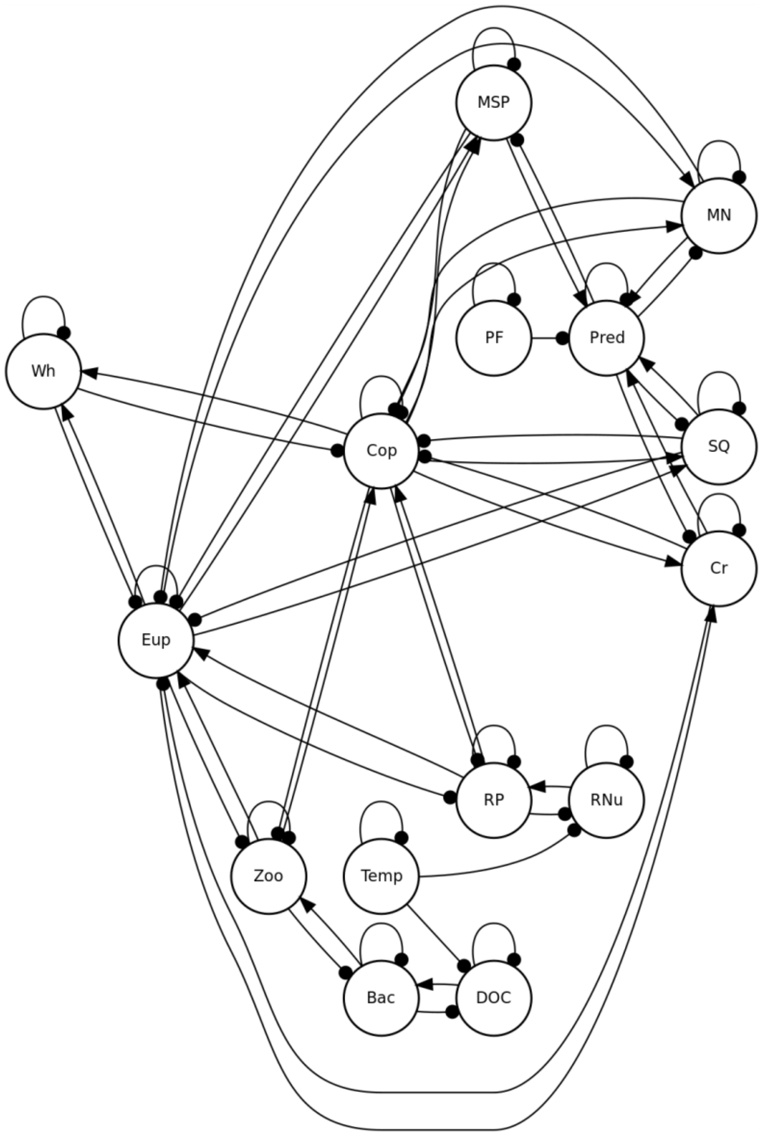


Figure 9: Ecosystem components in the qualitative model are: Whales (Wh), Predatory Fish (Pred), Medium Sized Predators (MSP), Micronekton (MN), Squid (SQ), Crustaceans (Cr), Euphausids (Eup), Copepods (Cop), Regerated Production (RP), Zooplankton (Zoo), Regenerated Nutrients (RNu), Bacteria (Bac), Disolved Organic Carbon (DOC) . Pressures acting on the system are: Pelagic Fisheries (PF), Temperature (Temp)

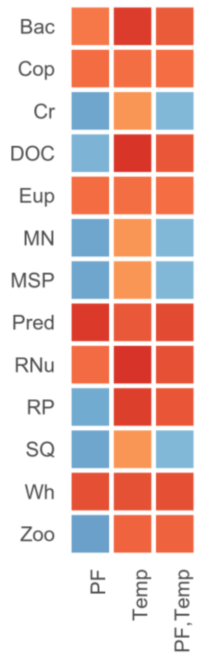
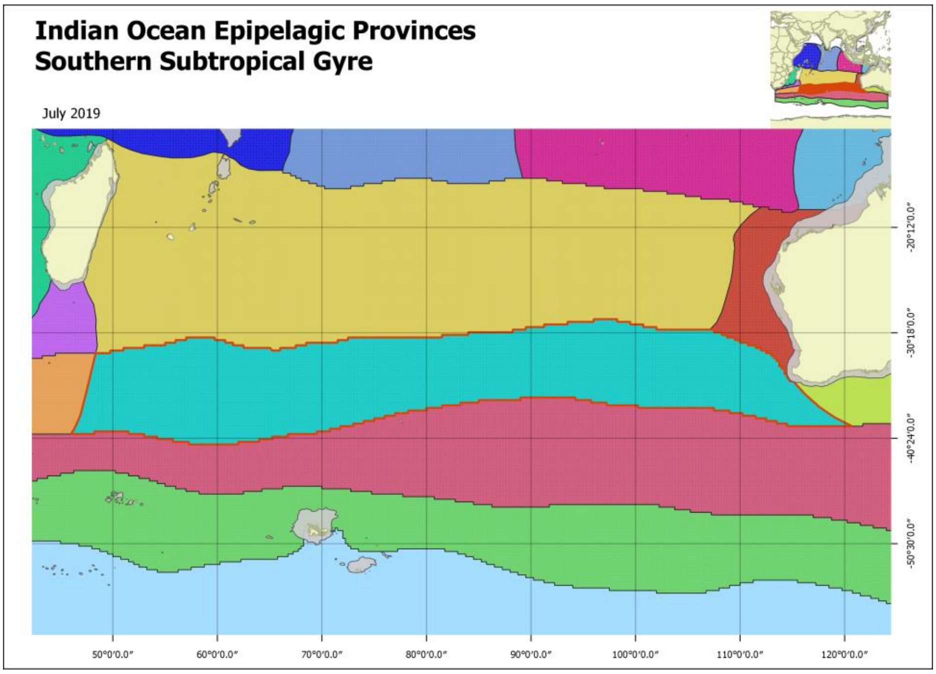


Figure 10: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

1.4.2 Southern Subtropical Gyre



The Southern Subtropical Gyre extends from the coast of Madagascar to the Coast of Australia between the latitudes of 13°S to 48°S.

- Warm (16-26°C), low-oxygenated 4.5-6 (ml/l), large range of salinity (34.5-36 psu) with highest values (~36 psu) at the centre of the gyre
- Oligotrophic waters with very low chlorophyll concentration throughout the year (0.02 mg/m3) due to the convergence of the surface waters (downwelling)
- Very small catch from surface tropical tuna fisheries, with the notable exception of the seasonal activities occurring in the Mozambique Channel (source: IOTC)
- Fishing activities targeting temperate tuna (mainly albacore) in the western part of the gyre (eastern coast of Madagascar) and all along the south of 25°S by longliners in deep waters down to 200 m (Nikolic et al. 2016)

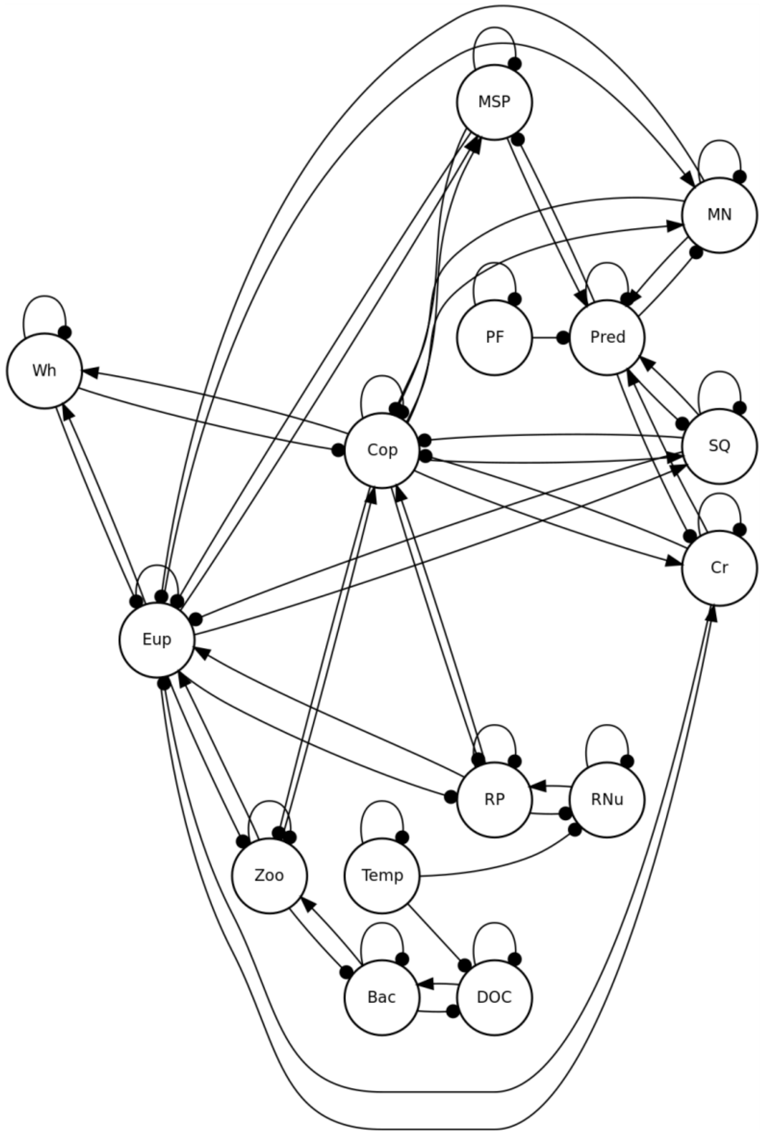


Figure 11: Ecosystem components in the qualitative model are: Whales (Wh), Predatory Fish (Pred), Medium Sized Predators (MSP), Micronekton (MN), Squid (SQ), Crustaceans (Cr), Euphausids (Eup), Copepods (Cop), Regenerated Production (RP), Zooplankton (Zoo), Regenerated Nutrients (RNu), Bacteria (Bac), Dissolved Organic Carbon (DOC) . Pressures acting on the system are: Pelagic Fisheries (PF), Temperature (Temp)

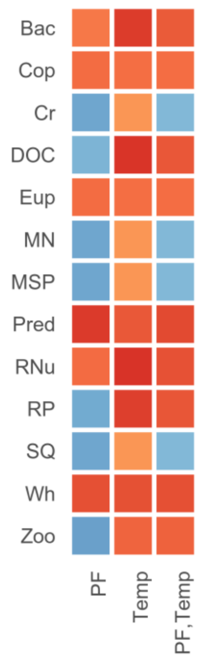
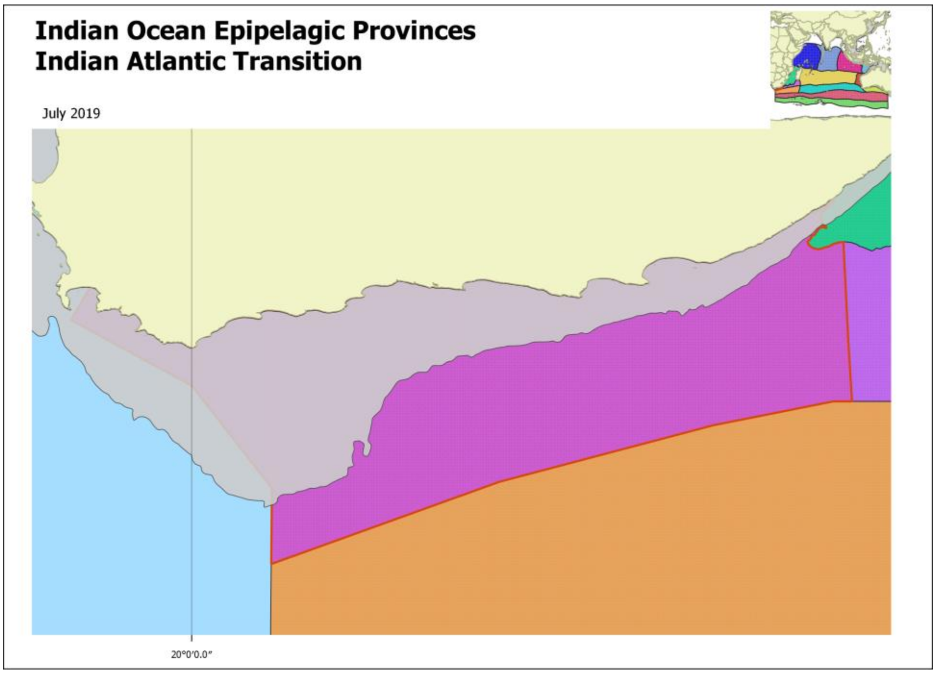
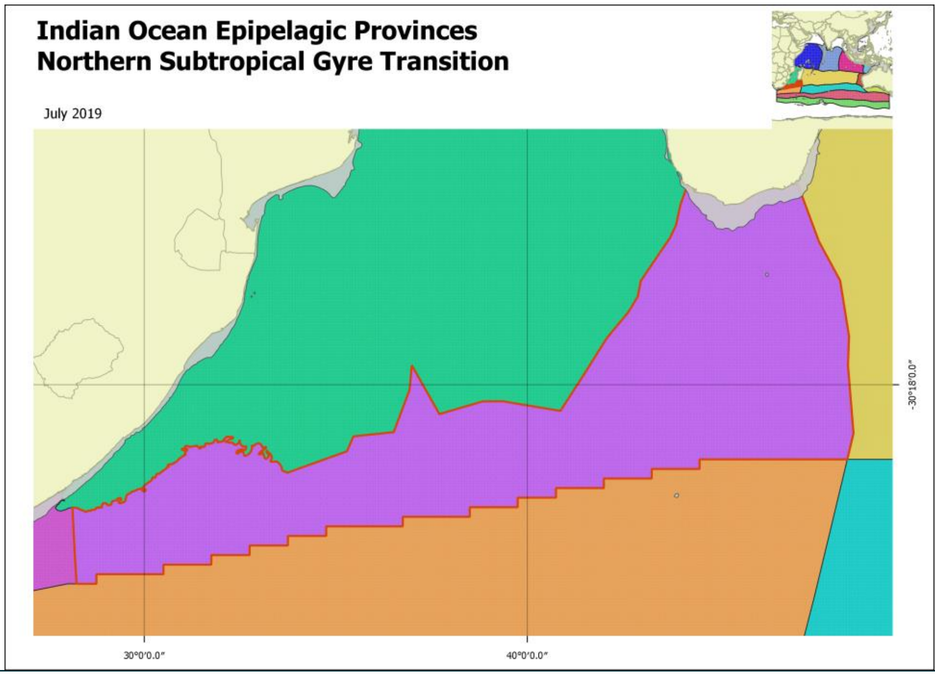


Figure 12: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

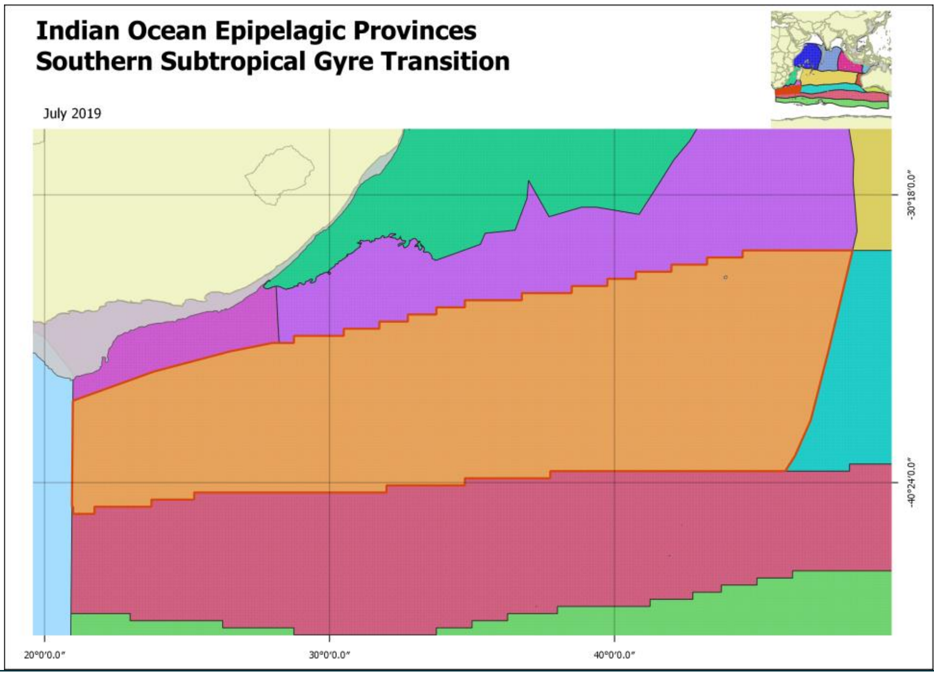
1.4.3 Indian Atlantic Transition



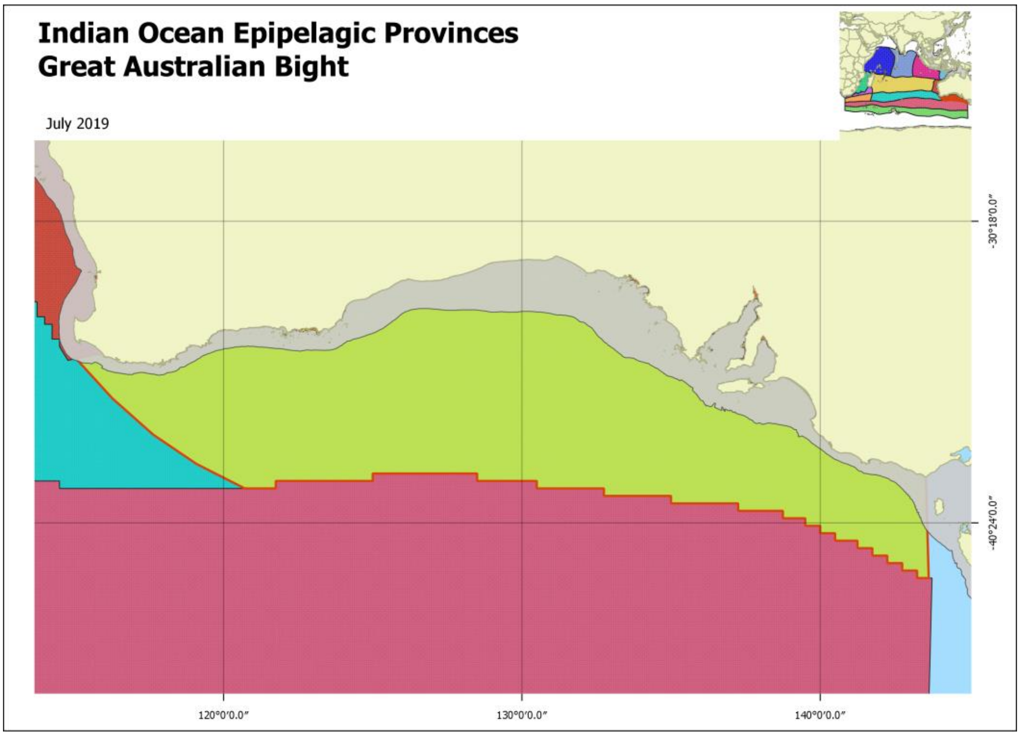
1.4.4 Northern Subtropical Gyre Transition



1.4.5 Southern Subtropical Gyre Transition

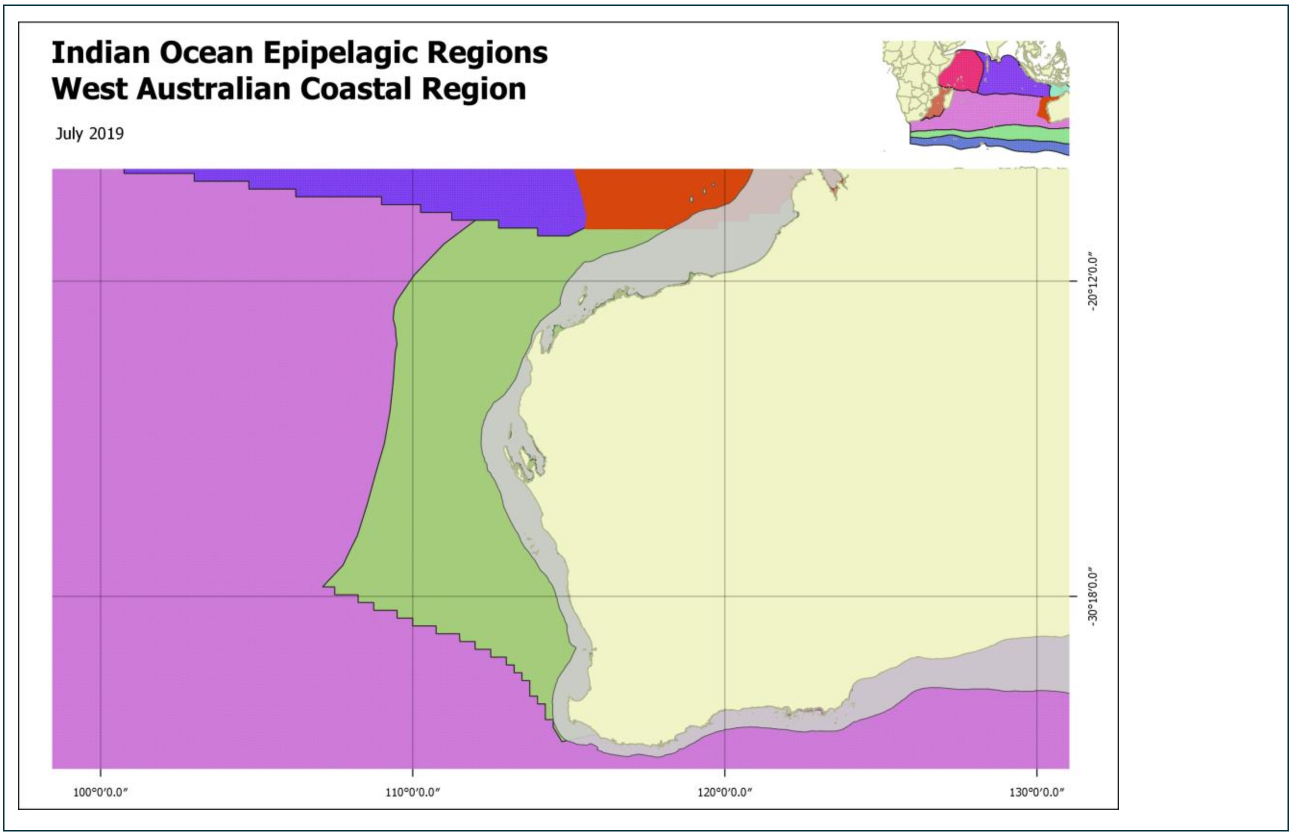


1.4.6 Great Australian Bight Province



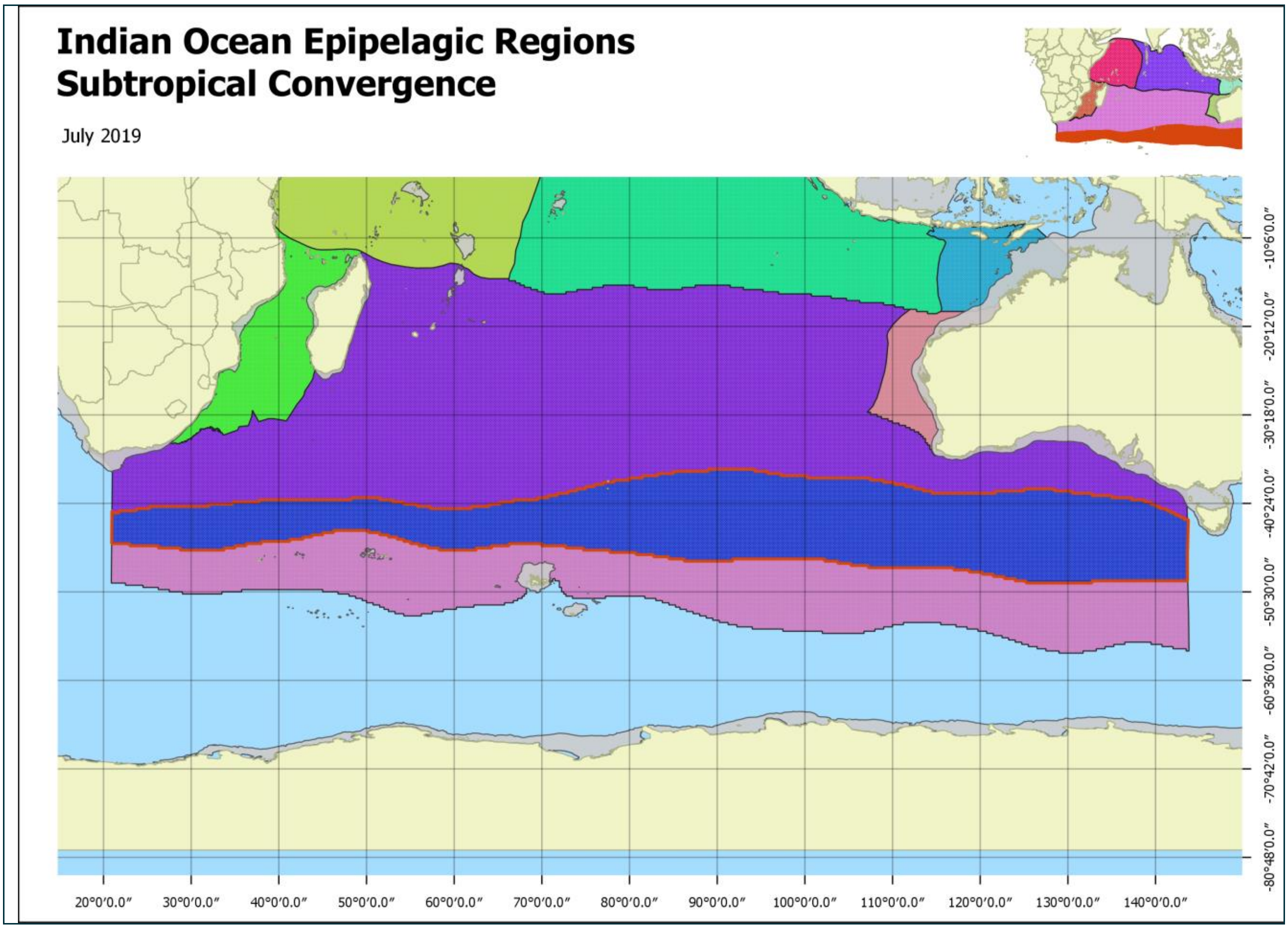
The broad structure of this band of water mass that is characterised by the topography of southern Australia and Tasmania. A narrowing of the band as it approaches Cape Leeuwin is accompanied by increased energetics. Likewise, as the water mass circulates around Tasmania, energetics increase to the south and east. The Level 2 substructure consists of a southern band terminating in the mixed region surrounding Tasmania. Part of it continues into the Tasman Sea. Comparatively high primary production due to upwelling. Qualitative model for the province can be found in Hayes et al. (2012)

1.5 Western Australian Coastal Region

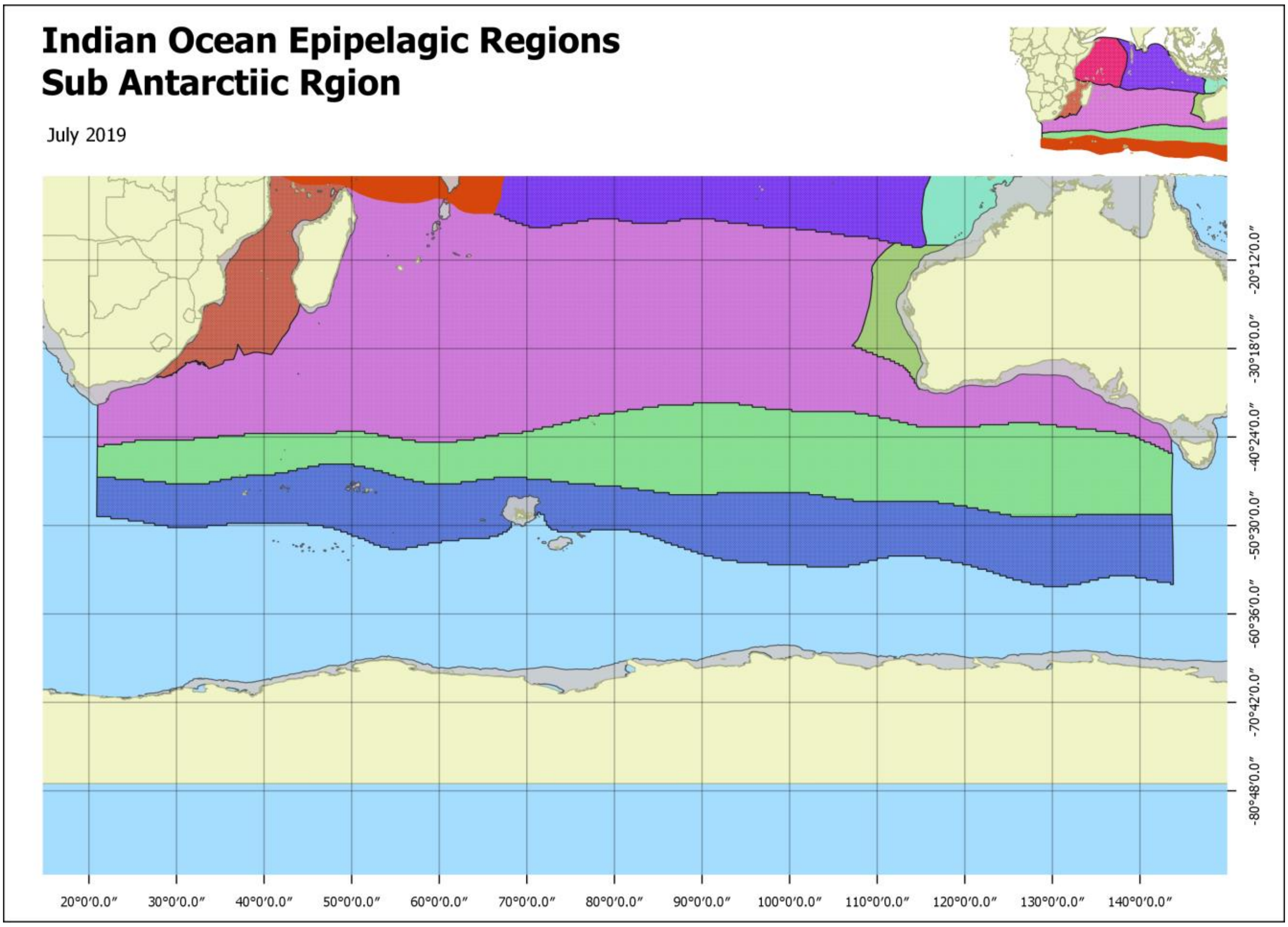


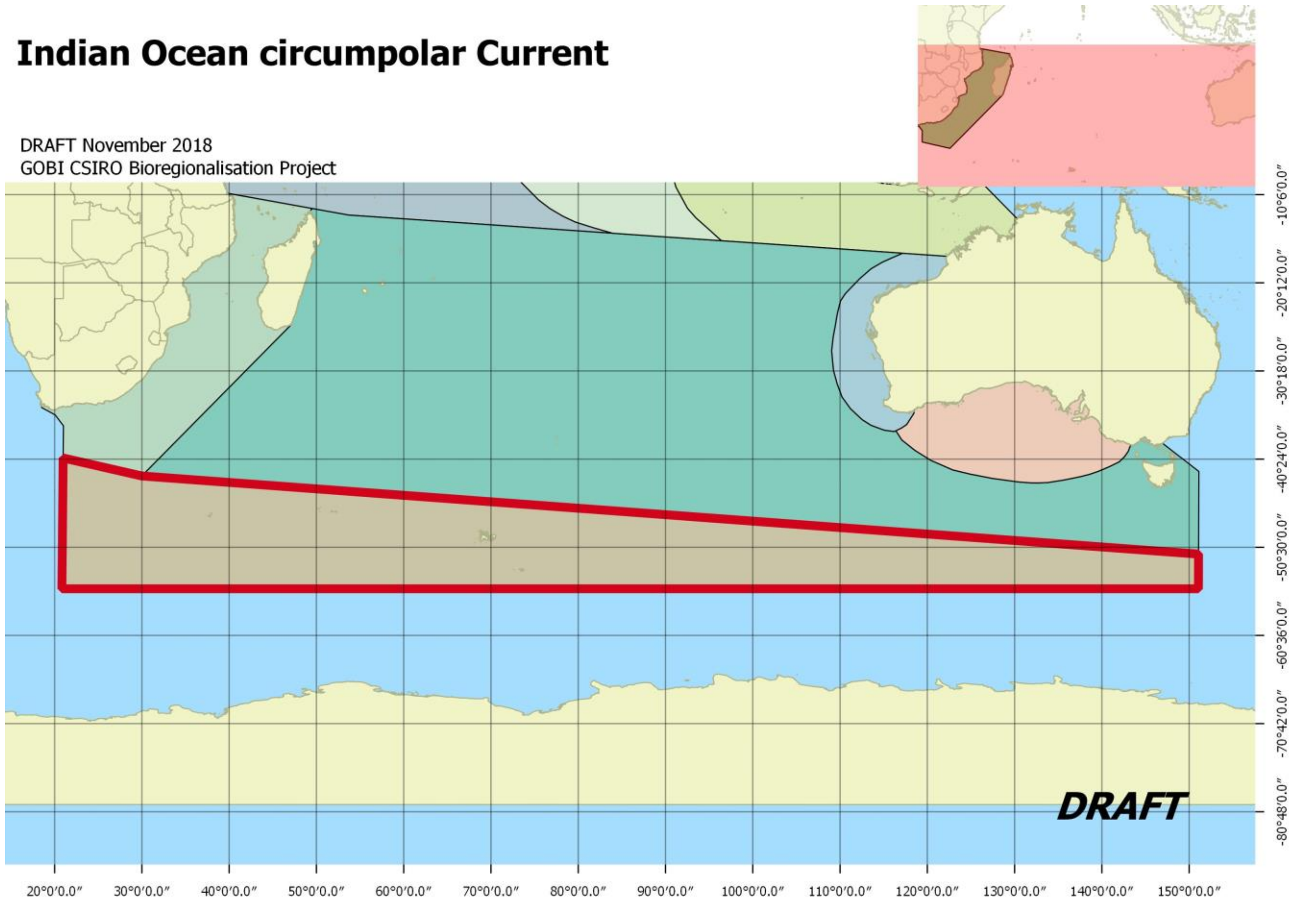
The seasonal Leeuwin Current, which flows down the west Australian coast from an origin around Shark Bay, suggests there will be seasonal changes in the circulation of this water mass. The bulk of the seasonal eastward drift feeding the Leeuwin Current continues around Cape Leeuwin and floods over the shelf of the Great Australia Bight, ending just to the east of Kangaroo Island in South Australia. The change in direction of the current around Cape Leeuwin coincides with increased eddy activity in the south-west shelf and offshore region of western Australia. This is indicated in the Level 3 energetics map, which also clearly demarcates the offshore edge of this current system. Near the central Great Australia Bight, the Leeuwin Current appears to dissipate and at the same time a core homogeneous water mass appears at the head of the bight. The extension of the Leeuwin Current reappears to the east of this region. Qualitative models for this province can be found in Hayes et al (2012) and Hosack et al. (2012).

1.6 Indian Ocean Subtropical Convergence Region



1.7 Indian Ocean Sub Antarctic Region



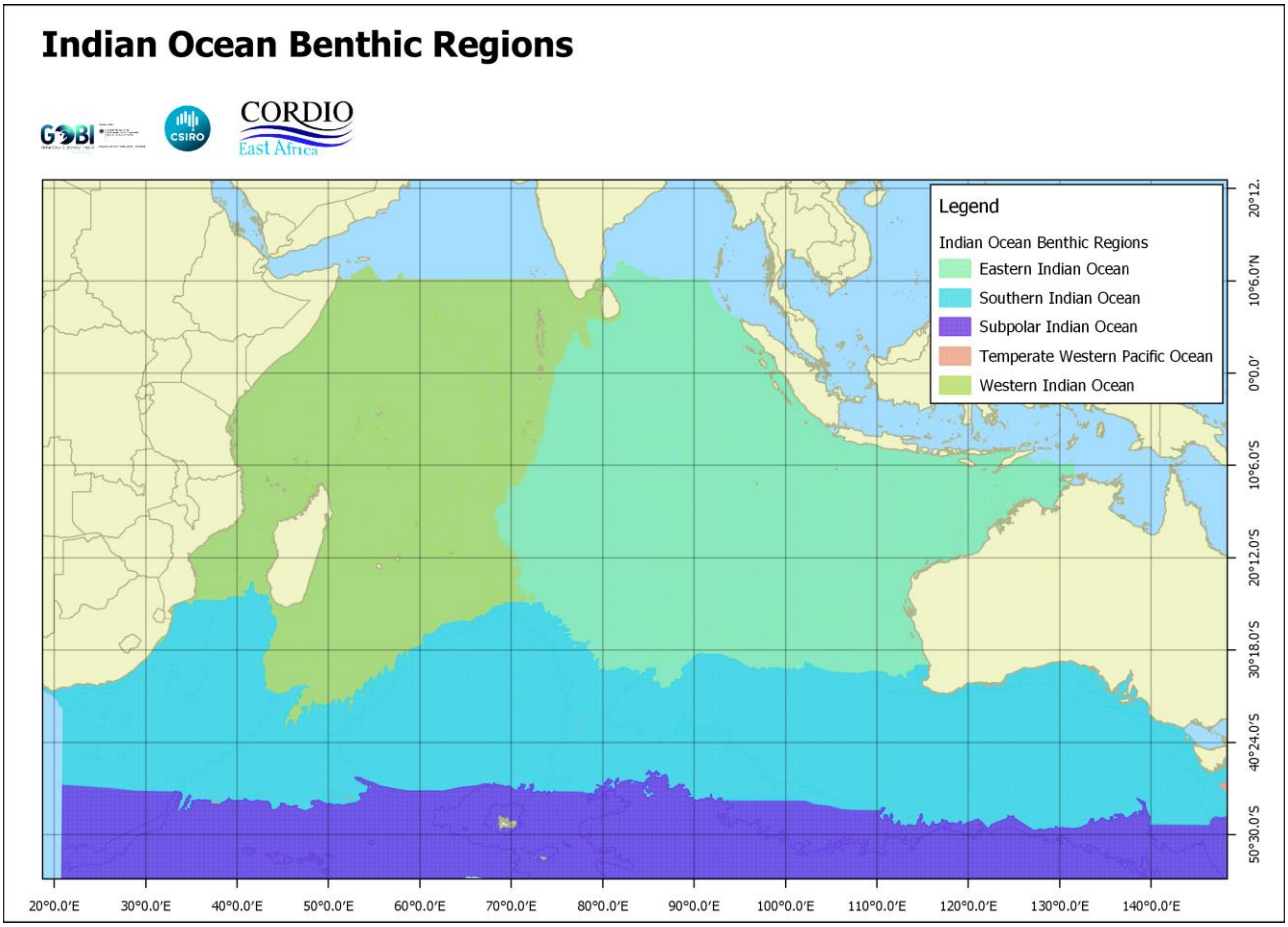


The Indian Ocean Circumpolar Current is a region of cold, homogeneous, oxygen-rich, low-saline waters described by strong currents and few fishing activities. The northern limit is the southern limit of the subtropical convergence area and the regions extends into the sub Antarctic region – it is comparable with the temperate water region 17 of the Antarctic regionalization work of Raymond (2017).

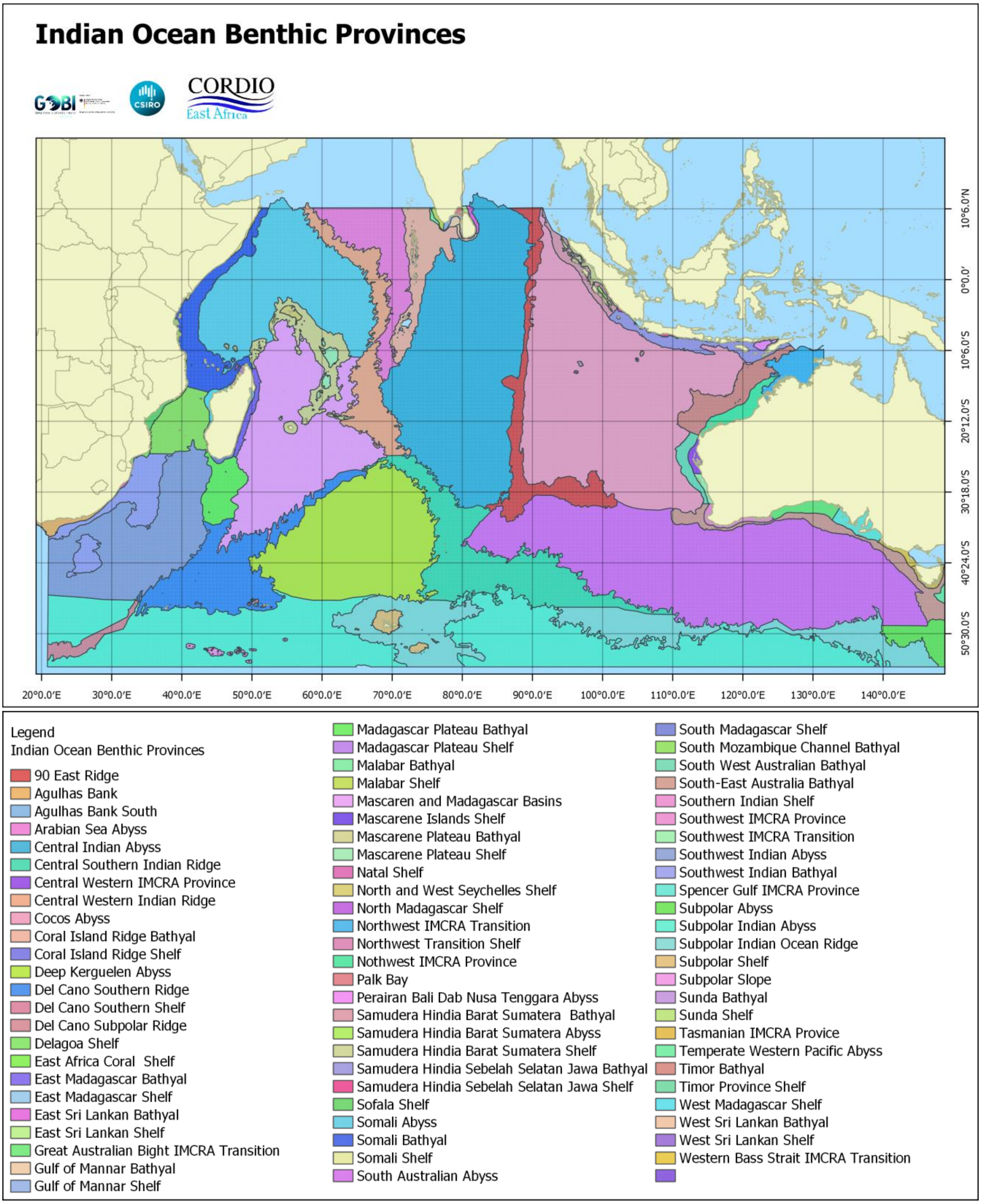
- Very homogeneous circumglobal waters with very strong currents (SSH anomalies and geostrophic currents)
- Cold (12-13°C), low-salinity (33.2-33.6 psu) and oxygen-rich (6-7 ml/l) surface waters
- Productive waters in summer (Nov-Feb)
- Very low chlorophyll in winter (Apr-Oct) due to light limitation

2 Benthic Bioregions

The distribution of the Large Marine Areas – the highest level of classification for the Indian Ocean is shown below.

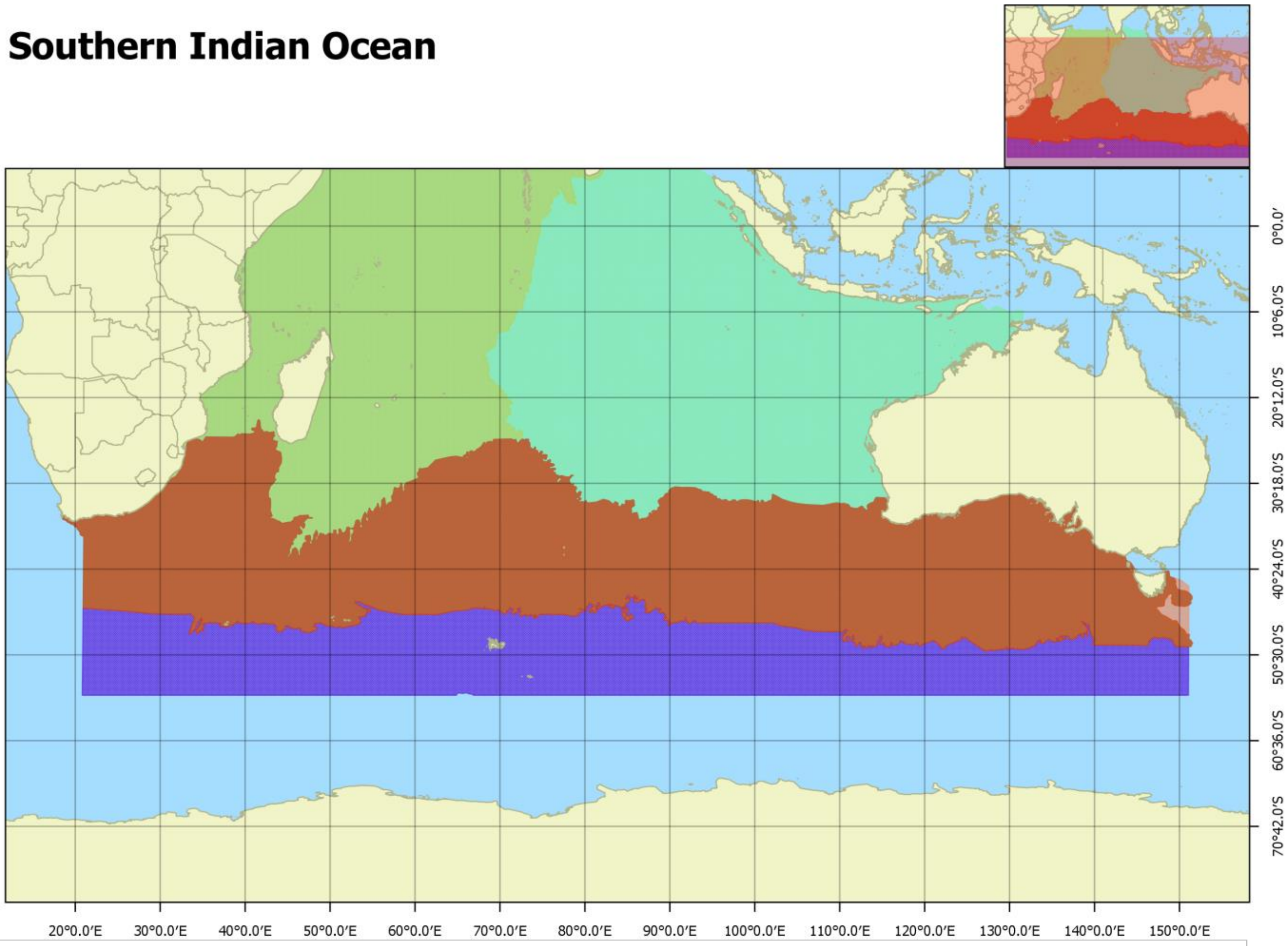


The distribution of the provinces within the Large Regions is shown below. More detailed descriptions of each of the provinces to given below.



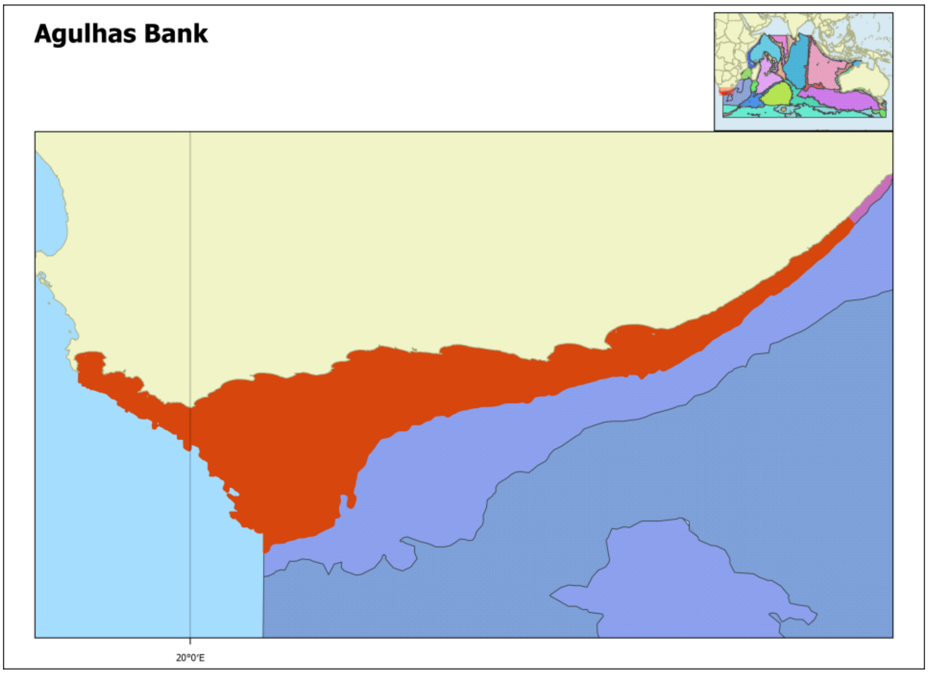
Indian Ocean Benthic Provinces
CORDIO
East Africa
CSIRO
10°6.0'N
0°0.0'
10°6.0'S
20°12.0'S
30°18.0'S
40°24.0'S
50°30.0'S
20°0.0'E
30°0.0'E
40°0.0'E
50°0.0'E
60°0.0'E
70°0.0'E
80°0.0'E
90°0.0'E
100°0.0'E
110°0.0'E
120°0.0'E
130°0.0'E
140°0.0'E
Legend
Indian Ocean Benthic Provinces
90 East Ridge
Agulhas Bank
Agulhas Bank South
Arabian Sea Abyss
Central Indian Abyss
Central Southern Indian Ridge
Central Western IMCRA Province
Central Western Indian Ridge
Cocos Abyss
Coral Island Ridge Bathyal
Coral Island Ridge Shelf
Deep Kerguelen Abyss
Del Cano Southern Ridge
Del Cano Southern Shelf
Del Cano Subpolar Ridge
Delagoa Shelf
East Africa Coral Shelf
East Madagascar Bathyal
East Madagascar Shelf
East Sri Lankan Bathyal
East Sri Lankan Shelf
Great Australian Bight IMCRA Transition
Gulf of Mannar Bathyal
Gulf of Mannar Shelf
Madagascar Plateau Bathyal
Madagascar Plateau Shelf
Malabar Bathyal
Malabar Shelf
Mascaren and Madagascar Basins
Mascarene Islands Shelf
Mascarene Plateau Bathyal
Mascarene Plateau Shelf
Natal Shelf
North and West Seychelles Shelf
North Madagascar Shelf
Northwest IMCRA Transition
Northwest Transition Shelf
Nothwest IMCRA Province
Palk Bay
Perairan Bali Dab Nusa Tenggara Abyss
Samudera Hindia Barat Sumatera Bathyal
Samudera Hindia Barat Sumatera Abyss
Samudera Hindia Barat Sumatera Shelf
Samudera Hindia Sebelah Selatan Jawa Bathyal
Samudera Hindia Sebelah Selatan Jawa Shelf
Sofala Shelf
Somali Abyss
Somali Bathyal
Somali Shelf
South Australian Abyss
South Madagascar Shelf
South Mozambique Channel Bathyal
South West Australian Bathyal
South-East Australia Bathyal
Southern Indian Shelf
Southwest IMCRA Province
Southwest IMCRA Transition
Southwest Indian Abyss
Southwest Indian Bathyal
Spencer Gulf IMCRA Province
Subpolar Abyss
Subpolar Indian Abyss
Subpolar Indian Ocean Ridge
Subpolar Shelf
Subpolar Slope
Sunda Bathyal
Sunda Shelf
Tasmanian IMCRA Provice
Temperate Western Pacific Abyss
Timor Bathyal
Timor Province Shelf
West Madagascar Shelf
West Sri Lankan Bathyal
West Sri Lankan Shelf
Western Bass Strait IMCRA Transition

2.1 Southern Indian Ocean



The Southern Ocean benthic region is the region at the join between the Indian Ocean Basin and the Antarctic dominated Southern Ocean. The regions in this location are derived from the regions identified in Douglass *et al.* (2014) to ensure consistency between the regions described in the Indian Ocean and those that have been described for the Southern Ocean.

2.1.1 Agulhas Bank South



The Agulhas Bank Province has been identified multiple times (Sink et al. 2011; Stephenson 1939; Stephenson and Stephenson 1972; Bustamante and Branch 1996; Emmanuel 1992; Turpie et al. 2000; Stegenga and Bolton 1992). It is characterised by warm surface temperate and extends from Cape Point to Mbashe River. It encompasses the wide shelf of South Africa and includes key fisheries on Agulhas Bank (linefish, Southcoast Rock lobster, squid, inshore and offshore demersal trawling; large pelagics). It has high productivity relative to the Western Indian Ocean.

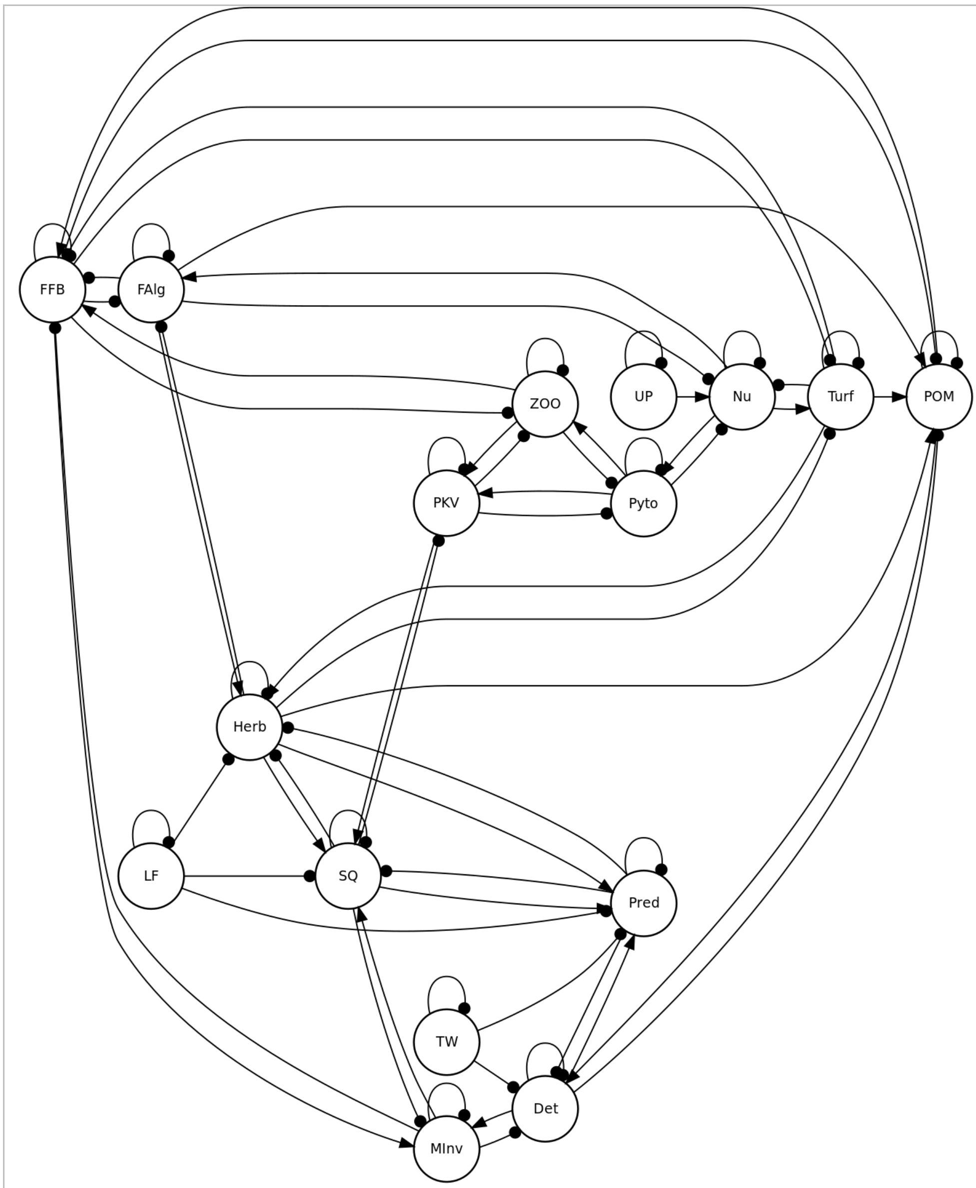


Figure 13: Ecosystem components in the qualitative model are: Filter Feeder Benthic (FFB), Fleshy Algae (FAlg), Turf Algae (Turf), Particulate Organic Matter (POM), Nutrients (Nu), PhytoPlankton (Pyto), ZooPlankton (ZOO), Predatory Fish (Pred), Herbivourous Fish (Herb), Detritivors (Det), Squid (SQ), Planktivores (PKV), Mobile Invertebrates (MInv) . Pressures acting on the system are: LineFishing (LF), Trawl (TW), Upwelling (UP)

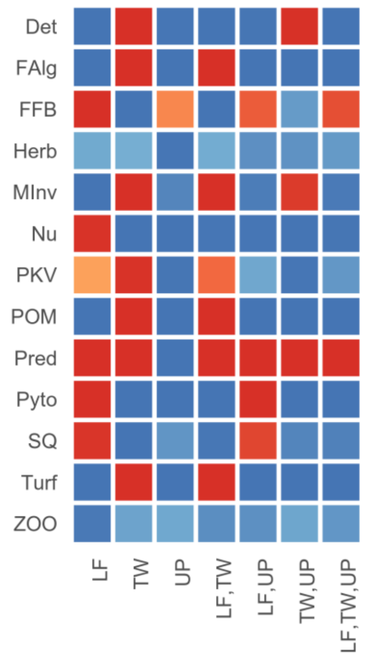
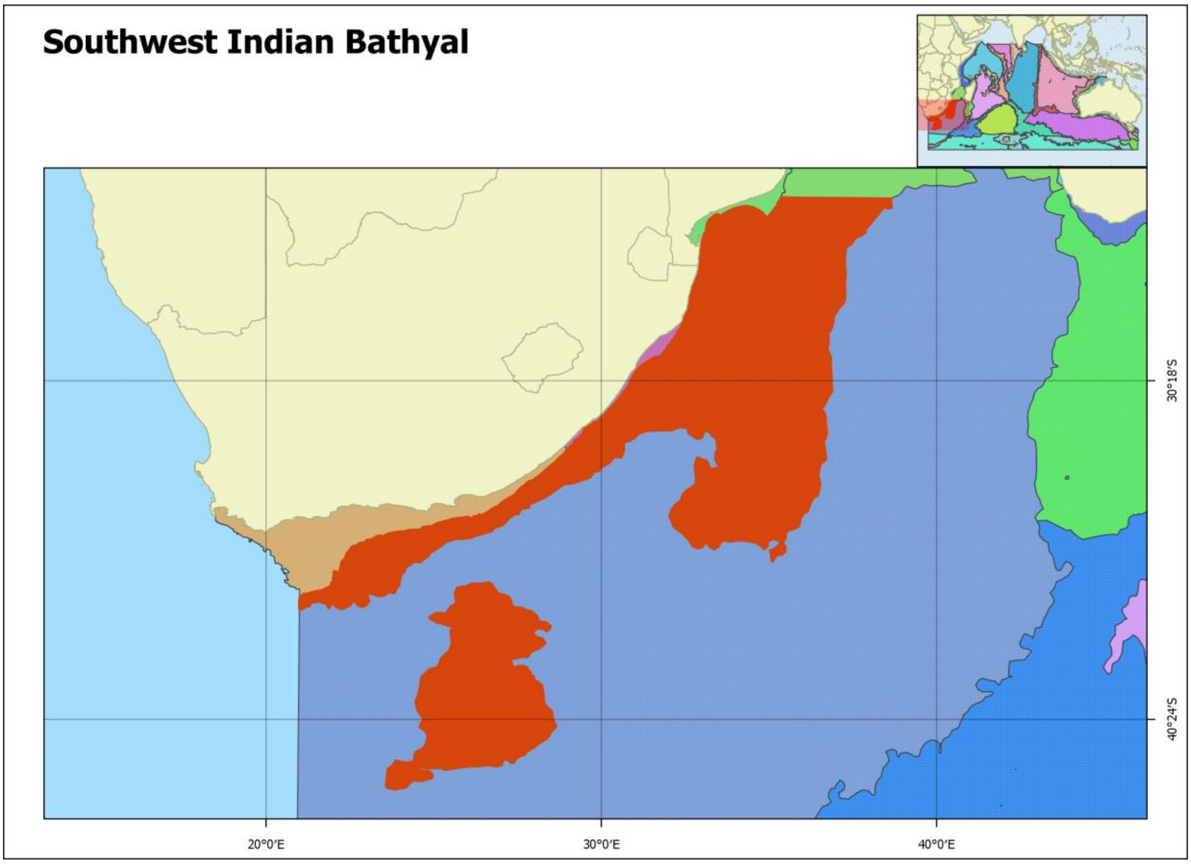


Figure 14: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.1.2 South West Indian Bathyal



The SouthWest Indian Bathyal is the broad province that includes all the slope off the Agulhas and Natal shelf provinces. It joins the South Mozambique Bathyl province in the north.

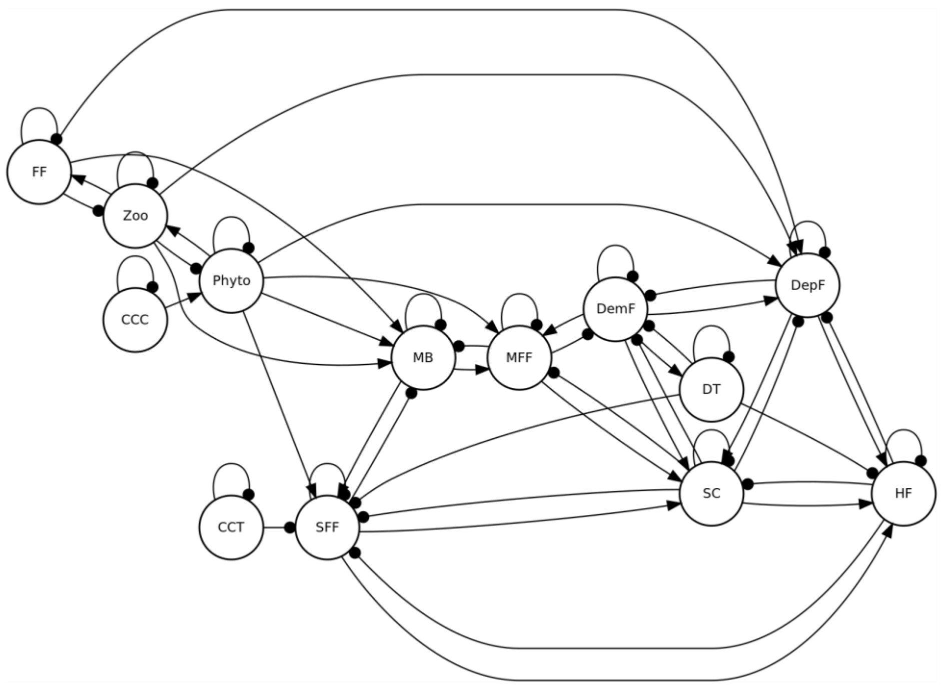


Figure 15: Ecosystem components in the qualitative model are: Sessile Filter Feeders (SFF), Food Falls (FF), Microbes (MB), Phytoplankton (Phyto), Zooplankton (Zoo), Deposit Feeders (DepF), Hake Fishery (HF), Scavengers (SC), Mobile Filter Feeders (MFF), Demersal Fishes (DemF) . Pressures acting on the system are: Climate Change Chlorophyll (CCC), Climate Change Temperature (CCT), Demersal Trawling (DT)

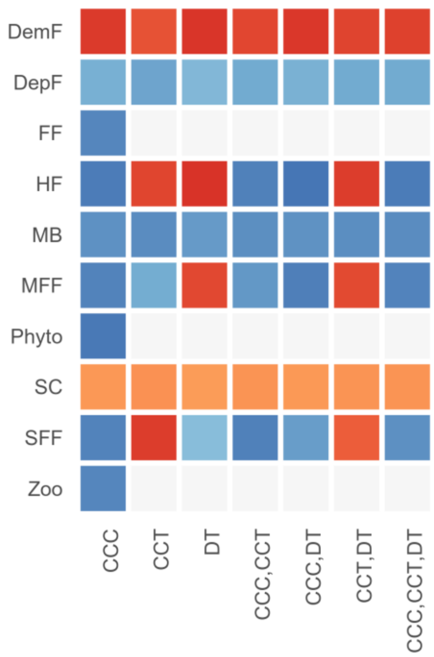
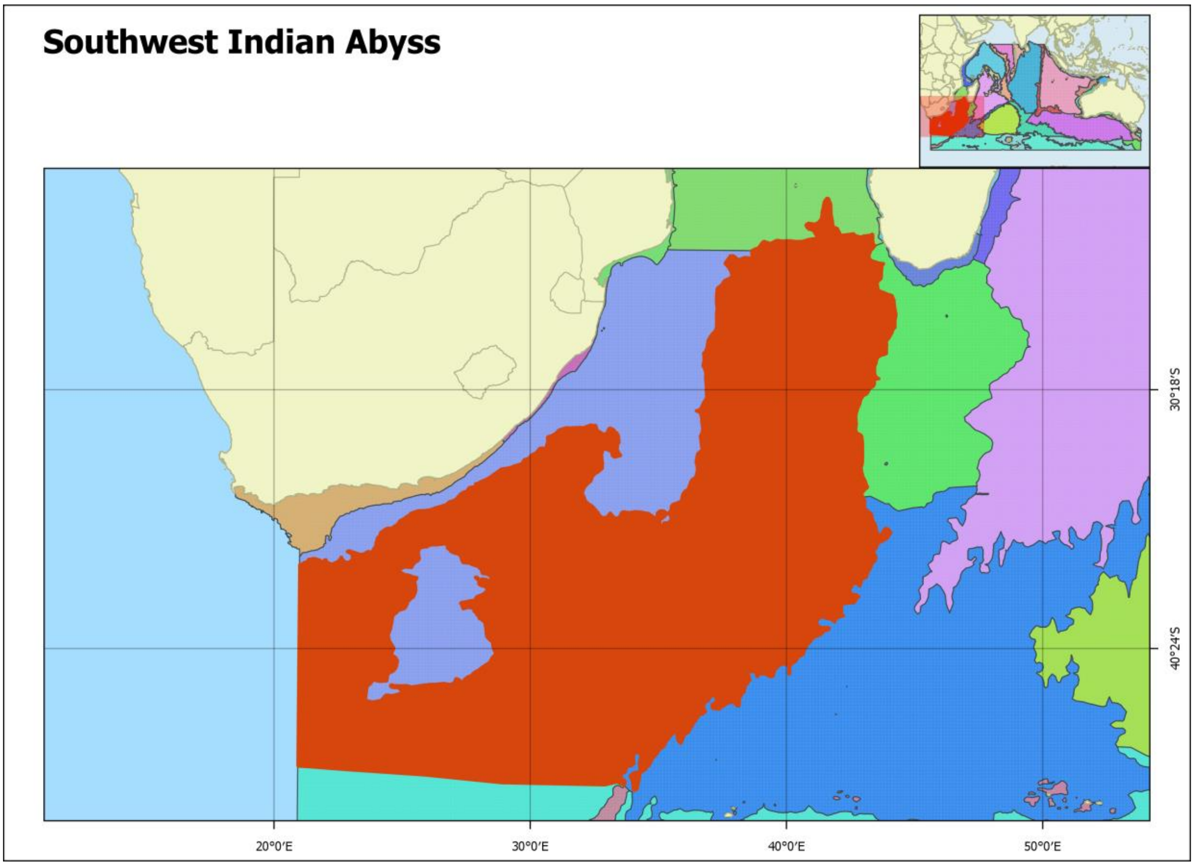


Figure 16: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.1.3 South West Indian Abyss



The South West Indian abyss is the abyssal region between South Africa and Madagascar and the Del Cano ridge.

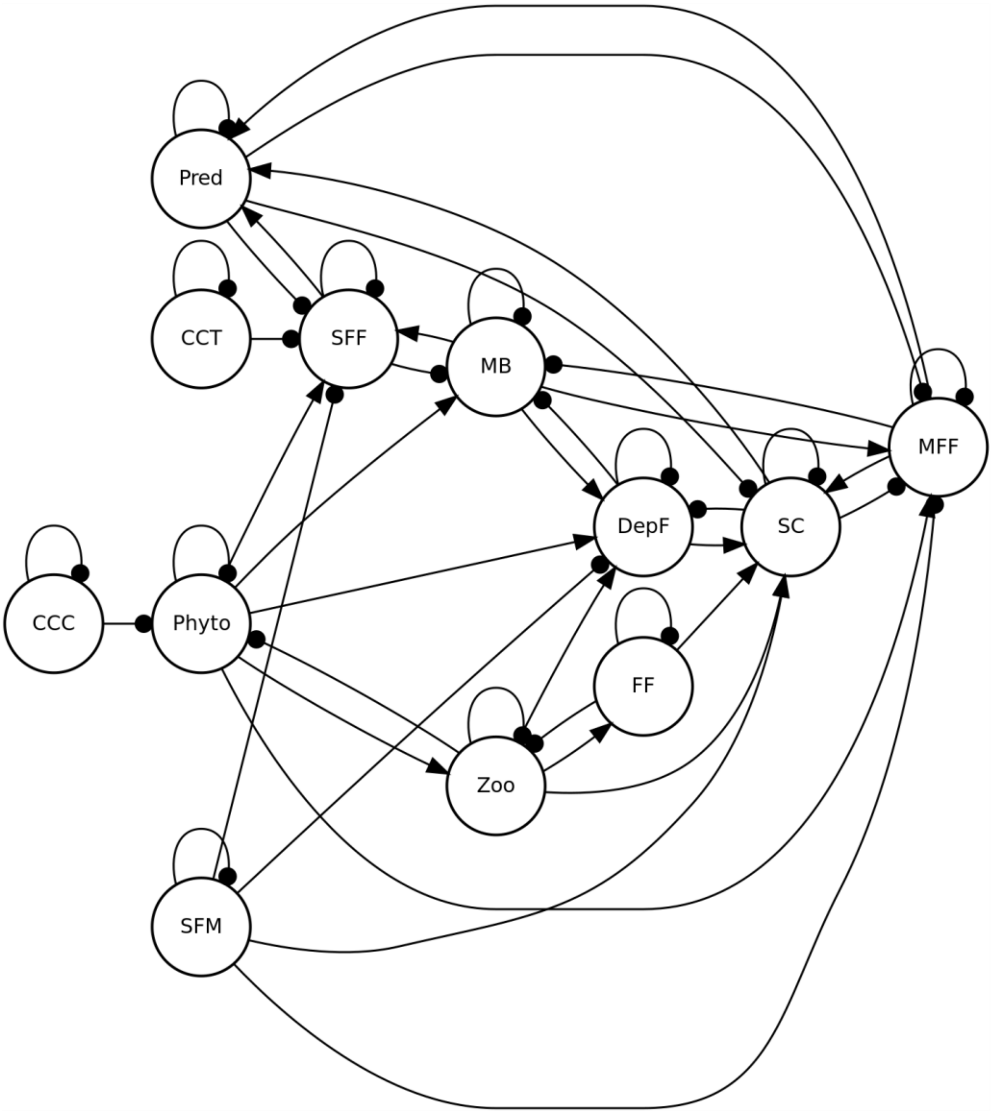


Figure 17: Ecosystem components in the qualitative model are: Predatory Fish (Pred), Sessile Filter Feeders (SFF), Mobile Filter Feeders (MFF), Scavengers (SC), Microbes (MB), Phytoplankton (Phyto), Zooplankton (Zoo), Food Falls (FF), Deposit Feeders (DepF) . Pressures acting on the system are: Seafloor Mining (SFM), Climate Change Chlorophyll (CCC), Climate Change Temperature (CCT)

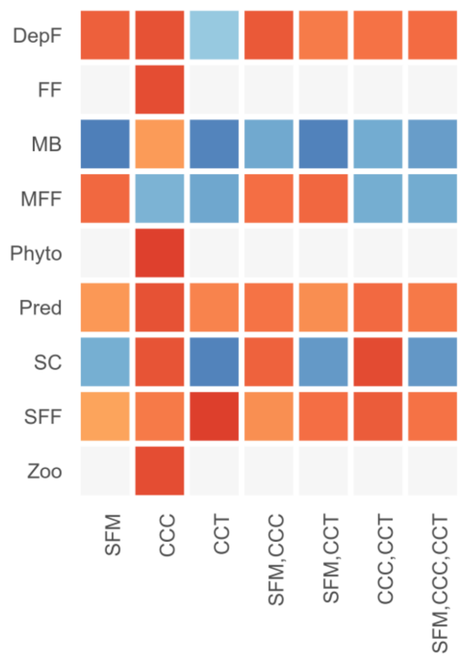
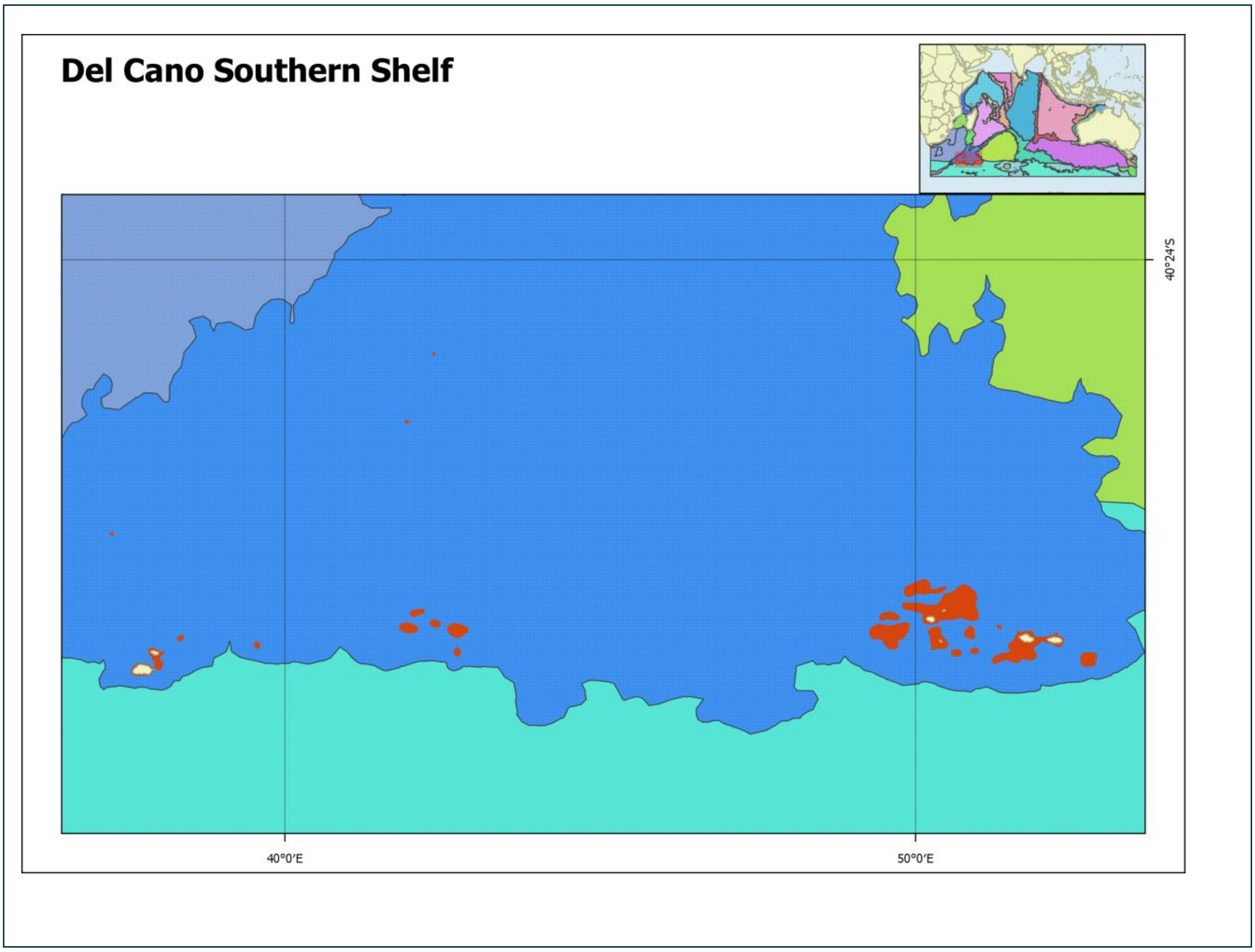
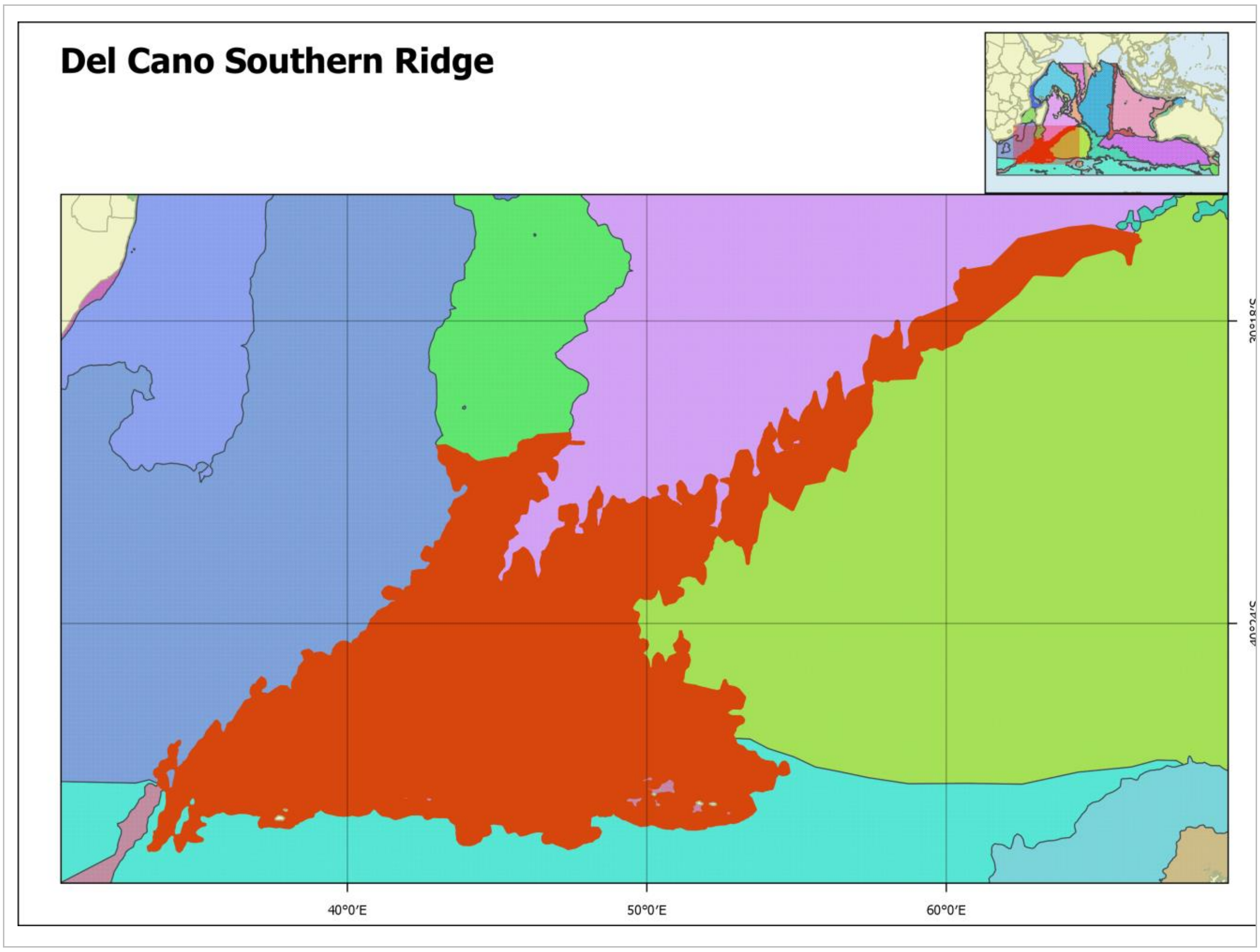


Figure 18: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

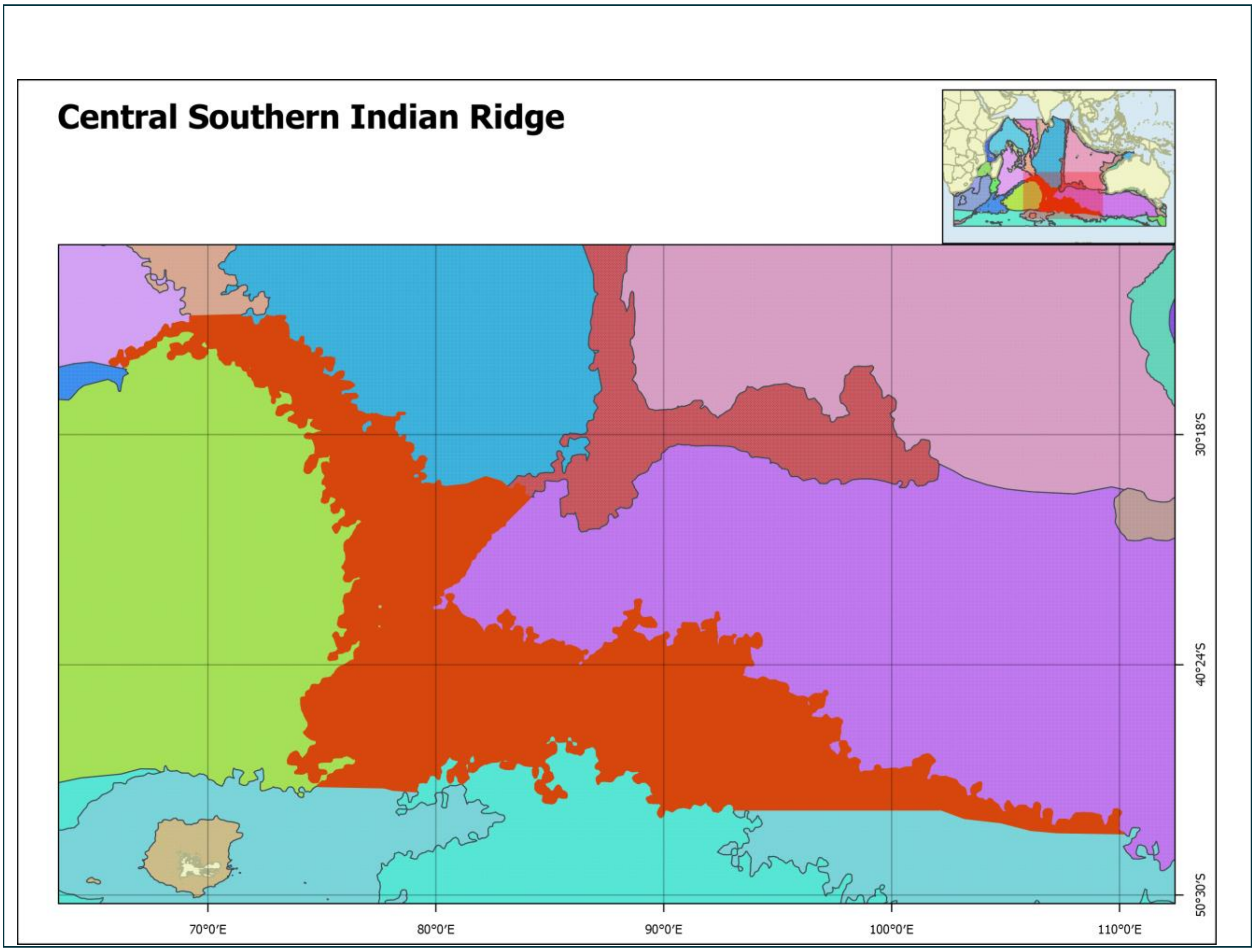
2.1.4 Del Cano Southern Ridge

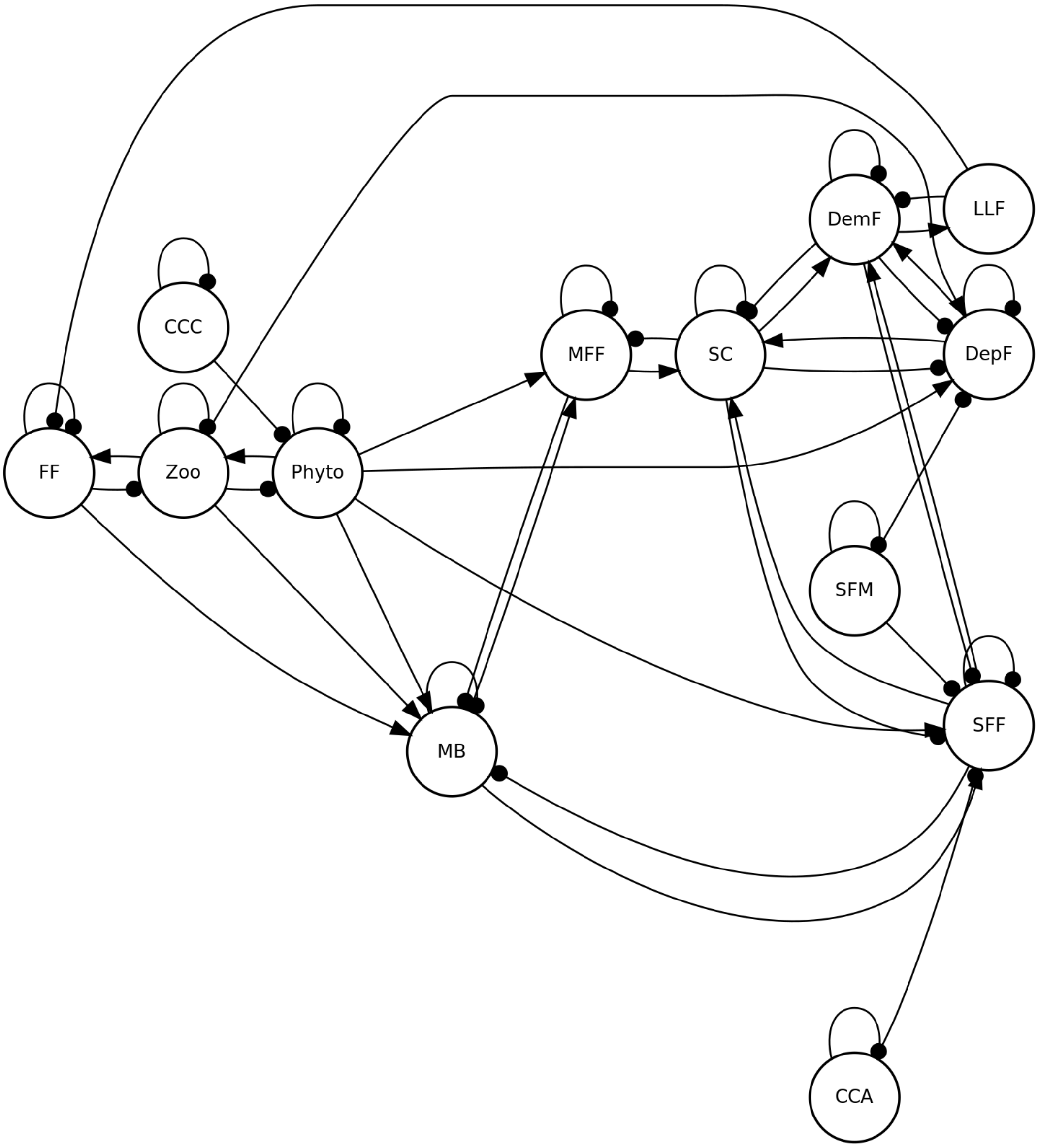




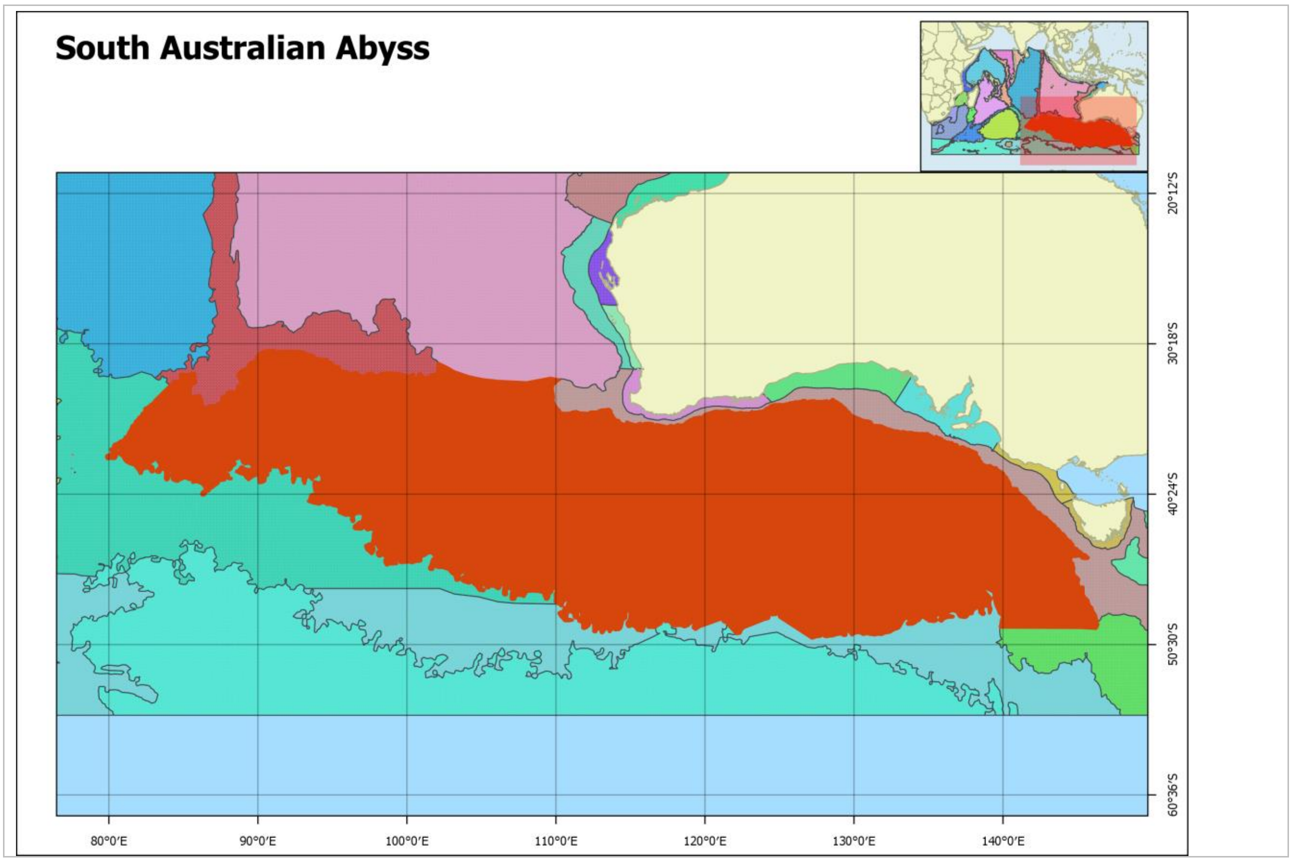
The Del Cano Shelf and bathyal regions are the shallow areas that are warmer than Antarctic waters – but cooler than the rest of the Indian Ocean (Douglass et al. 2014). They represent the transition between the Antarctic and temperate Indian Ocean. These regions belong to the Ecological Marine Units (EMU) bathypelagic cluster 37 with a mean temperature 3°C and are slightly shallower at 3000-6000m (Sayre *et al.,* 2017). Squat lobster Regions of Common Profile analysis captures this pattern.

2.1.5 Central Southern Indian Ridge



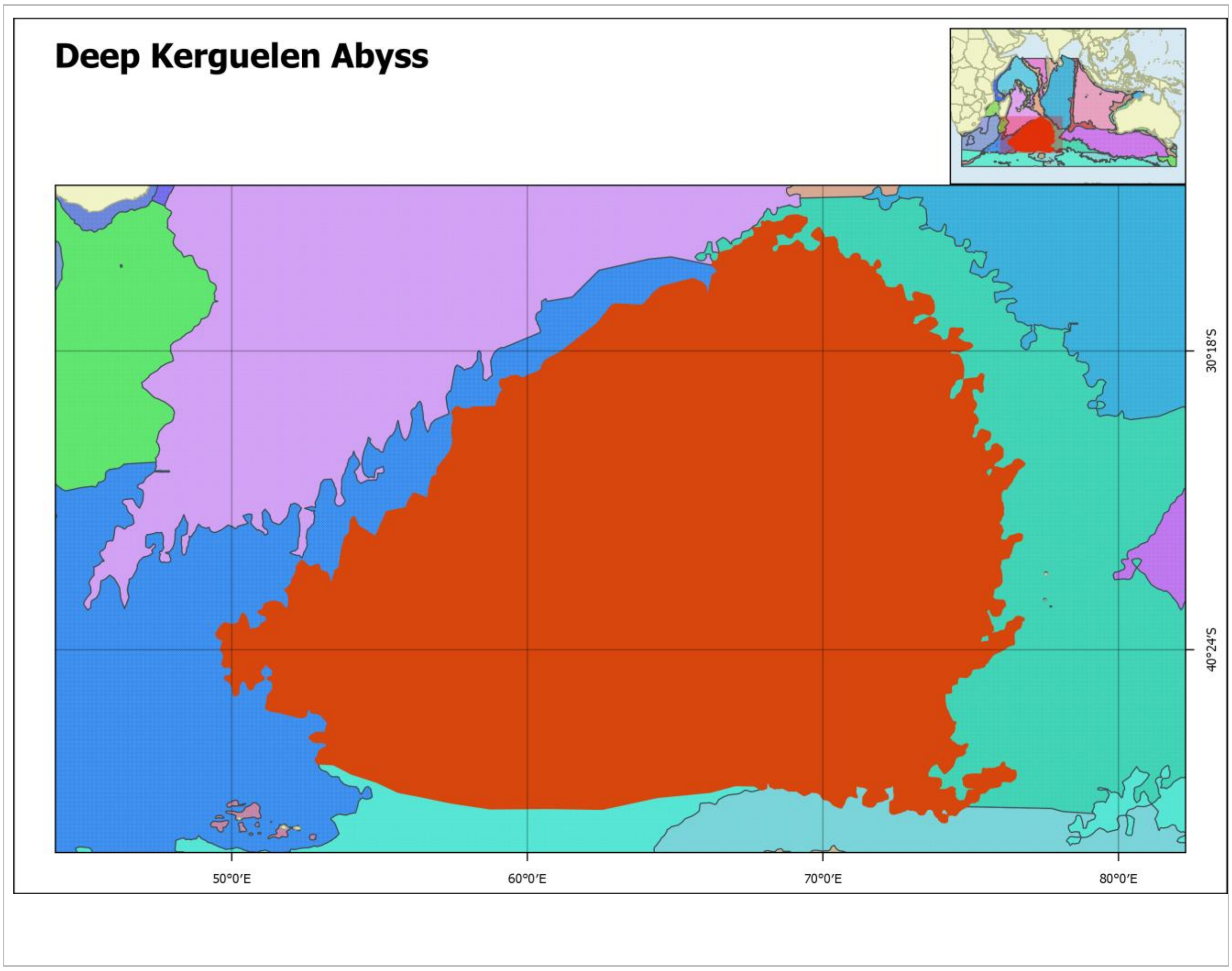

DemF
LLF
CCC
MFF
SC
DepF
FF
Zoo
Phyto
SFM
MB
SFF
CCA

2.1.6 South Australian Abyss



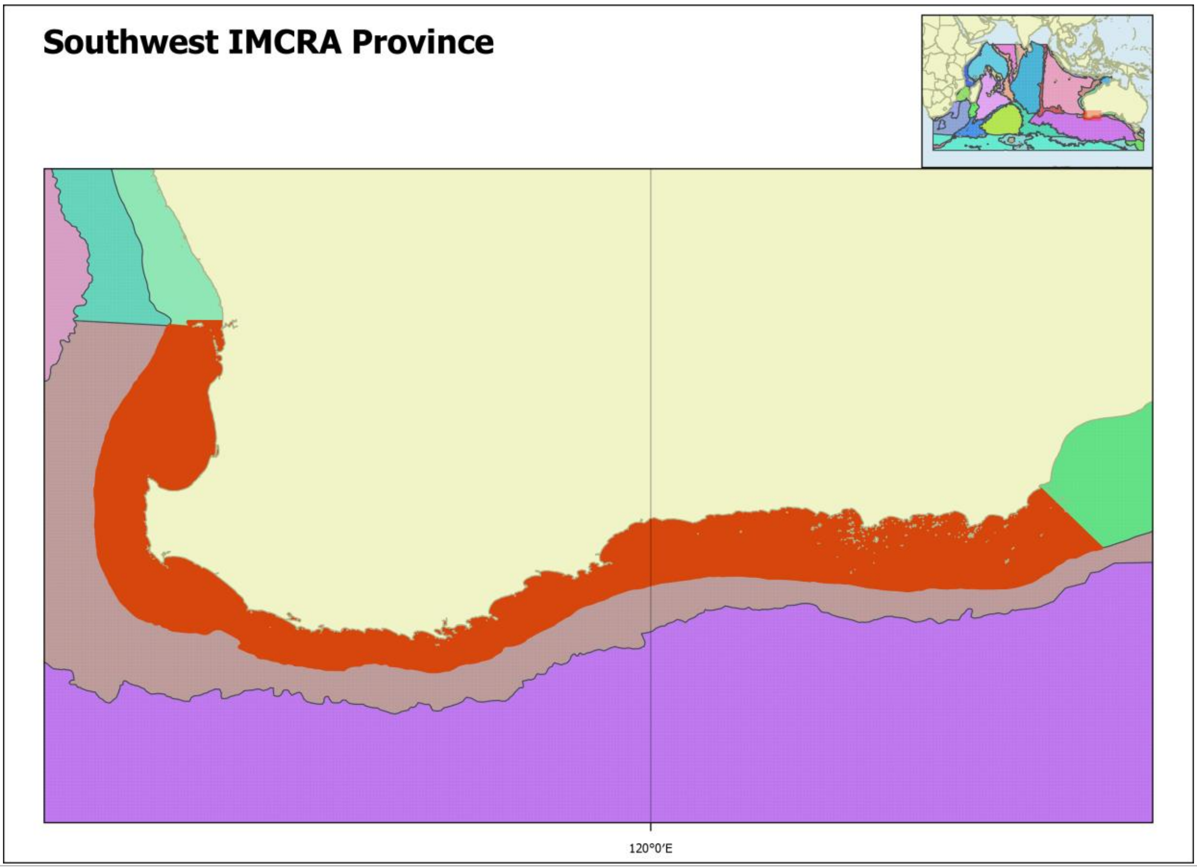
The Southern Australian Abyssal region extends from the bathyal regions south of Australia to the South-East Indian Ridge. It is a large, unexplored abyssal plain.

2.1.7 Deep Kerguelen Abyss



Bounded by Del Cano and southern portion of Central Indian Ocean ridge. It is identified as EMU cluster 14 and is very cold and very deep, typically greater than 3000m. This region is consistent with the Deep Kerguelen region identified in Douglass et al. (2014) and is captured in the Ophuriod statistical bioregionalisation.

2.1.8 Southwest IMCRA Shelf Province



Extract from Benthic Marine Bioregionalisation of Australia's Exclusive Economic Zone (Heap et al. 2005)

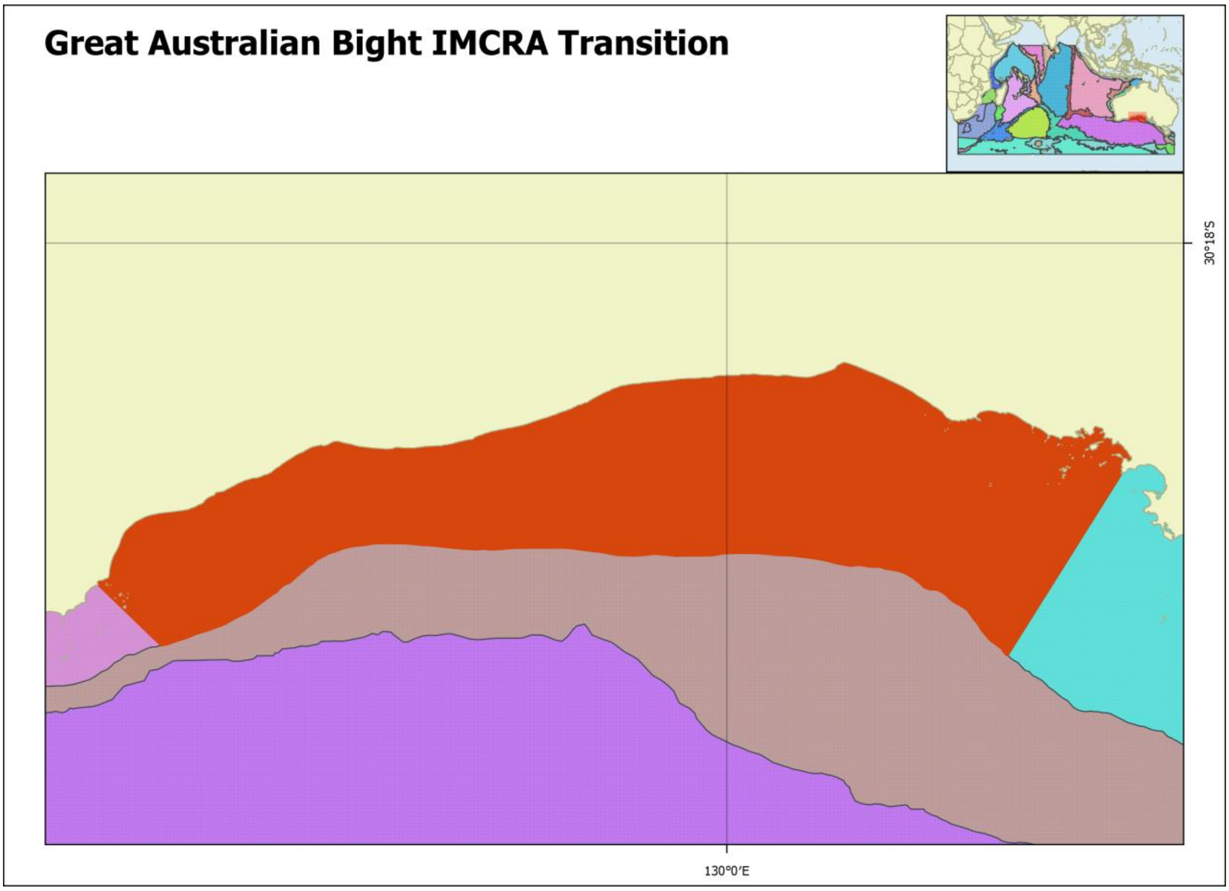
This bioregion contains the second deepest seabed habitats of all the IMCRA shelf bioregions.

• Class 1 includes units defined by the distribution and abundance of pinnacles, banks, and sand banks.

• This bioregion is only IMCRA shelf bioregion to contain three classes of geomorphic units.

The qualitative models for this province can be found in Hayes et al. (2012).

2.1.9 Great Australian Bight IMCRA Transition



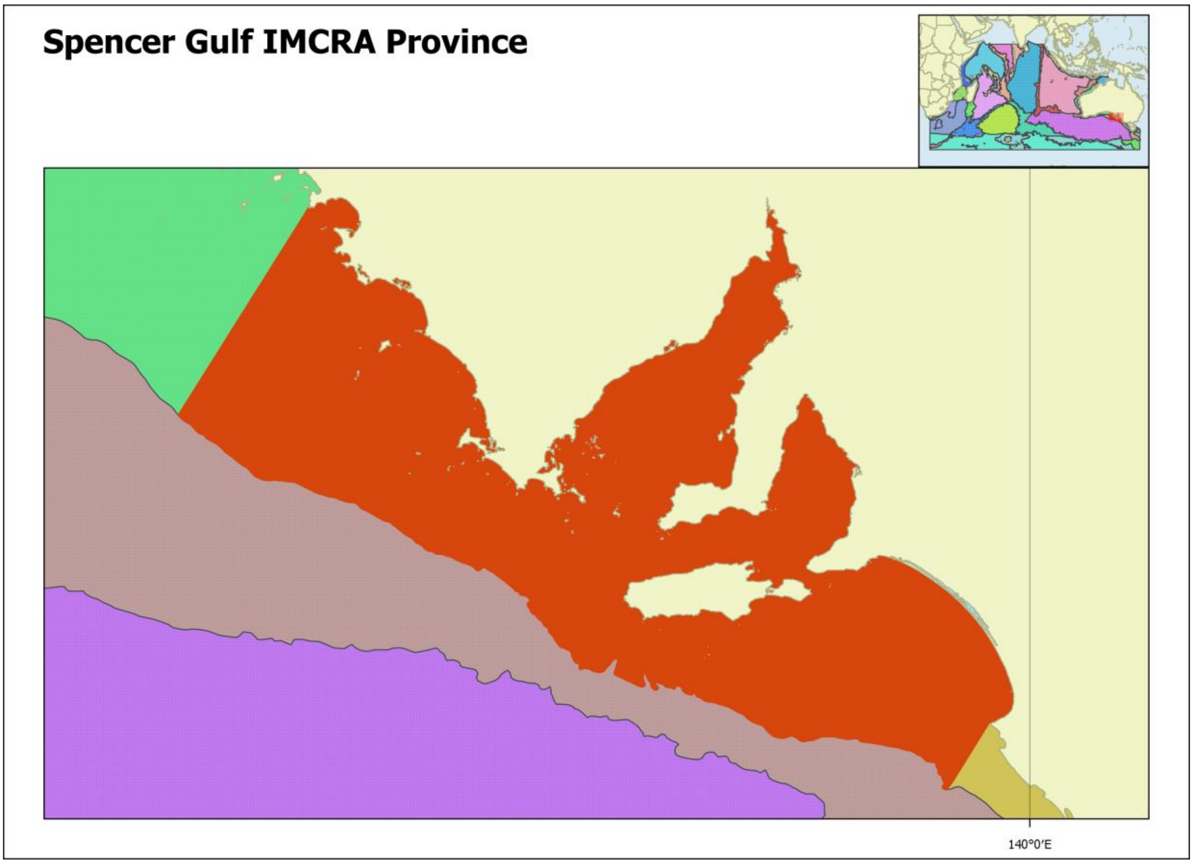
Extract from Benthic Marine Bioregionalisation of Australia's Exclusive Economic Zone (Heap et al. 2005)

This bioregion is the 5th largest bioregion of the IMCRA shelf bioregions.

- Class 1 includes units defined by the distribution and abundance of pinnacles, banks, and sand banks.
- This bioregion contains the 4th largest area of Class 1 units and 6th largest area of Class 7 units of all the IMCRA shelf bioregions.
- This bioregion is one of six IMCRA shelf bioregions that contain two classes of geomorphic units.

The qualitative models for this province can be found in Hayes et al. (2012).

2.1.10 Spencer Gulf IMCRA Province



Extract from Benthic Marine Bioregionalisation of Australia's Exclusive Economic Zone (Heap et al. 2005)

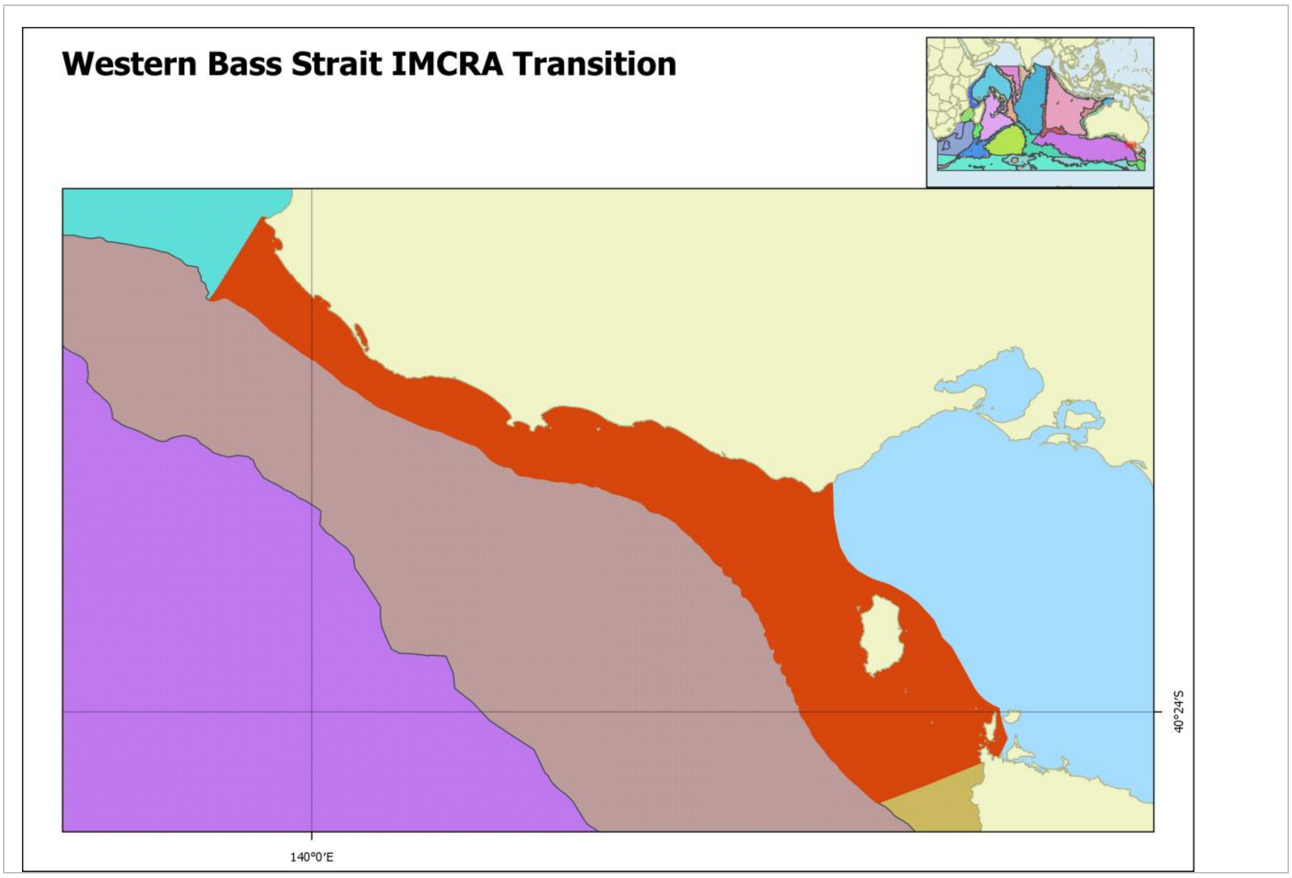
This bioregion is the 6th largest bioregion of the IMCRA shelf bioregions.

• Class 1 includes units defined by the distribution and abundance of pinnacles, banks, and sand banks.

• This bioregion is one of four IMCRA shelf bioregions to contain five classes of geomorphic units.

The qualitative model for this province can be found in Hayes et al. (2012).

2.1.11 Western Bass Strait IMCRA Transition



Extract from Benthic Marine Bioregionalisation of Australia’s Exclusive Economic Zone (Heap et al. 2005)

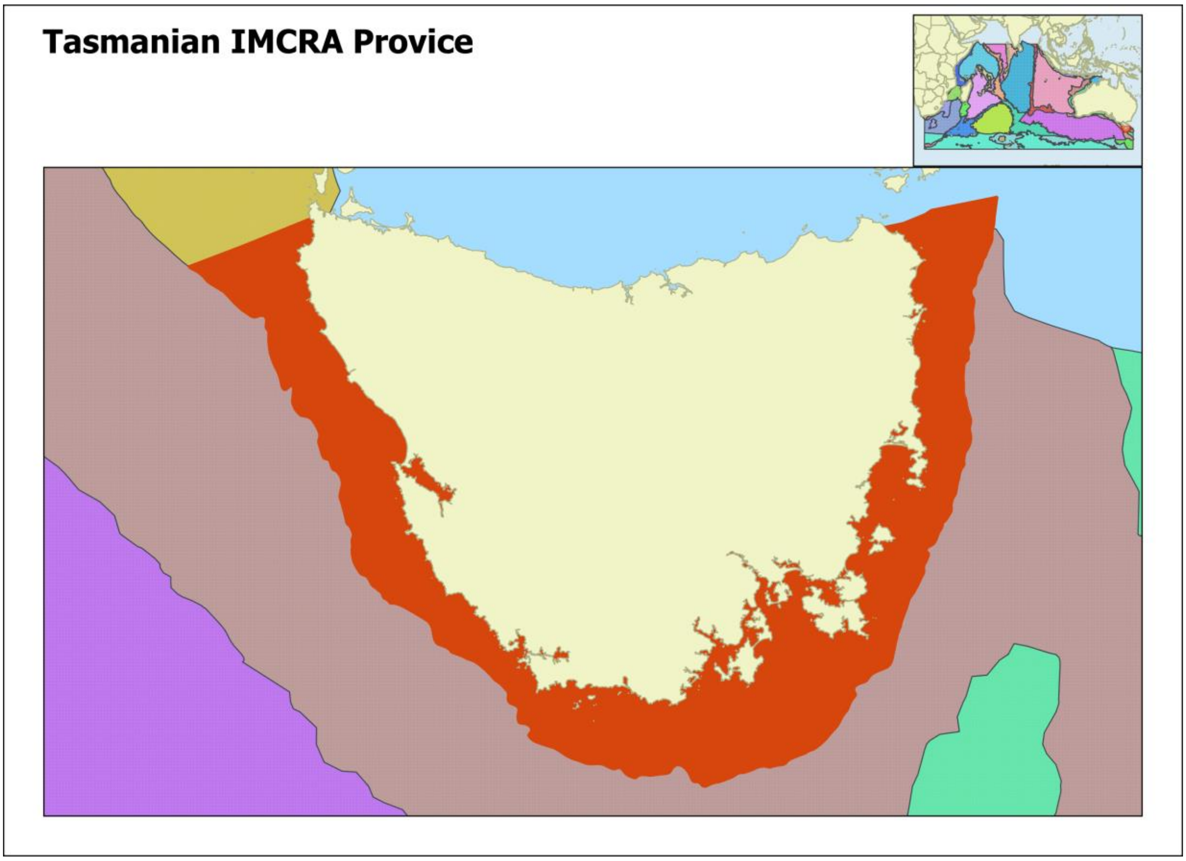
This bioregion is the 11th largest bioregion of the IMCRA shelf bioregions.

• This is one of four IMCRA shelf bioregions to contain four classes of geomorphic units.

• This bioregion contains the 5th largest area of Class 1 units of all the IMCRA shelf bioregions.

The qualitative models for this region can be found in Hosack and Dambacher et al. (2012)

2.1.12 Tasmanian IMCRA Province



Extract from Benthic Marine Bioregionalisation of Australia's Exclusive Economic Zone (Heap et al. 2005)

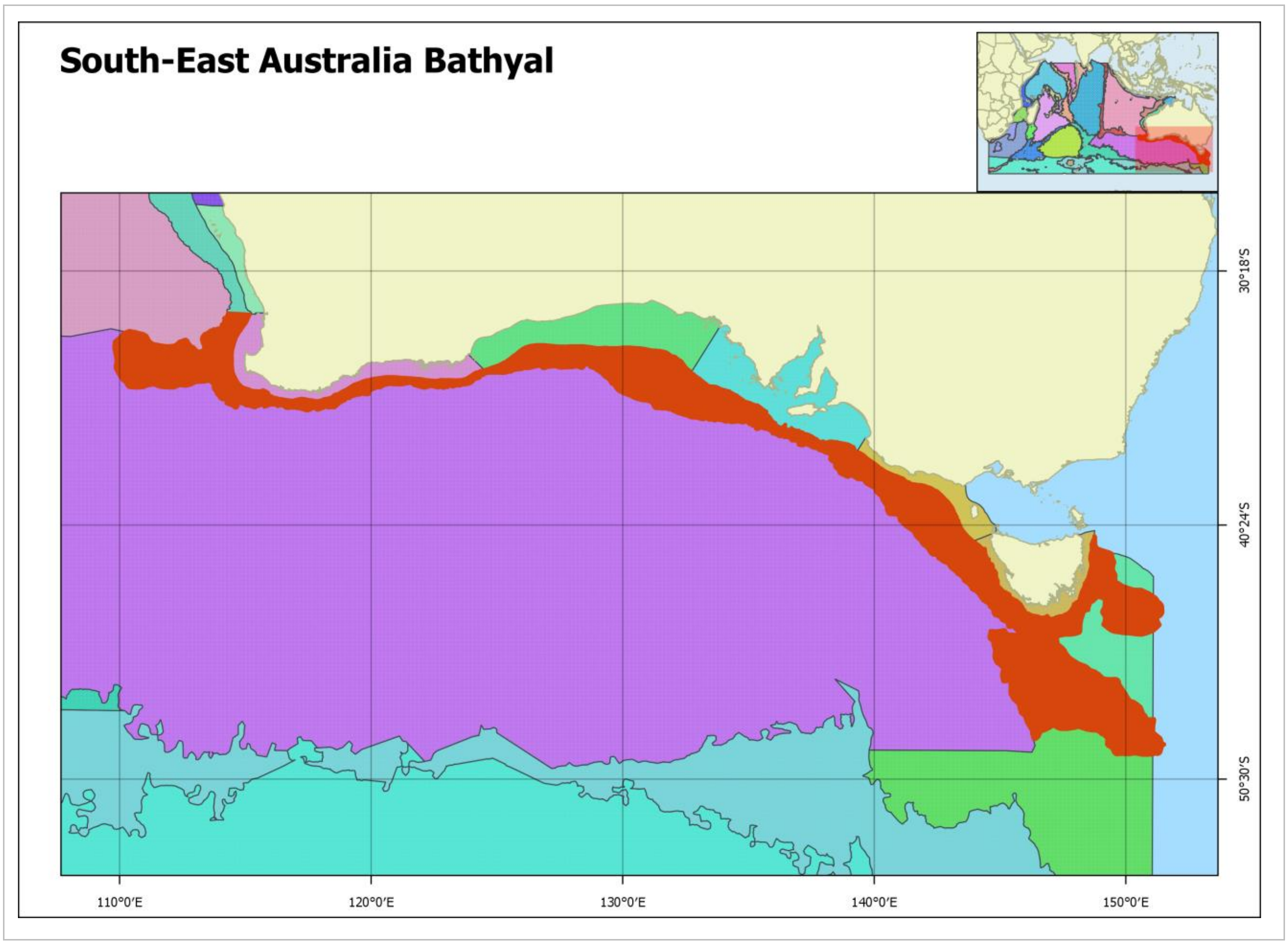
This bioregion is the 14th largest bioregion of the IMCRA shelf bioregions.

• This bioregion contains the deepest seabed habitats and is the deepest bioregion on average of all the IMCRA shelf bioregions.

• This bioregion is one of four IMCRA shelf bioregions to contain four classes of geomorphic units.

The qualitative model for this province can be found in Hosack and Dambacher (2012).

2.1.13 Southern Australian Bathyal



This bioregion is one of 11 NBMB bioregions to cover two Primary Bathymetric Units, and one of nine to occur on the slope and abyssal plain/deep ocean floor.

• This bioregion contains the 2nd largest area of abyssal plain/deep ocean floor and 4th largest slope area of all the NBMB bioregions.

• This bioregion is one of 14 NBMB bioregions to contain all of the biome types.

• The ratio of endemics to total fish species is the lowest for all the NBMB bioregions.

• The central distribution of demersal fishes is located in the Great Australian Bight (Last et al., 2005).

• Biomes defined by the demersal fish depth structure are the third largest in terms of their total area and cover the 11th largest area as a percentage of the bioregion area for all the NBMB bioregions.

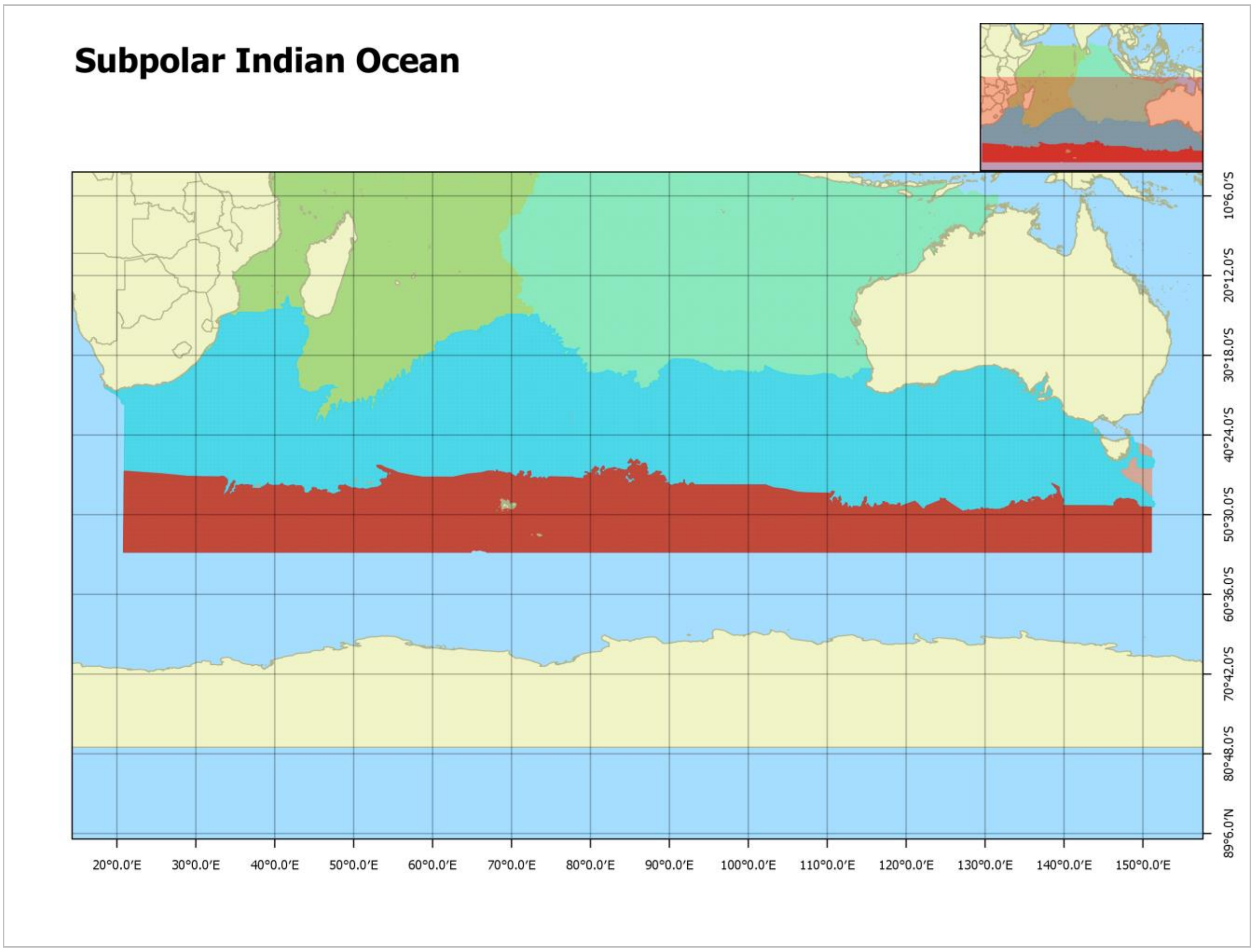
• This bioregion is one of five NBMB bioregions to contain eight classes of geomorphic units.

• Class 2 includes units defined by the spacing of submarine canyons on the slope.

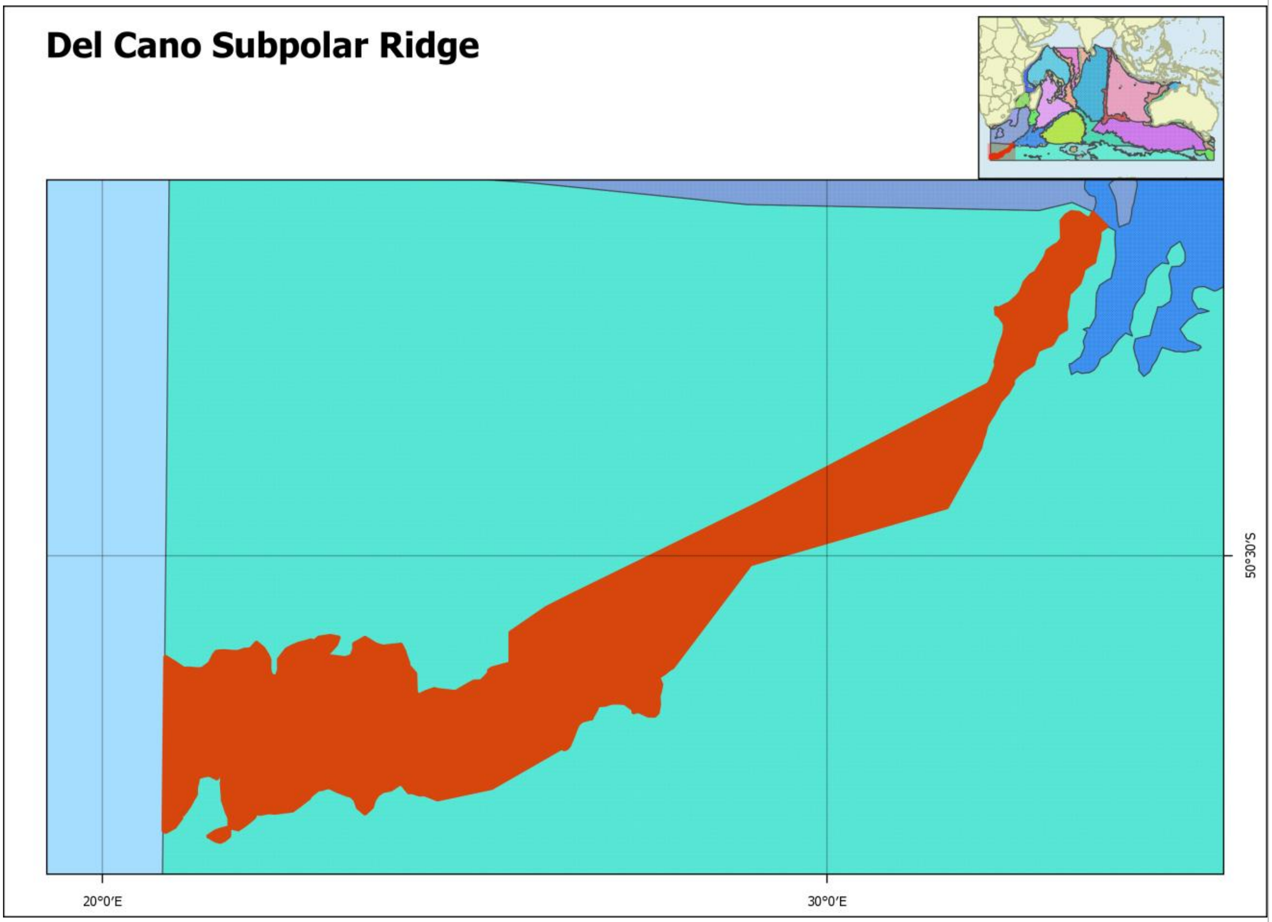
• This bioregion contains the largest Class 2, 2nd largest Class 1, and 5th largest Class 7 unit of all the NBMB bioregions.

• The province also contains the Diamantina Fracture Zone a region of very rugged seabed comprised of numerous deep-sea ridges and troughs which represents. This is a unique region of deep-sea habitats.

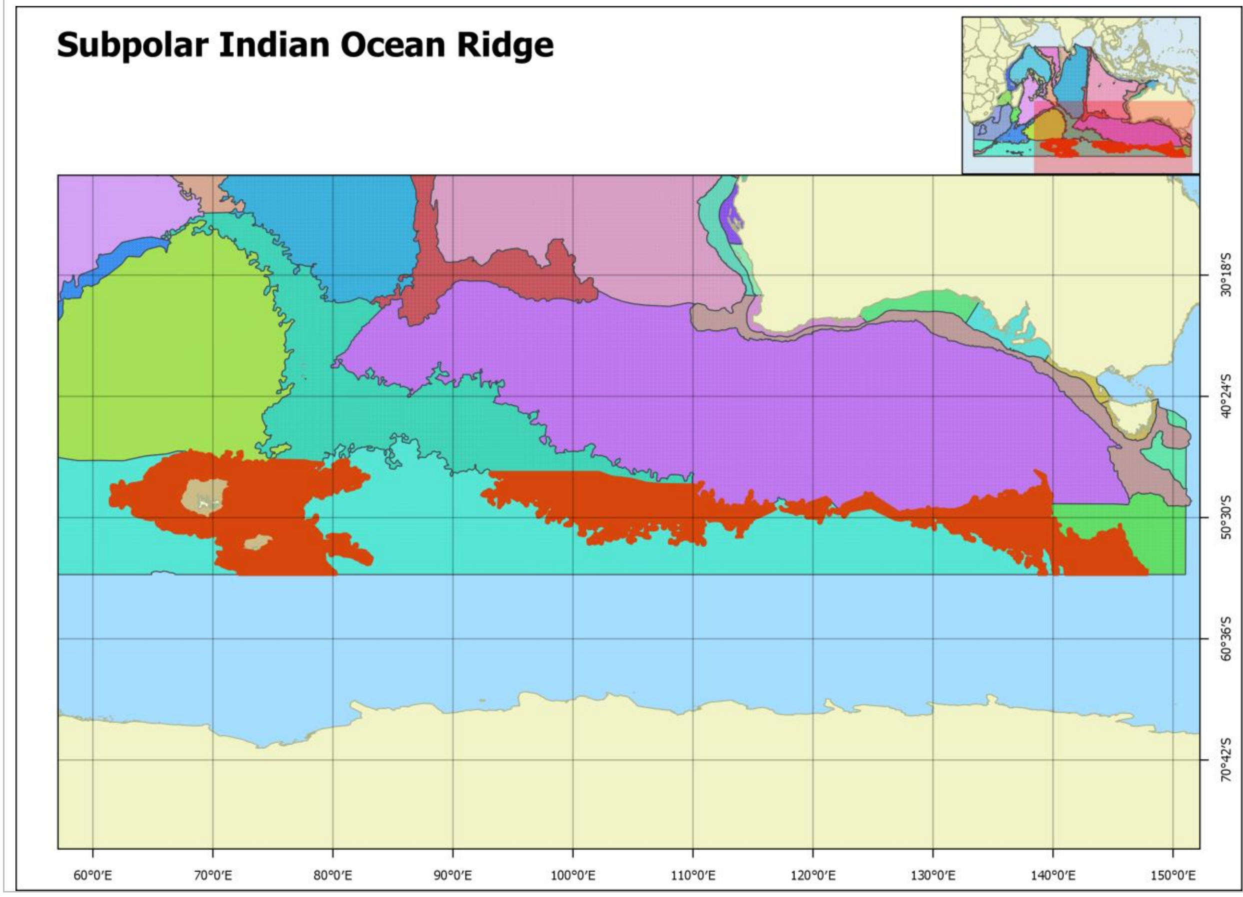
2.2 Subpolar Indian Ocean



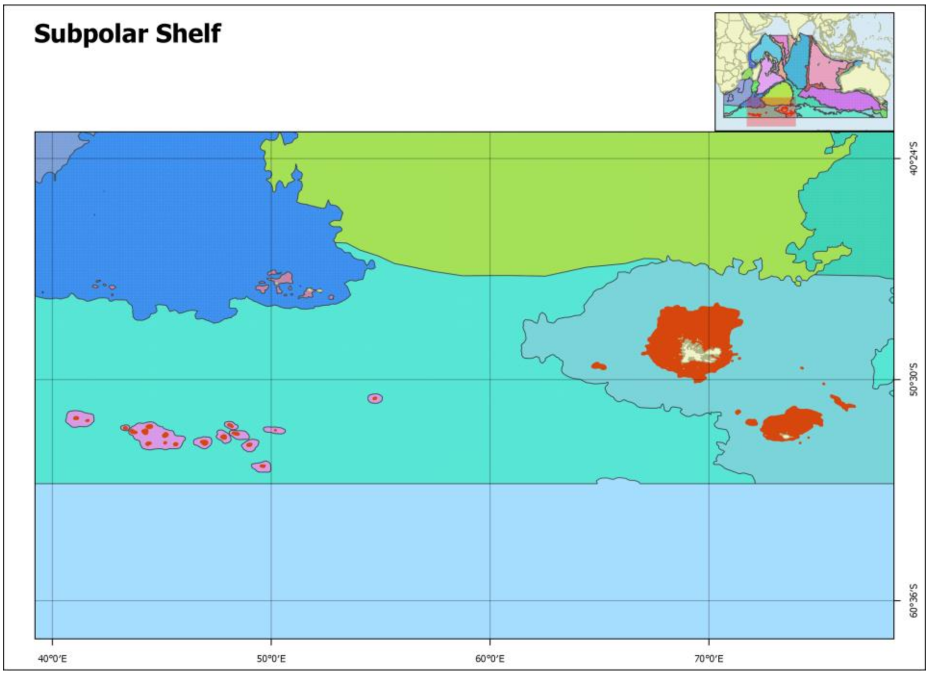
2.2.1 Del Cano Subpolar Ridge

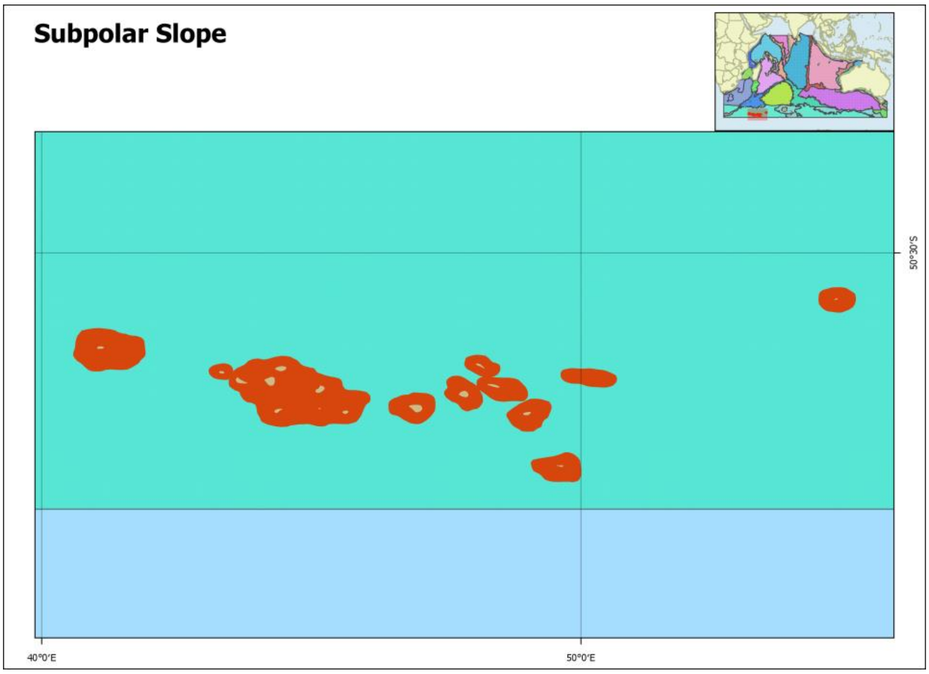


2.2.2 Subpolar Indian Ocean Ridge



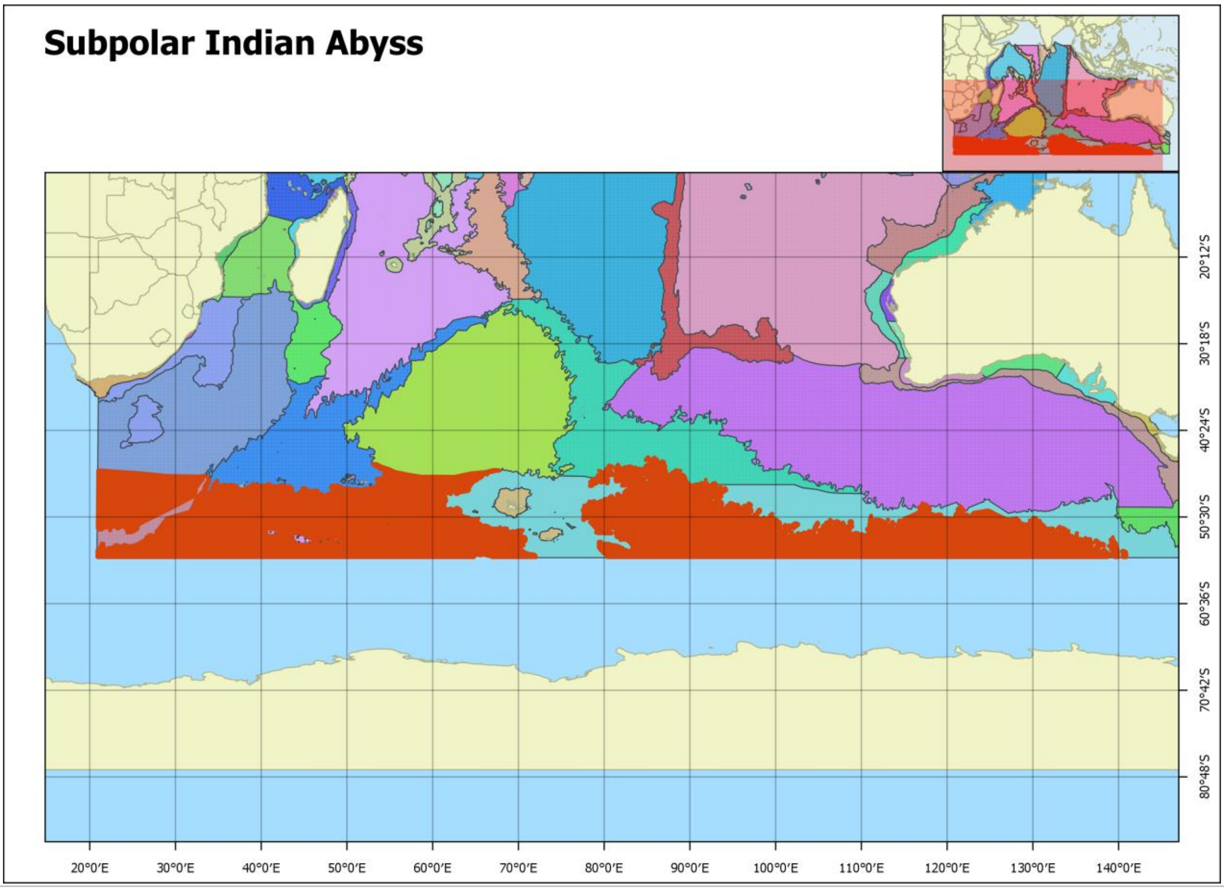
2.2.3 Subpolar Indian Shelf and Slope





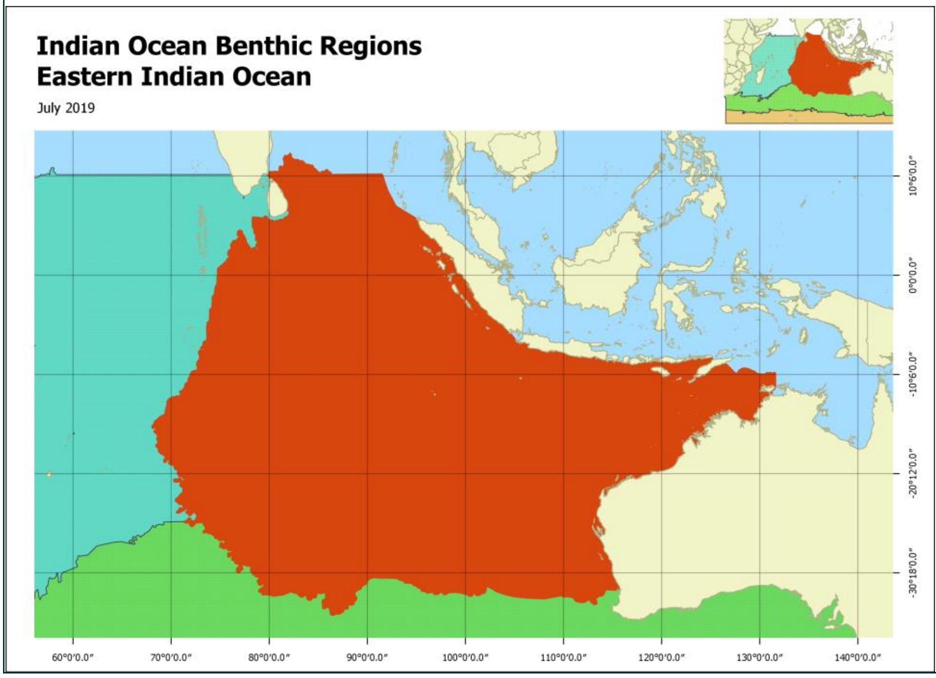
These provinces are identified in Douglas et al (2014) and belong to the Del Cano sub-region within the Antarctic bioregionalisaiton.

2.2.4 Subpolar Indian Abyss



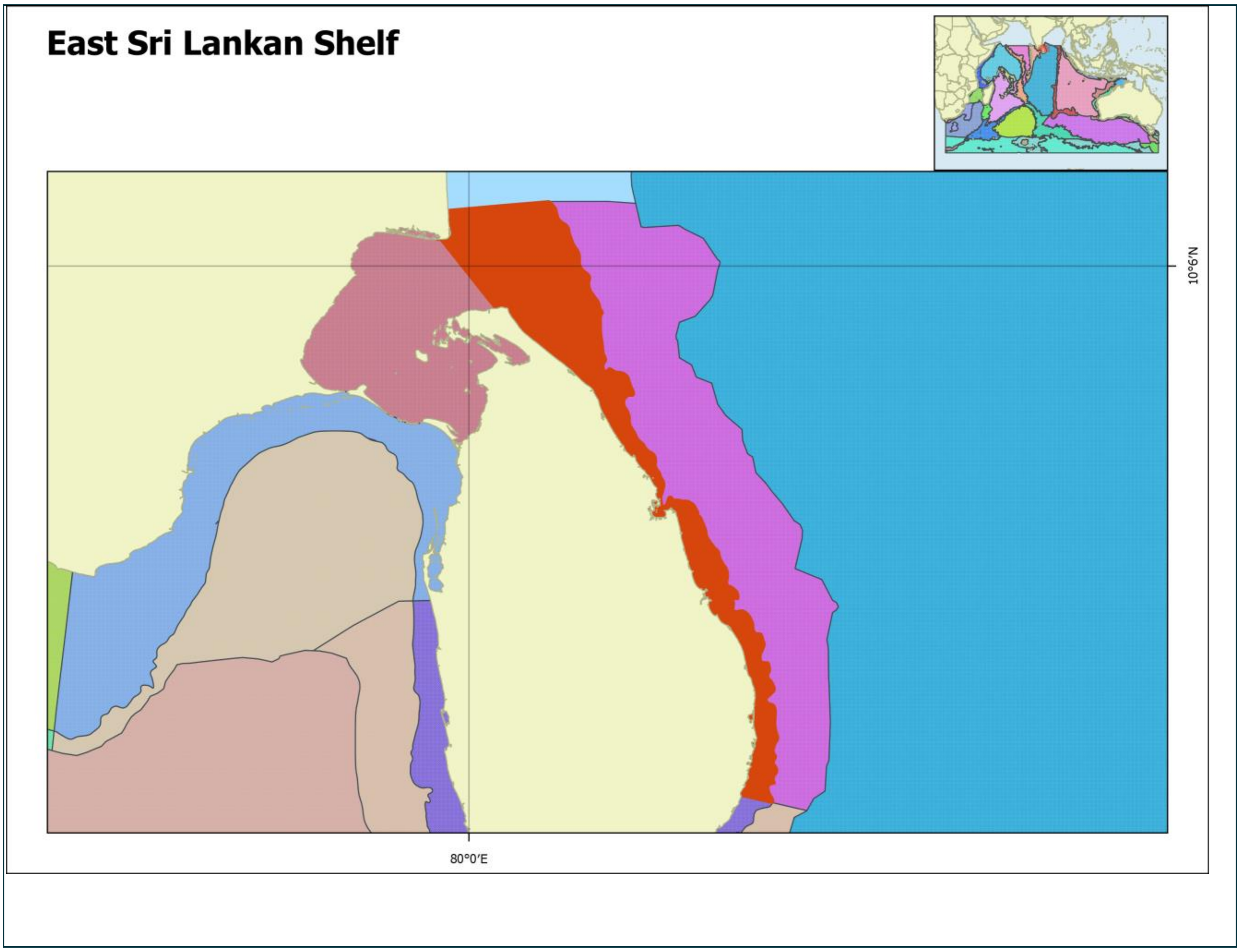
These are the deep cold seabeds identified in Douglas et al (2014) as the East Indian Abyssal. This is distinct from the more northern abyssal regions based on based on Ophiuroid RCP5 (see Appendix 1) and GOODS bioregions (UNESCO, 2006). This region has a strong southern ocean effect. It has higher oxygen levels and belongs to Ecological Marine Units (EMU) cluster 14 (Sayre *et al.,* 2017).

2.3 Eastern Indian Ocean



The Eastern Indian Ocean is formed by the large basin to the east of the Central Indian Ridge. This ridge divides the more topographically complex western Indian Ocean from the eastern Indian Ocean and represents a large fauna barrier that is apparent both coastally and at depth.

2.3.1 East Sri Lanka Shelf Province



The Sri Lanka Shelf Province has the same boundaries and characteristics as described in Brewer et al (2015). The Sri Lankan Shelf Province comprises the shelf waters (coastline to 200 m depth) encompassing most of Sri Lanka. However, in the north-west of Sri Lanka, the shelf environment is segregated into the Palk Bay Province and the Gulf of Mannar Shelf Province. The Palk Bay Shelf Province is a unique shallow sandy environment with a high proportion of basin habitats, substantial terrestrial and freshwater input from the Indian mainland and unique ecological communities. To the south of Palk Bay and forming the north-western boundary of the Sri Lankan Shelf Province is the eastern extent of the Gulf of Mannar Shelf Province. This is a deeper shelf separated from Palk Bay by chain of low islands and reef shoals known as Adams's bridge or the Bridge of Rama. It forms the north-eastern boundary of the Sri Lankan Shelf Province and is differentiated by its connection to terrestrial inputs, productivity dynamics and the influence of steeper depth gradient. The very north-eastern boundary of the province butts against the Coromandel Shelf Province. This boundary is based on the influences of major physical drivers including the various sources of terrestrial input, the influence of different current systems and substantial differences in productivity dynamics. The Sri Lankan Shelf Province is bounded on its deepest margin by the Sri Lankan Slope Province, a steeply grading continental slope habitat surrounding most of Sri Lanka.

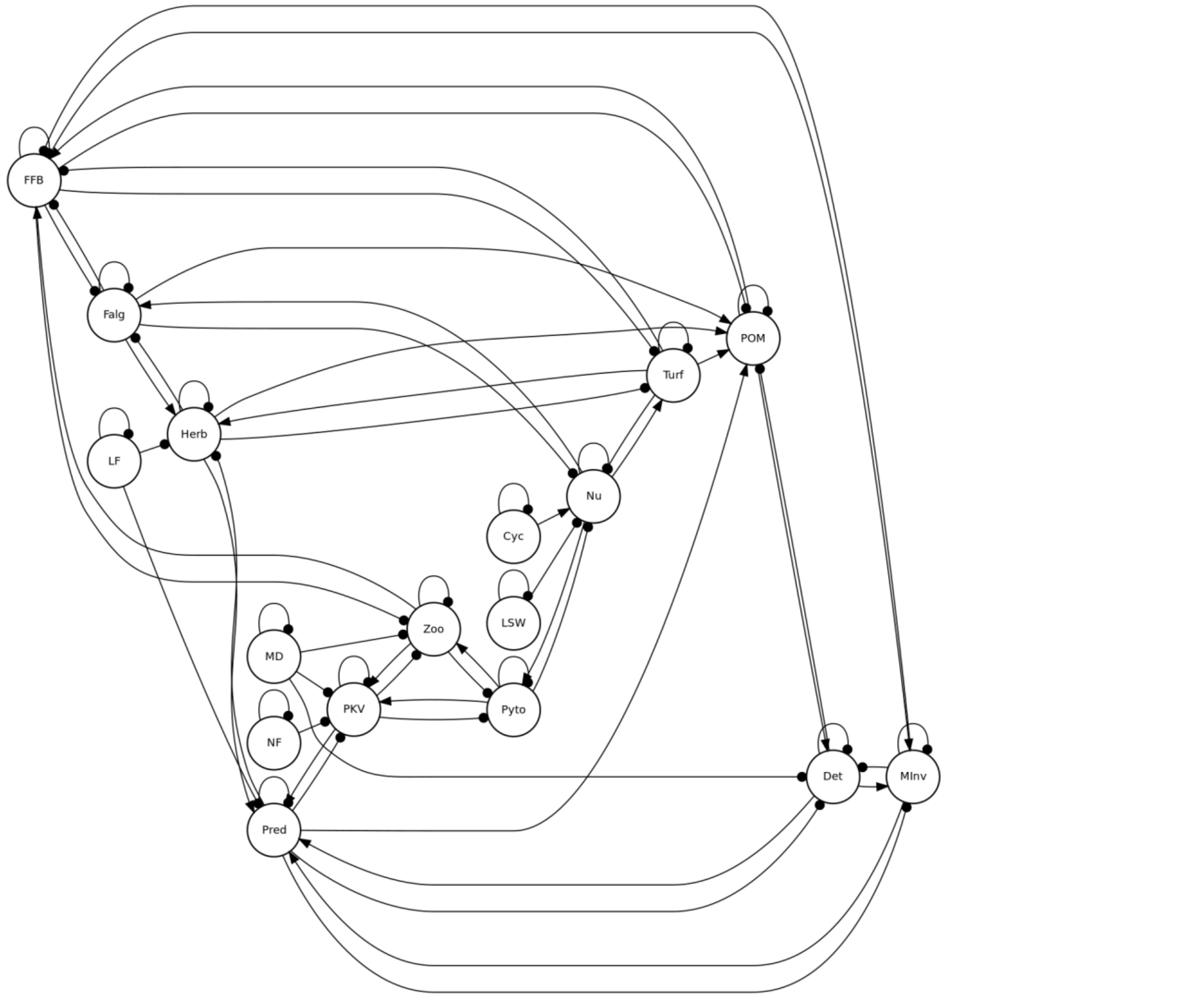


Figure 19: Ecosystem components in the qualitative model are: Filter Feeder Benthic (FFB), Fleshy Algae (Falg), Turf Algae (Turf), Particulate Organic Matter (POM), Nutrients (Nu), Phytoplankton (Pyto), Zooplankton (Zoo), Predatory Fish (Pred), Herbivorous Fish (Herb), Detritivores (Det), Planktivorous (PKV), Mobile Invertebrates (MInv) . Pressures acting on the system are: Line Fishing (LF), Net Fishing (NF), Low Saline Water (LSW), Marine Debris (MD), Cyclones (Cyc)

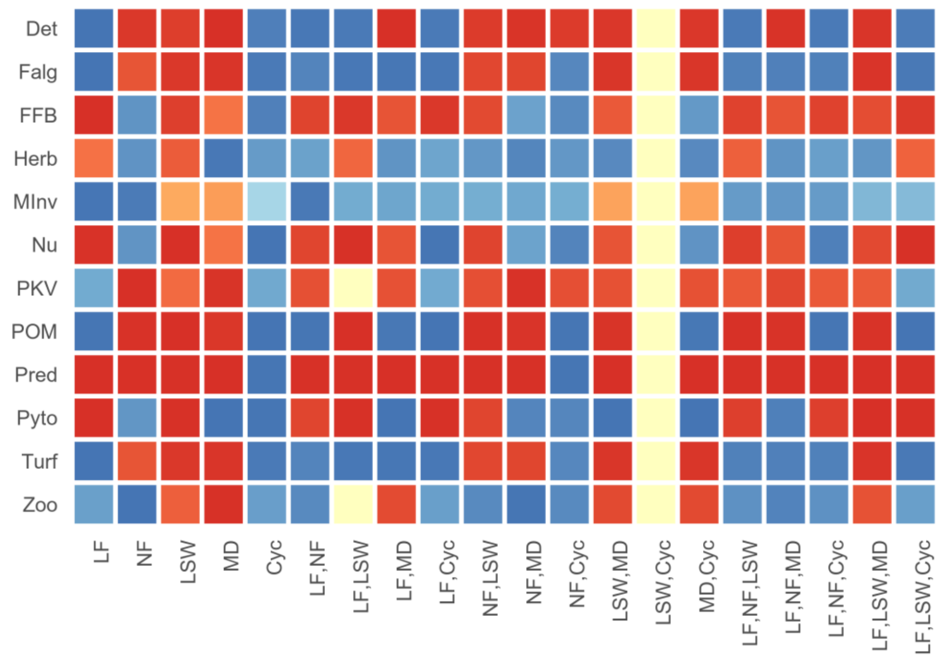
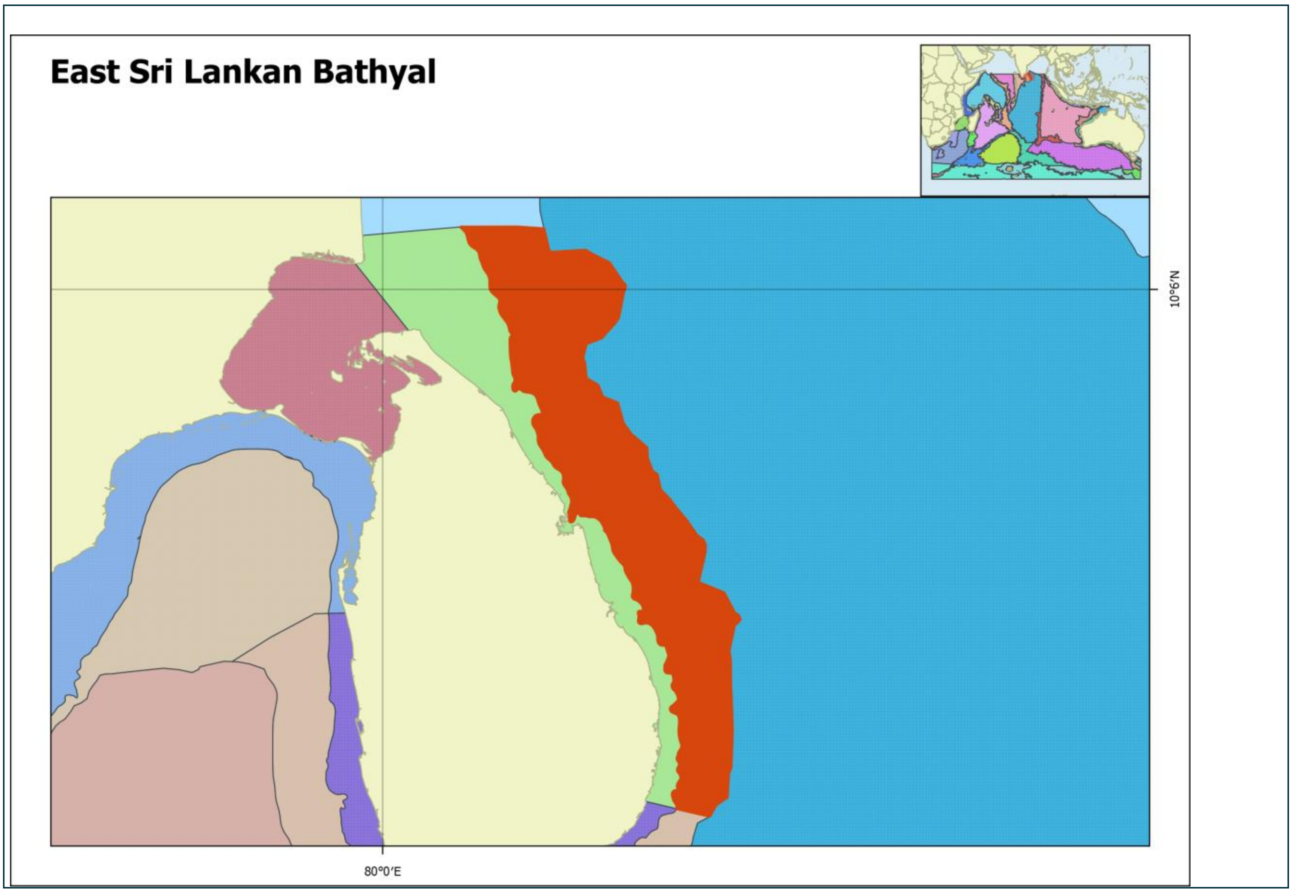


Figure 20: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.3.2 East Sri Lanka Bathyal Province



The Sri Lanka Bathyal Province has the same boundaries and characteristics as described in Brewer et al (2015). The Sri Lankan Slope Province encompasses the Sri Lankan Shelf Province and hence uses some of the same justification for the boundaries. Throughout most of its extent it is a narrow and steep sloping province. The north-western boundary butts against the Gulf of Mannar Slope Province where the slope widens substantially, the gradient decreases and the influence of the Indian continent increases. The deeper extent of the slope joins the Bay of Bengal Abyss Province to the east, the abyssal ocean within the Laccadive Sea to the west and the deep abyssal Indian Ocean environment to the south.

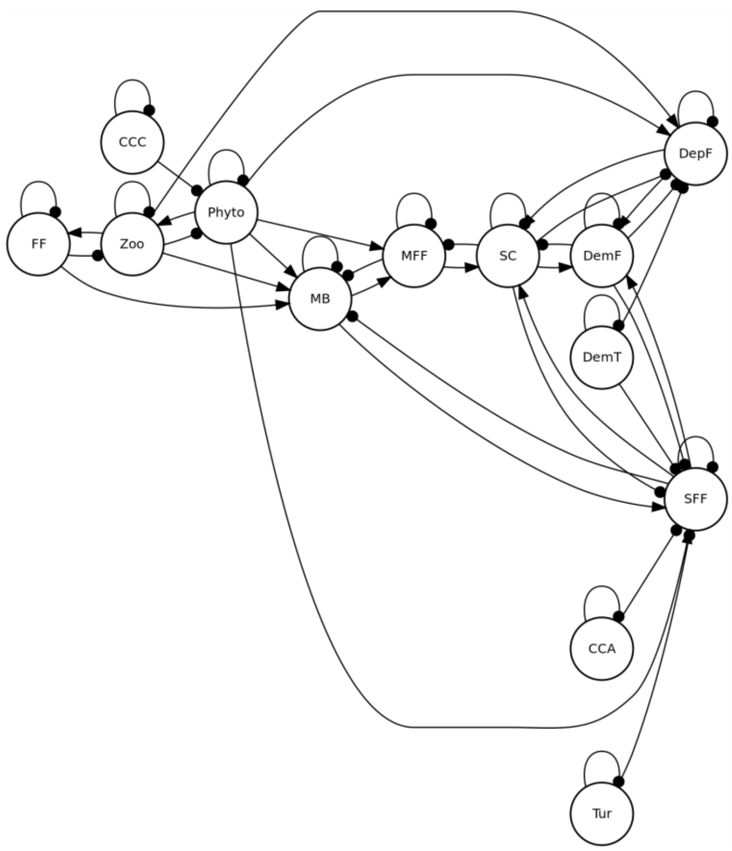


Figure 21: Ecosystem components in the qualitative model are: Food Falls (FF), Microbes (MB), Phytoplankton (Phyto), Zooplankton (Zoo), Deposit Feeders (DepF), Demersal Fishes (DemF), Scavengers (SC), Mobile Filter Feeders (MFF) . Pressures acting on the system are: Sessile Filter Feeders (SFF), Demersal Trawling (DemT), Climate Change Chlorophyll (CCC), Climate Change Acidification (CCA), Turbidity Increase (Tur)"

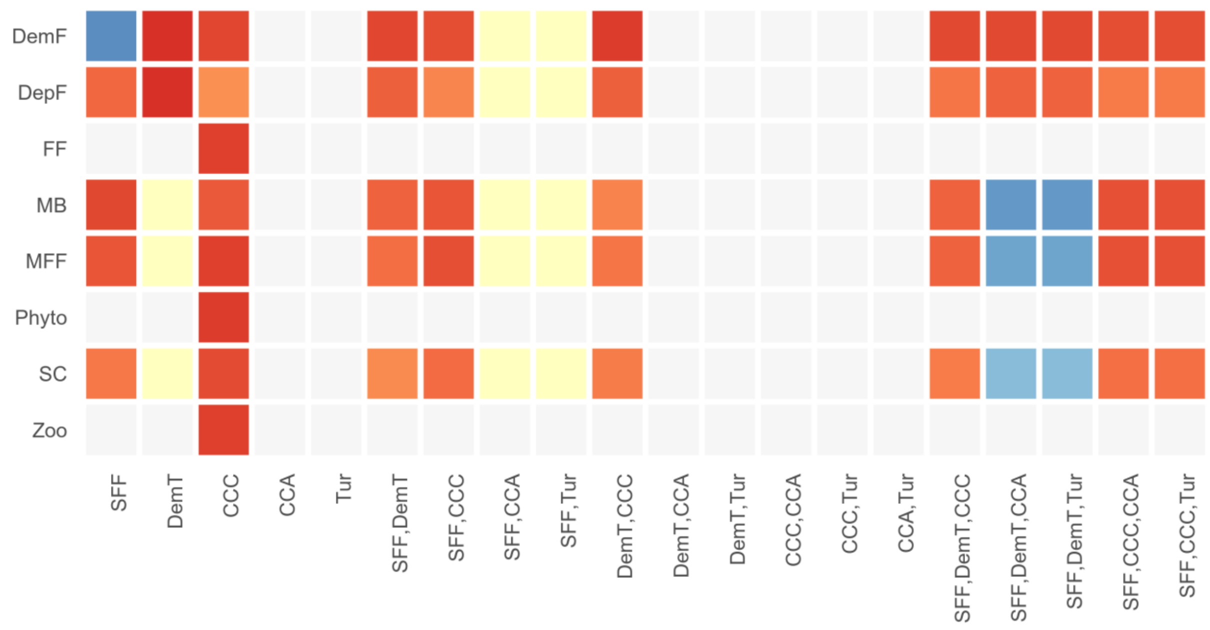
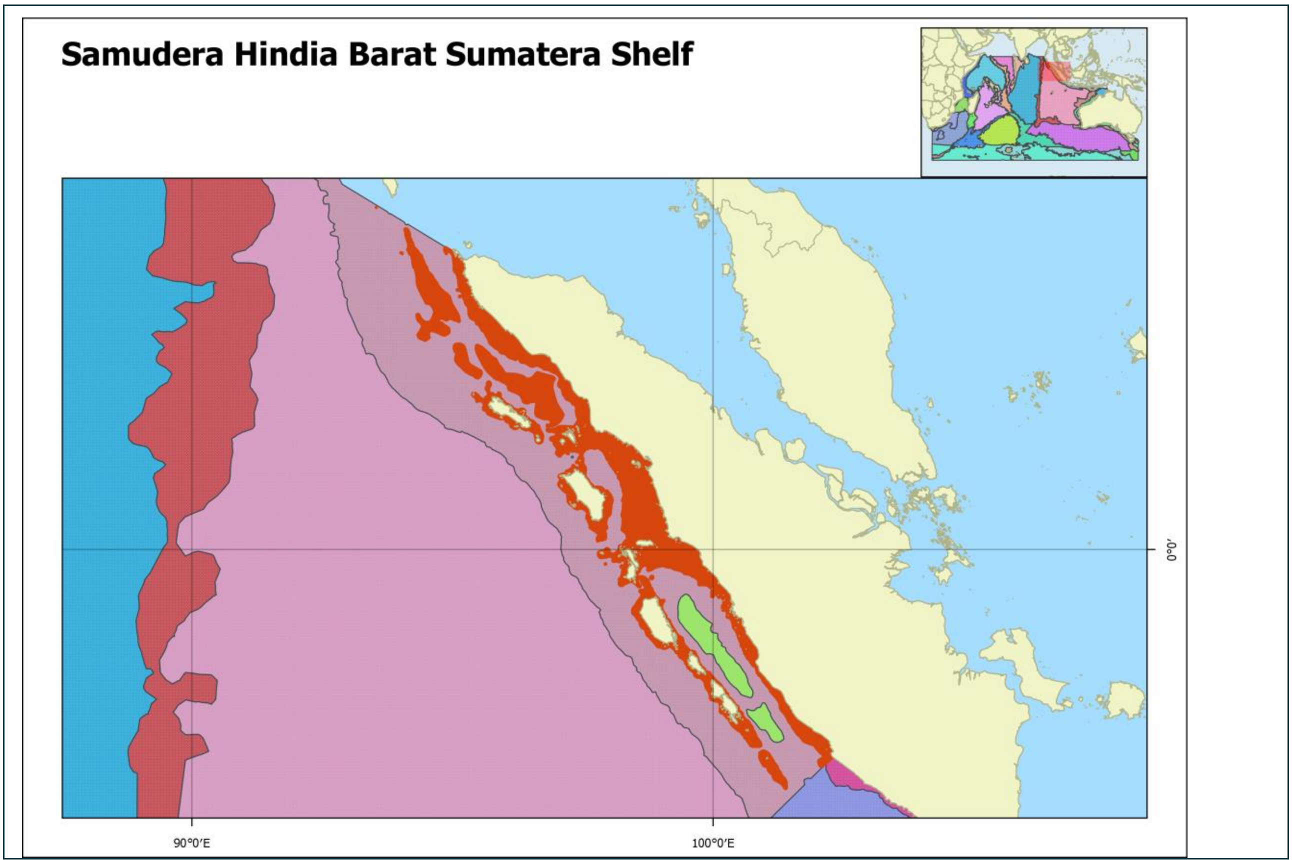


Figure 22: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.3.3 South West Sumatran Shelf (Samudera Hindia Barat Sumatran) Province



The Samudera Hindia Barat Sumatran Shelf Province has the same boundaries and characteristics as described in Brewer et al (2015). The Samudera Hindia Barat Sumatran (West Indian Ocean of Sumatra) Shelf Province is a relatively narrow, steep shelf running along the western coastline of Sumatra. It is a complex shape due to the shallow ridge running offshore from the Sumatran mainland. It is bordered to the north by the Andaman and Nicobar Ridge Province and to the west by the Samudera Hindia Barat Sumatran Slope Province, with which it has a complex boundary. The adjacent slope province is also relatively narrow and adjoins the Cocos Abyss Province. The southern boundary of the South West Sumatran Shelf is an artificial boundary representing the southern extent of the BOBLME.

According to the Ministry of Environment of the Indonesia Republic, 2013, The Indian Ocean of West Sumatra includes the Indian Ocean. The ecoregion is located on the West Coast of Sumatra and Aceh Province with an area of 782,861 km2. The distinctive feature of this ecoregion is that it has circulating currents and water masses formed due to contrasting bathymetry conditions, namely by the canal trough of the Java Trench which is connected to the western Indian Ocean and basin waters on the West coast of Sumatra. There is a unique phenomenon of the propagation of the Wyrtki Jet and Coastally Trapped Kelvin Waves due to the influence of the Equatorial currents generated by the Indian Ocean monsoon wind which is closely related to the periodicity of upwelling and downwelling in this ecoregion. In the East Monsoon, Southeast winds that move parallel to the West Coast of Sumatra will cause upwelling phenomena. Whereas in the Transitional I and II Monsoon, there are equatorial currents generated by propagating Kelvin waves from the Indian Ocean to the east then pounding the western part of Sumatra. The current then splits towards the southwest (Bay of Bengal) and heads southeast along the West Coast of Sumatra to the south of Java and Nusa Tenggara.

The salinity ranges is around 34 psu with temperature of around 27^{o}C at the surface, and same range of salinity with temperature of around 7^{o}C at 1000m depth (Bernawis et al, 2018).

This ecoregion is part of the Sunda shelf. The bathymetry comprises of continent shelf, slope, and deep sea shelf down to 5.500 m. The tide here is mix tends to semidiurnal type according to the Geospatial Information Agency of Indonesia.

This sub region is having high biodiversity because of the nutrient supply as a result of the upwelling. It is also considered as the largest deposit of reef in Indonesia with limited distribution in the Indian, South of Java and East of Nusa Tenggara. Some of the coral species is reported to be originated from the Phuket of Thailand and not found anywhere else.

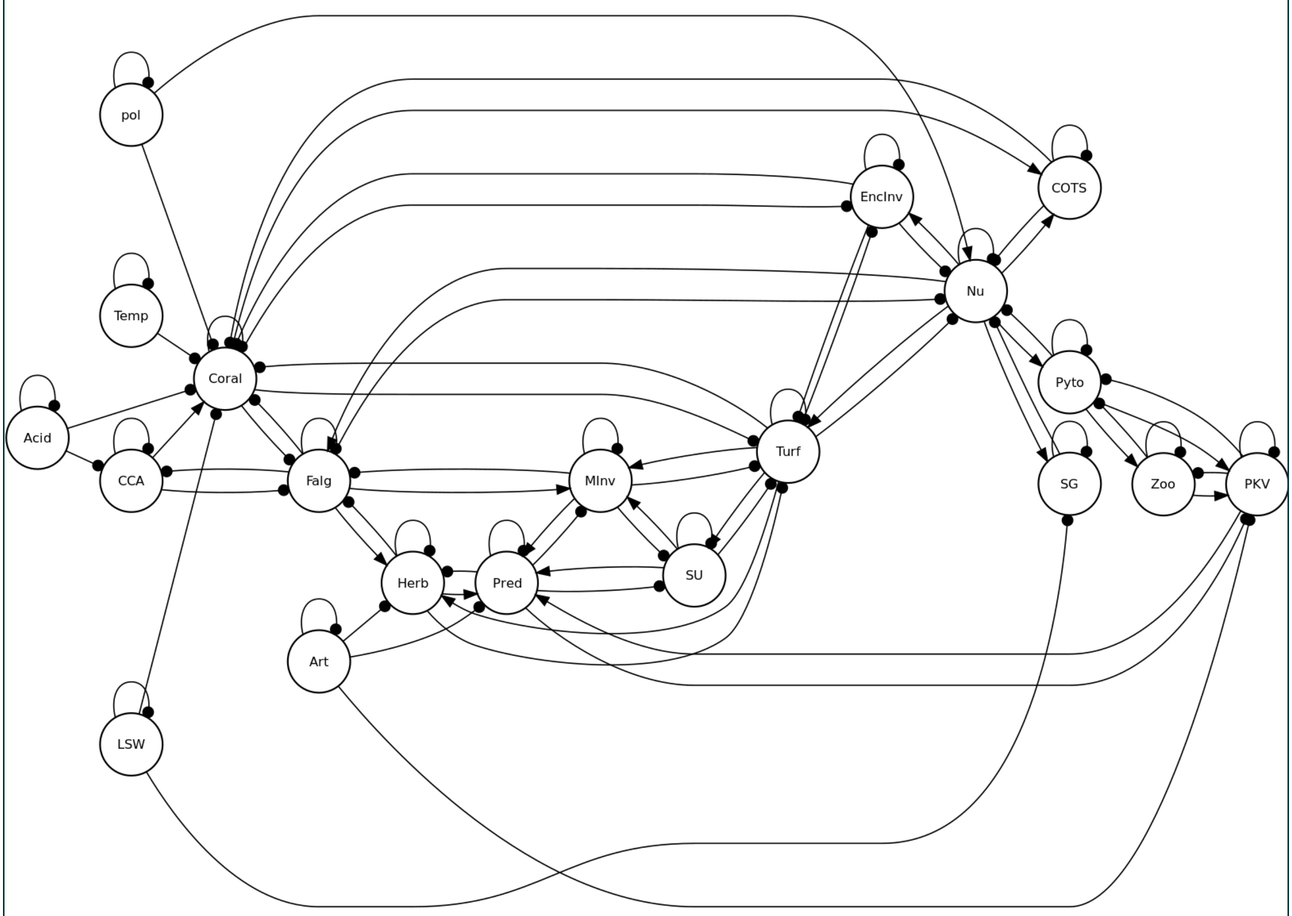


Figure 23: Ecosystem components in the qualitative model are: CCA (CCA), CoralPredators (COTS), Coral (Coral), Fleshy Algae (Falg), Mobile Invertebrates (MInv), Predatory Fish (Pred), Planktivores (PKV), Herbivorous Fish (Herb), Sea Urchins (SU), Turf Algae (Turf), Nutrients (Nu), Phytoplankton (Pyto), Seagrass (SG), Zooplankton (Zoo) . Pressures acting on the system are: Encrusting Invertebrates (EncInv), Low Saline Water (LSW), Pollution (pol), Artesinal Fisheries (Art), Temperature (Temp), Acidification (Acid)

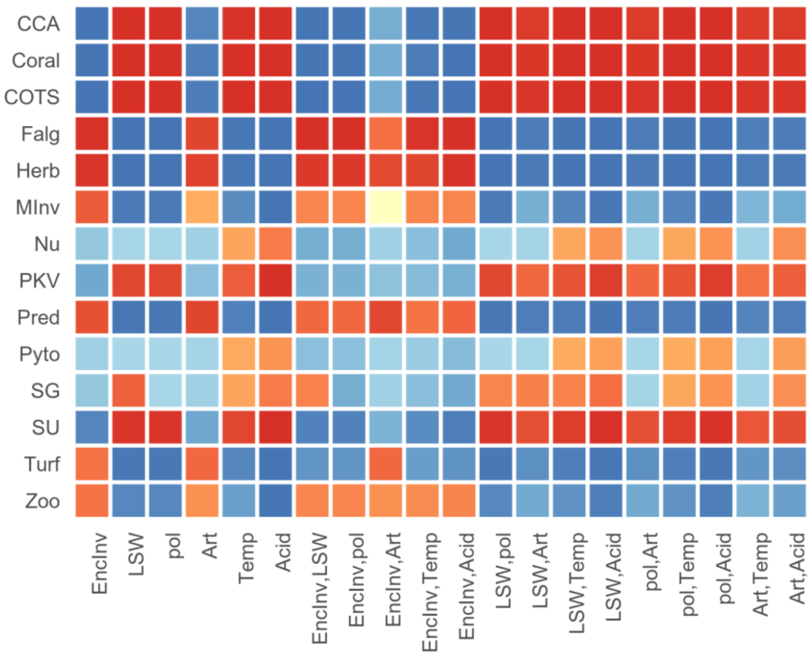
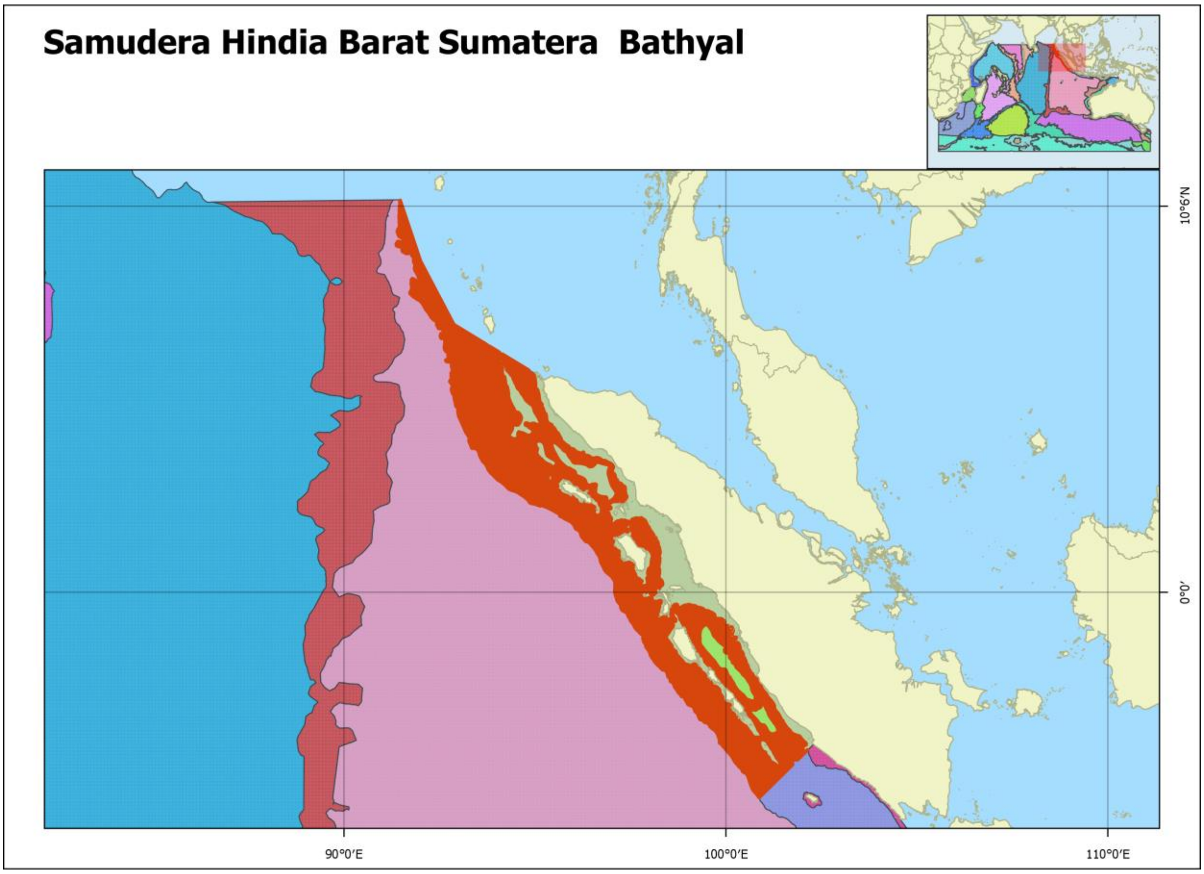


Figure 24: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.3.4 South West Sumatran (Samudera Hindia Barat Sumatran) Bathyal Province



The Samudera Hindia Barat Sumatran bathyal Province has the same boundaries and characteristics as described in Brewer et al (2015). The Samudera Hindia Barat Sumatran Slope Province is a narrow, steep slope between the Samudera Hindia Barat Sumatran Shelf and the Cocos Abyss. To the north is the Andaman and Nicobar Ridge Province with the boundary defined by the southern extent of the ridge. The southern boundary is an artificial boundary representing the southern extent of the BOBLME. Its eastern and western boundaries are defined by bathymetric delineations between shelf and slope (200 m) and between slope and abyss (2000 m).

The deep sea fisheries exploration in 2003 by The Republic Indonesian Ministry of Marine Affairs and Fisheries found some spesies demersal fishes and shrimps in the 500 - 1000 m depth. The demersal fishes such as: *Caelorinchus divergens*, *Beryx splendens, Hoplostetus sp., Hoplostethus melanopus, Diretmoides pauciradiatus*, and the deep sea shrimp species which founded in more than 700 m depth such as: *Heterocarpus sp, Aristeus virilis, Achanthephyra armata, Plesiopenaeus edwardsianus*. (Wudianto, 2004).

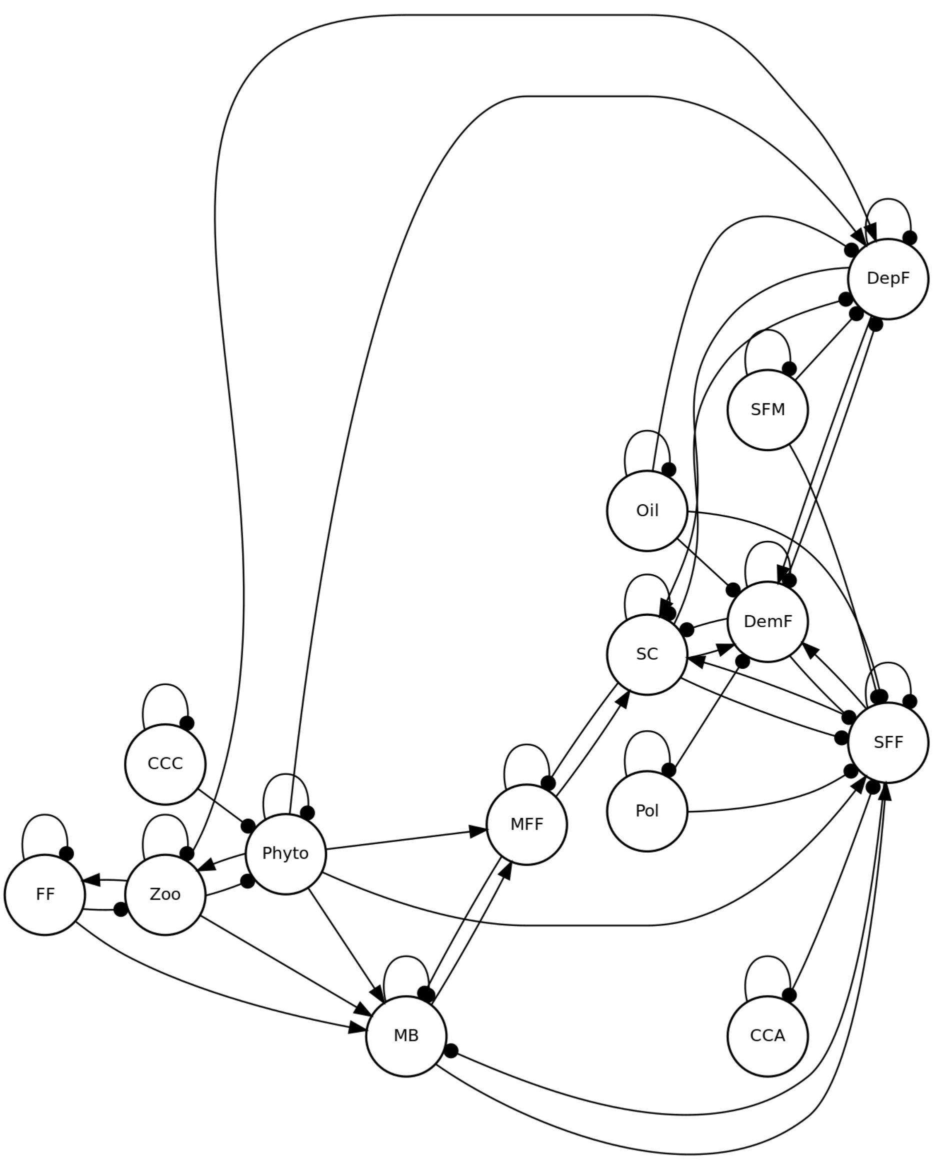


Figure 25: Ecosystem components in the qualitative model are: Food Falls (FF), Microbes (MB), Phytoplankton (Phyto), Zooplankton (Zoo), Deposit Feeders (DepF), Demersal Fishes (DemF), Scavengers (SC), Mobile Filter Feeders (MFF) . Pressures acting on the system are: Sessile Filter Feeders (SFF), Seafloor Mining (SFM), Climate Change Chlorophyll (CCC), Climate Change Acidification (CCA), OilSpills (Oil), Pollution (Pol)

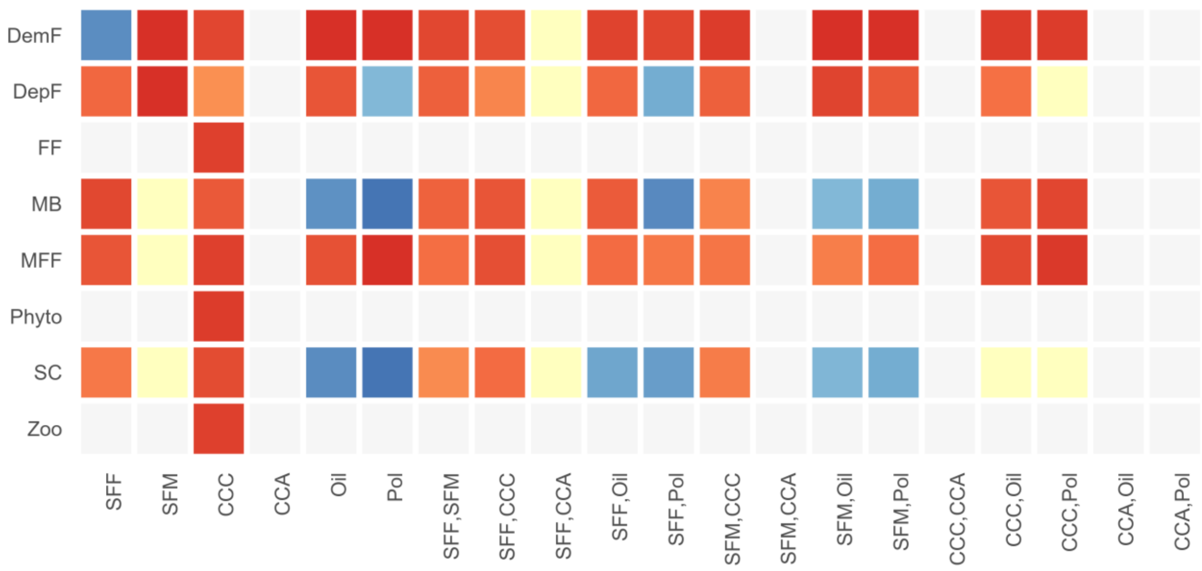
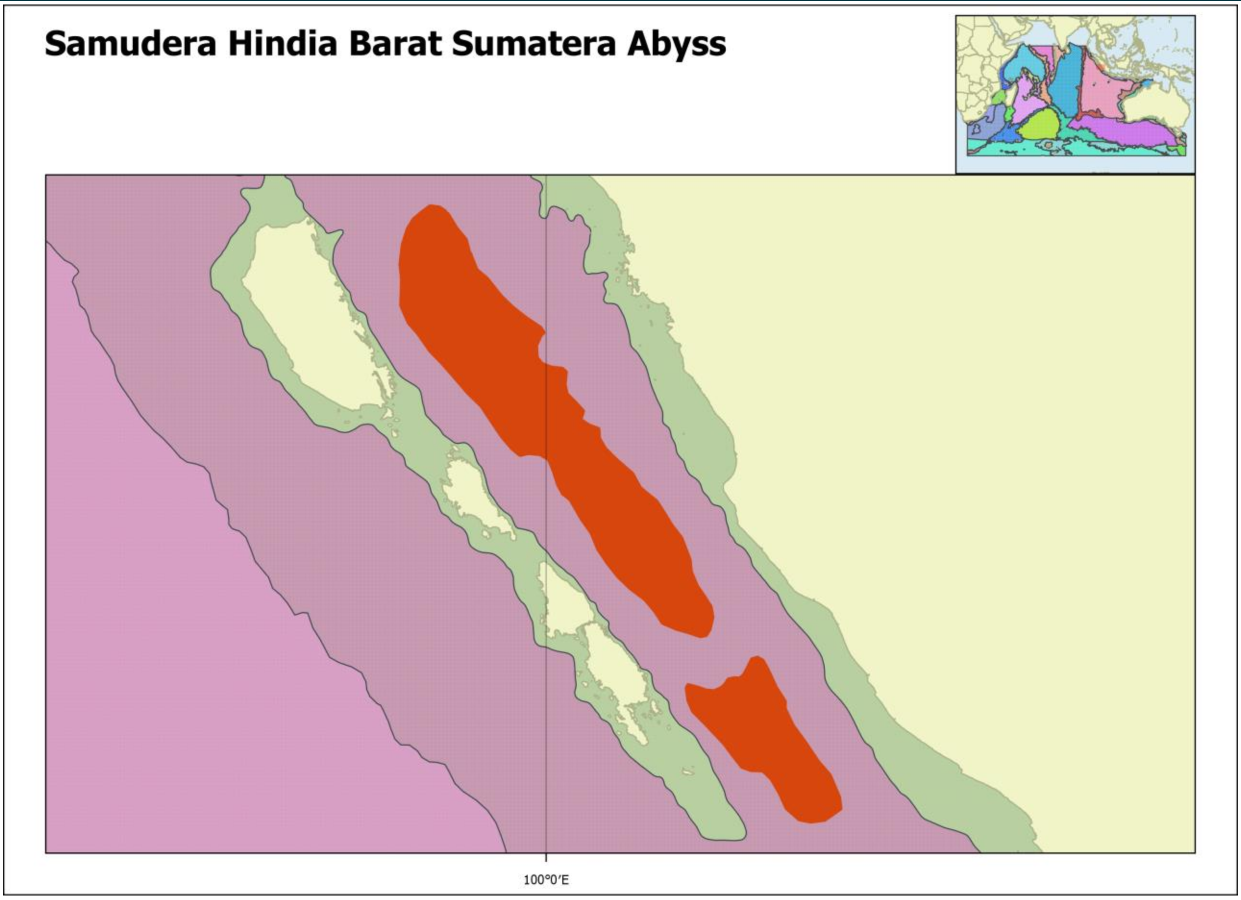


Figure 26: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.3.5 Samudera Hindia Barat Sumatran Abyss Province



This part is referred to as abyss due to its more than 3500 m depth. The monsoon is governing this region. Within the transitional period of the monsoon the Wyrtki jet applies to the sub region. The Wyrtki jet is an extension of the Indian Ocean North Equatorial Counter Current, when it reaches the tip of Sumatra Island it may have bifurcation; parallel along the west Sumatra coast and the other goes up north to the Malacca strait. Some of the main demersal catch in this subregion is the red snapper and shrimp, *nakamuraginme (Diretmoides pauciradiatus)* and *Hiuchi red (Hop/ostethus crassispinus)* according to Ali Suman (2008). The difference of demersal catch between west Sumatra and South of Java is presumably due to the difference of the bottom topography. It is flat and muddy in South Java and it is solid and hilly makes suitable habitat for the *Hoplosthethus, Diretmoides pauciradiatus*, and *Beryx splendens* (Anonimus, 2006)

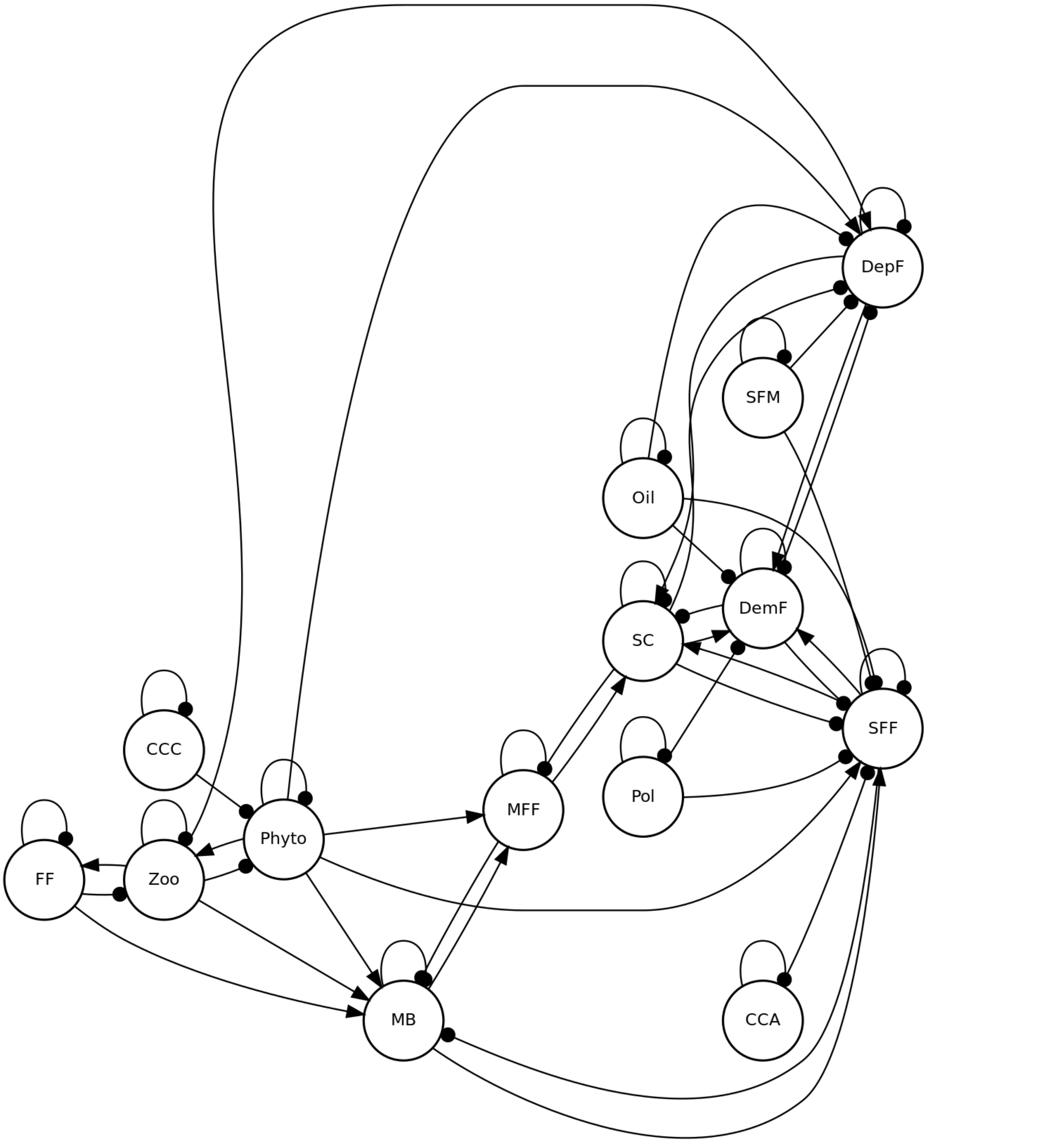


Figure 27: Ecosystem components in the qualitative model are: Food Falls (FF), Microbes (MB), Phytoplankton (Phyto), Zooplankton (Zoo), Deposit Feeders (DepF), Demersal Fishes (DemF), Scavengers (SC), Mobile Filter Feeders (MFF) . Pressures acting on the system are: Sessile Filter Feeders (SFF), Seafloor Mining (SFM), Climate Change Chlorophyll (CCC), Climate Change Acidification (CCA), OilSpills (Oil), Pollution (Pol).

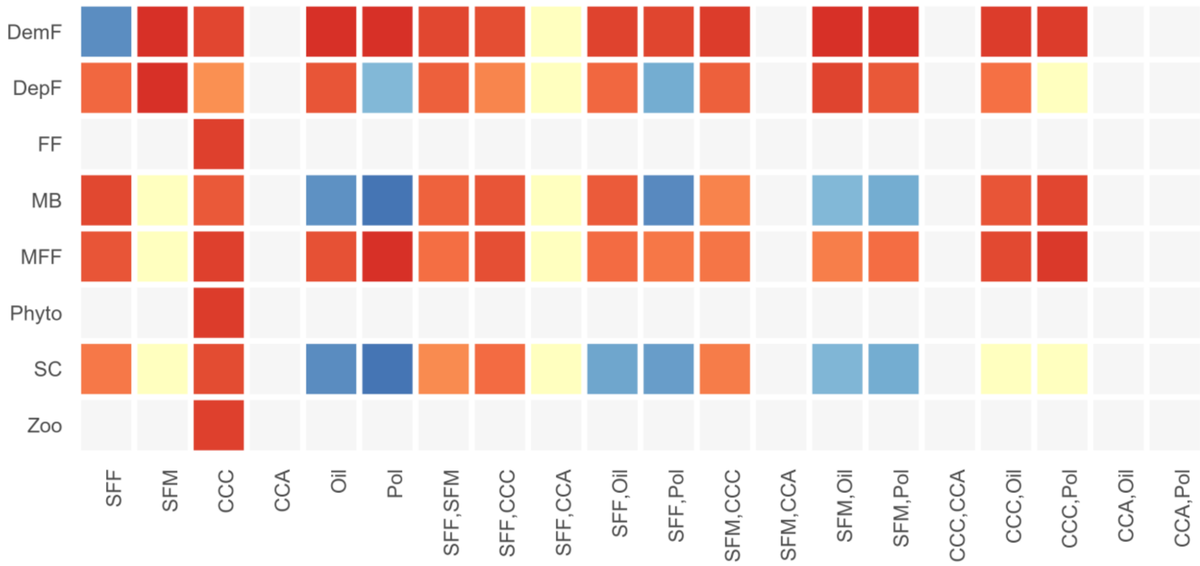
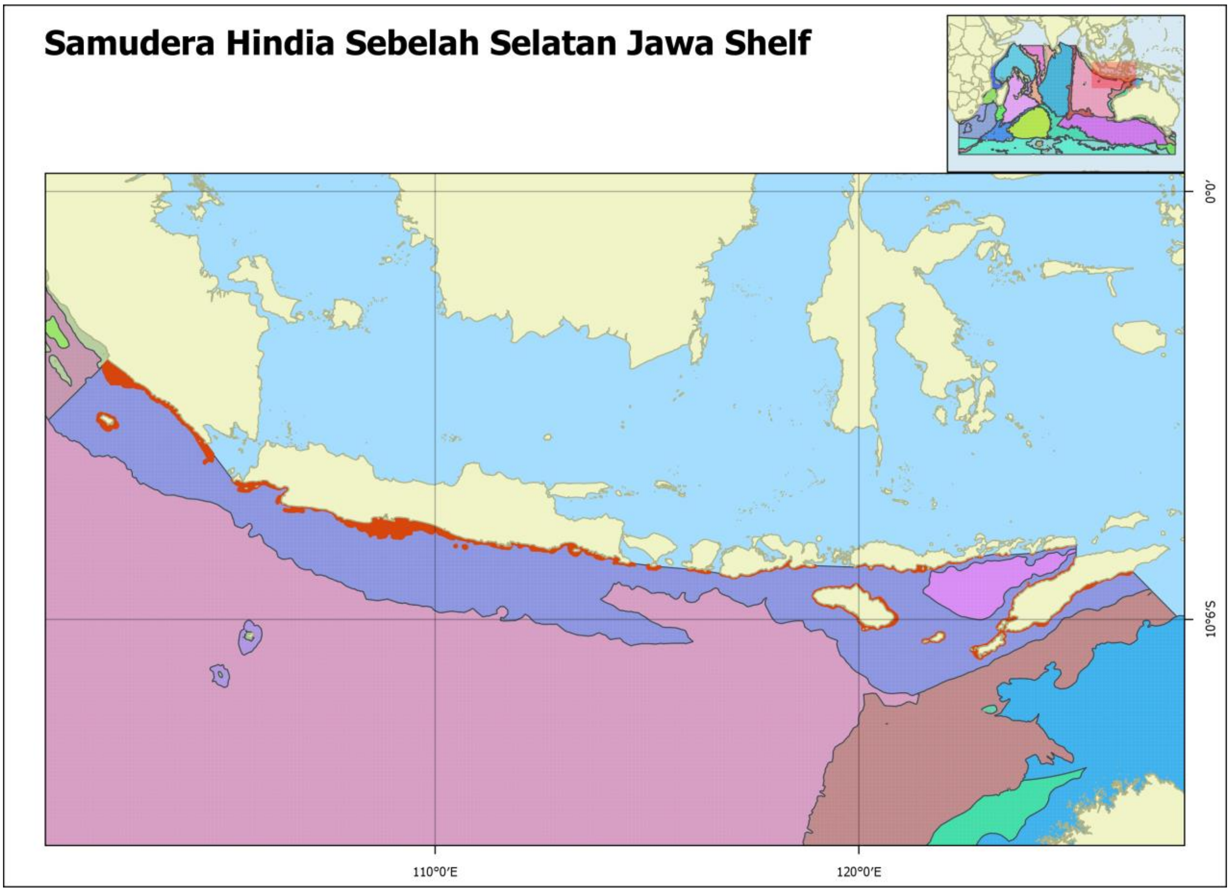


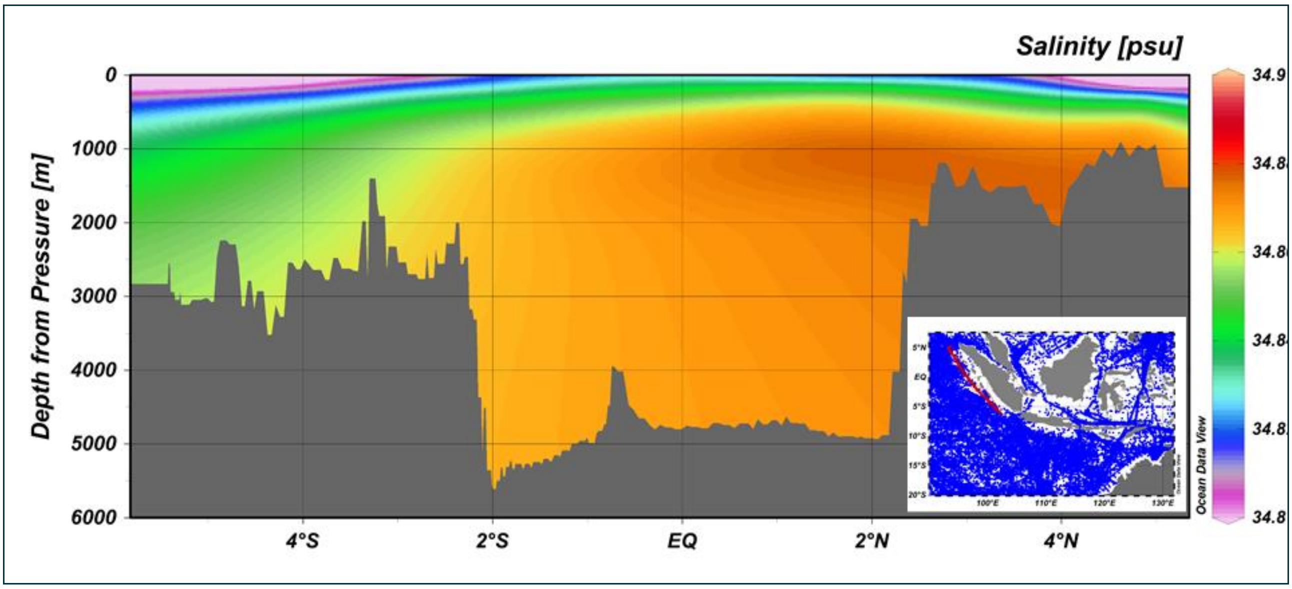
Figure 28: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.3.6 Samundera Hindia Sebelah Selatan Jawa and Perairan Bali Dab Nusa Shelf



Sea surface current in the Bali and Nusa Tenggara Shelf region mostly generated by tidal and monsoonal wind. The tidal current is dominantly by mixed tide prevailing semidiurnal (Wyrtki, 1961; Pratomo et al., 2016). The Southeast monsoonal wind which brings the Australian cold and dry wind, generating java bali and nusa tenggara coastal upwelling which is start from June, its westward propagate and endup in west Sumatra in August (Susanto et al., 2001; Pranowo et al., 2005; Tussadiah et al., 2016; Tussadiah et al., 2018).

The characteristics of this Bali and Nusa Tenggara Shelf region has variation of 27-29 ^{o}C sea surface temperature; 32-34 PSU of salinity; 4.0 – 4.7 ml/l oxygen concentration; and 8.0-8.75 of pH (Wyrtki, 1961; Boyer et al., 2009). The nutrients variation shows 0.25 – 0.35 µmol/l of phosphate; 2.5 – 12.5 µmol/l of silicate; 0.5 – 5.0 µmol/l of nitrate; and 0.25 – 0.50 µgram/l of chlorophyll (Baumgart et al., 2005; Boyer et al. 2009).



Reefs in this shelf region has a little bit disturbance from the wave dynamics. The propagation of Indian Ocean significant wave height to the reef zone and the cold water of java coastally trapped upwelling lowering growth rate of coral reefs (Adrim, 2007). In the reefs of Enggano island, there are 30 species of reef fishes, 3 species of them is endemic in Indian Ocean, i.e.: Chaetodon guttatissimus, C. triangulum and C. falcula (Adrim, 2007).

In this shelf region, especially in along South Java coastal region mostly a nursery ground for some turtle such as Eretmochelys imbricata, Chelonia mydas, Lepidochelys olivacea, and Dermochelys coriacea. Those turtle are migrating from this region, accrosing southeast Indian Ocean, to western coast of Australia (MoE, 2013).

In the eastern part of this shelf region, especially in the Banyuwangi coastal area is the beginning of Java coastal upwelling development, and it may contribute to existence of the small pelagic fish of Sardinella lemuru in Bali Strait (Pranowo et al., 2005; Xue et al., 2016; Pranowo & Realino, 2006).

Bali and Nusa Tenggara Shelf

The unique characteristics in this Bali and Nusa Tenggara Self is the existence of several inlet of the Indonesian Through Flow (ITF) such as Lombok Strait, Ombai Strait, Sawu Sea, and Timor Passage (Gordon et al., 2008; Gordon et al. 2010). The tidal type in this shelf is mixed prevailing semidiurnal (Wyrtki, 1961; Mustikasari et al., 2010; Pranowo & Wirasantosa, 2011).

This shelf have some unique bio-ecosystems, one of them is Bali Strait as play a role for Sardinella lemuru's habitat, which is not exist in other provinces (Realino et al., 2005). This shelf is the main corridor for the migration path of Cetaean such as whale and whaleshark from Pacific to Indian Oceans (Brodjonegoro et al. 2004; Realino et al., 2005; Supangat et al., 2006; Pranowo et al., 2006; Wagey & Arifin, 2008). The Whale species being reported observed in this corridor pathways such as Megaptera novaeangliae, Balaenoptera physalis, Balaenoptera borealis, and Physater catodon (MoE RI, 2013).

The existence of Dugong in the Western part of Timor island coastal area has been reported since 1997 and to be confirmed in 2004, 2007 and 2010 by interviewed to the local people, divers, and some expedition (MoE RI, 2013). Ibu Mega observed 2 Dugongs in Kupang coastal bay during an expedition with PT. Jaya Ancol Seaworld Oceanorium Jakarta (De Iongh et al., 2006). In 2007, Suharsono (pers. comm) observed Dugong during his diving expedition (MoE RI, 2013). In 2010, Kuriandewa (pers comm.) Dugong has been also observed in the coastal waters between Rote island Timor island (MoE RI, 2013).

In this shelf region, the existence of 5 species turtle has been reported by Tomascik et al. (1997) and MoE RI (2013), of them has been reported is Natator depresus (Flatback Turtle).

Wallace et al. (2001) reporting 2 species of reefs i.e.: Acropora suharsonoi and Acropora palmerae, which may a highly endemic in this shelf and having probability connection with species in western Australia coastal waters.

The variation of seawater mass and nutrient characteristics are suitable for marine lifes. According to Wyrtki (1961) and Boyer et al. (2009): sea temperature range of 26.5 – 28.0 ^{o}C; salinity range of 33.0 - 34.5 PSU; dissolved oxygen range of 4.2 – 4.7 ml/l; pH range of 8.0 – 8.25; phosphate range of 0.15 – 0.75 µmol/l; silicate 2.50 – 22.50 µmol/l; nitrate 1.0 – 9.0 µmol/l; and chlorophyll range of 0.05 – 0.50 µgram/l.

Generally, the monsoonal wind is exist in this shelf. The northwesterly and southwesterly winds blowing southeastward during west monsoon period. In contrary, during east monsoon period, the southeasterly wind moving up to northwest direction. During the transitional monsoon period, the wind direction has non paternal and has low intensity compare with the other monsoon periods (Wyrtki, 1961; Mustikasari et al., 2010).

Mustikasari et al. (2010) reported during the first period of transitional monsoon (March - May), upwelling appearing in Bali and Nusa Tenggara shelf. Weak until strong upwelling appearing in west and south of Lombok and Sumbawa islands until Sape Strait, and also reaching southern part of Flores, Sumba and Timor islands. Strong upwelling appearing in the north and south of Adonara, Siantar and Alor islands. The upwelling during East Monsoon, June - August, is the strongest among the periods. It appears in south of Bali,south and west of Lombok island, south of Sumbawa until reaching to Sape Strait. The strongest upwelling is also spread to south of Flores, Sumba, Sawu, Rote, Timor islands, and also reaching to north and southern part of Adonara, Siantar and Alor islands. During the second transitional monsoon, strong upwelling still appears in south of Bali and Lombok islands until October. Weak upwelling some time still appears in south of Sumbawa island, Sapi Strait, south of Flores, northern and southern part of Andonara until Alor.

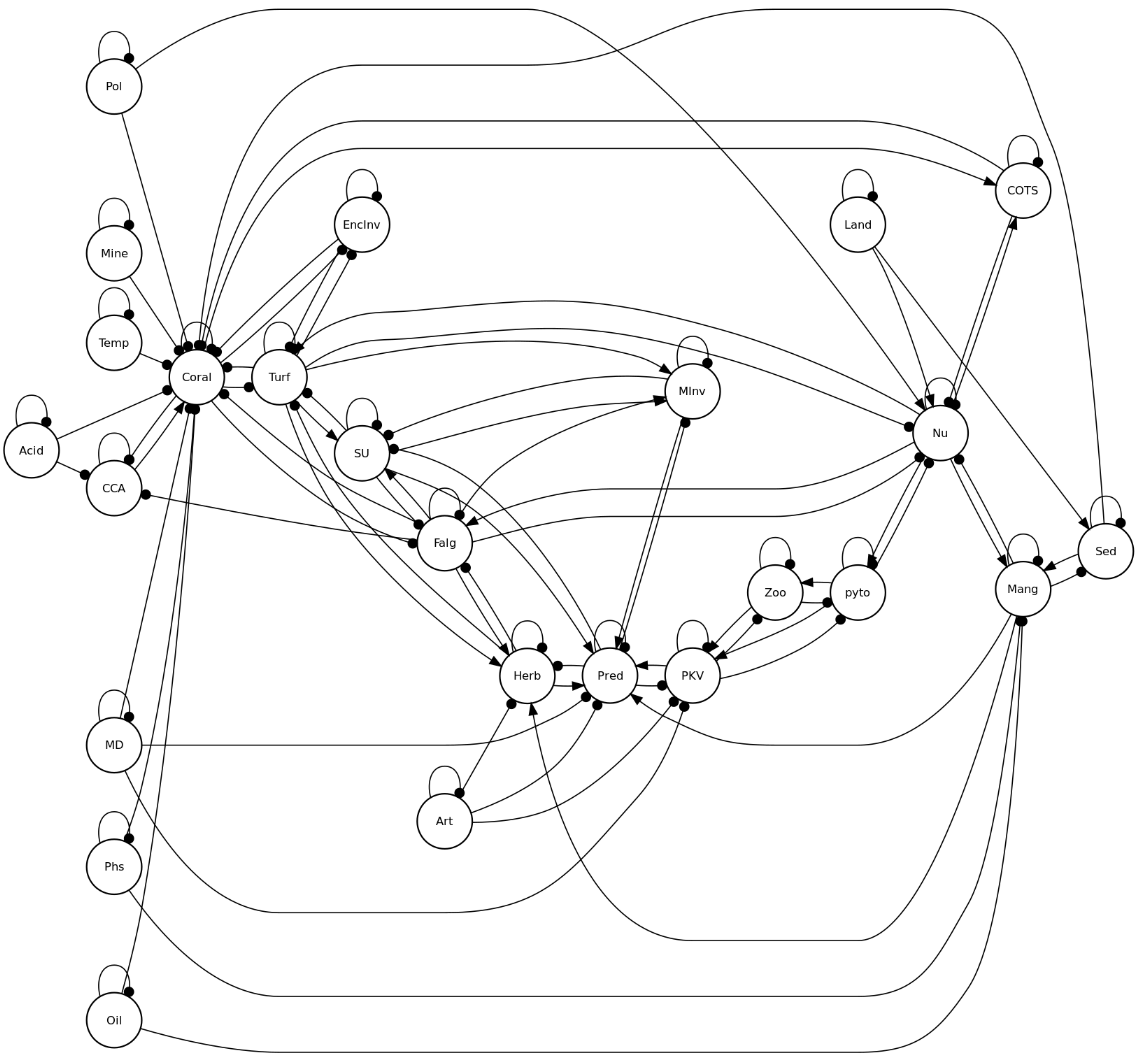


Figure 29: Ecosystem components in the qualitative model are: CCA (CCA), Coral Predators (COTS), Coral (Coral), Fleshy Algae (Falg), Mobile Invertebrates (MInv), Predatory Fish (Pred), Planktivorous (PKV), Herbivorous Fish (Herb), Sea Urchins (SU), Encrusting Invertebrates (EncInv), Turf Algae (Turf), Nutrients (Nu), Phytoplankton (pyto), Mangrove (Mang), Zooplankton (Zoo) . Pressures acting on the system are: Sediment (Sed), Pollution (Pol), Artisanal Fisheries (Art), Temperature (Temp), Acidification (Acid), Land Use Change (Land), OilSpills (Oil), Physical Disturbance (Phs), Mine Tailings (Mine), Marine Debris (MD)

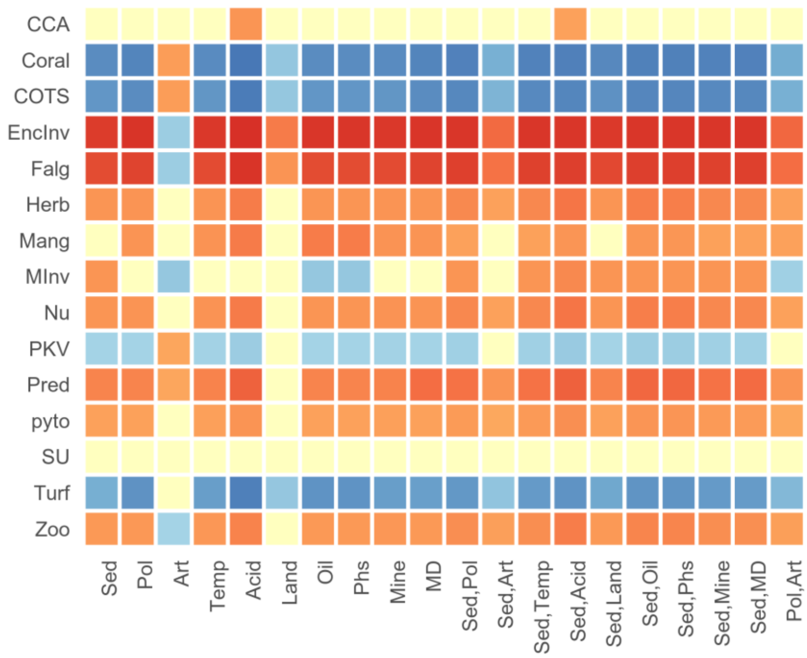
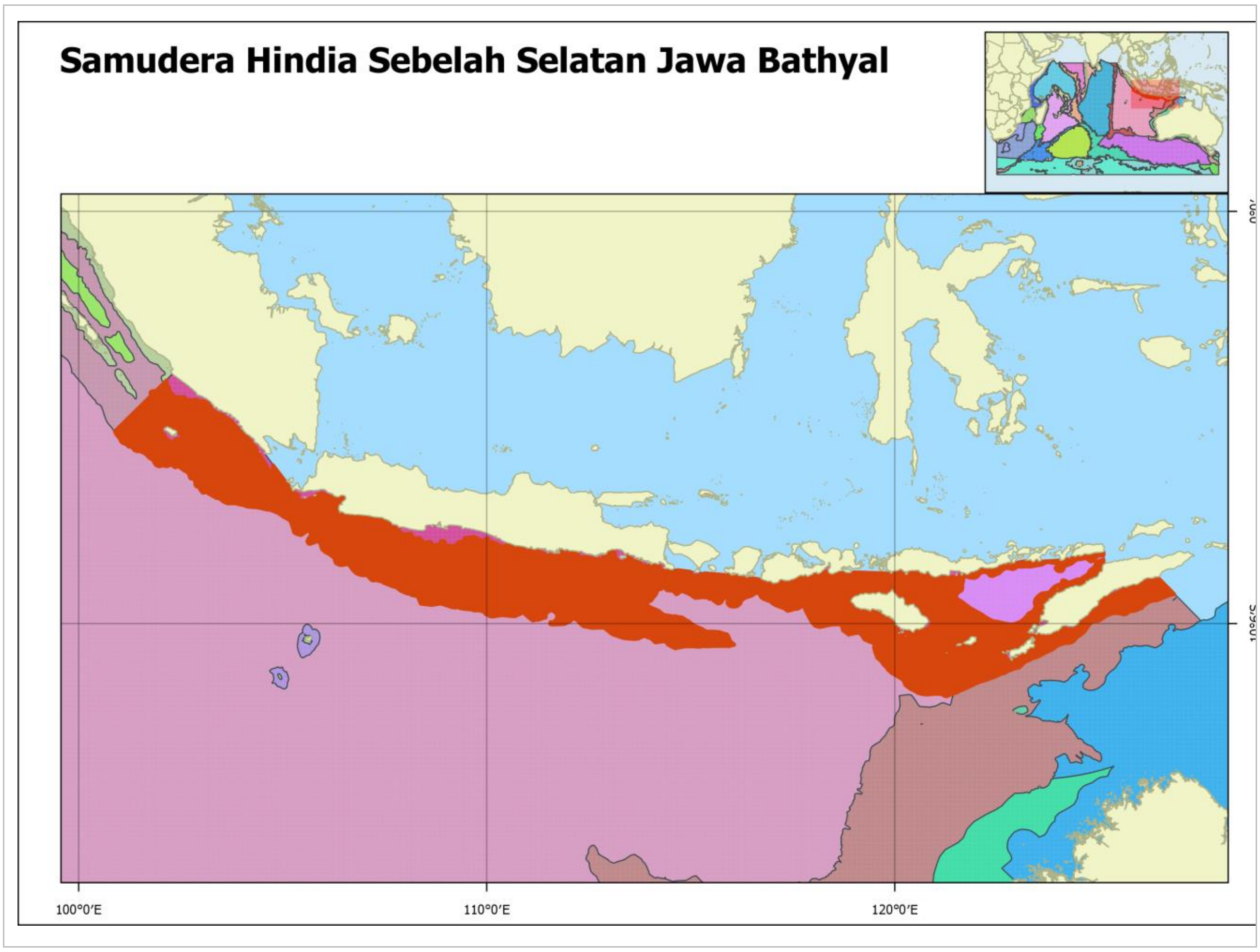


Figure 30: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.3.7 Samundera Hindia Sebelah Selatan Jawa and Perairan Bali Dab Nusa Bathyal



The deep sea fisheries exploration in 2003 by The Republic Indonesian Ministry of Marine Affairs and Fisheries found some spesies demersal fishes and shrimps in the depth more than 500. The demersal fishes such as: Trichiurus lepturus, Lampogramus niger, and the deep sea shrimp species which founded in more than 400 m until 800 m depth such as: Heterocarpus sp. (Wudianto, 2004). Other fish are Ashiro (Lamprogrammus niger'), Layur (Trichiurus lepturus), Manta (Plesiobatis sp., Plesiobatis davies) and Malakichtys griceus. The muddy bottom makes ideal habitats for those fish (Suman, 2008).

Almost all of the region is sloping from 1-3°, 3-10°, 10-20° and very steep ones >20° (Sulistyo and Suyono, 2009). This region has four basins; the Enggano, Bengkulu, Nusakambangan and Nusabarong.

This slope is linked to the Ekoregion Laut 9 in the Indonesian Marine Ecoregion and also linked to Indonesian Fisheries Management Area (WPPNRI 573). It has potential big pelagic fish about 201.4 thousand ton/year (MoE RI, 2013). The species has been reported in this slope such as big eye tuna, southern bluefin tuna, skipjack and albacore (MoE RI, 2013).

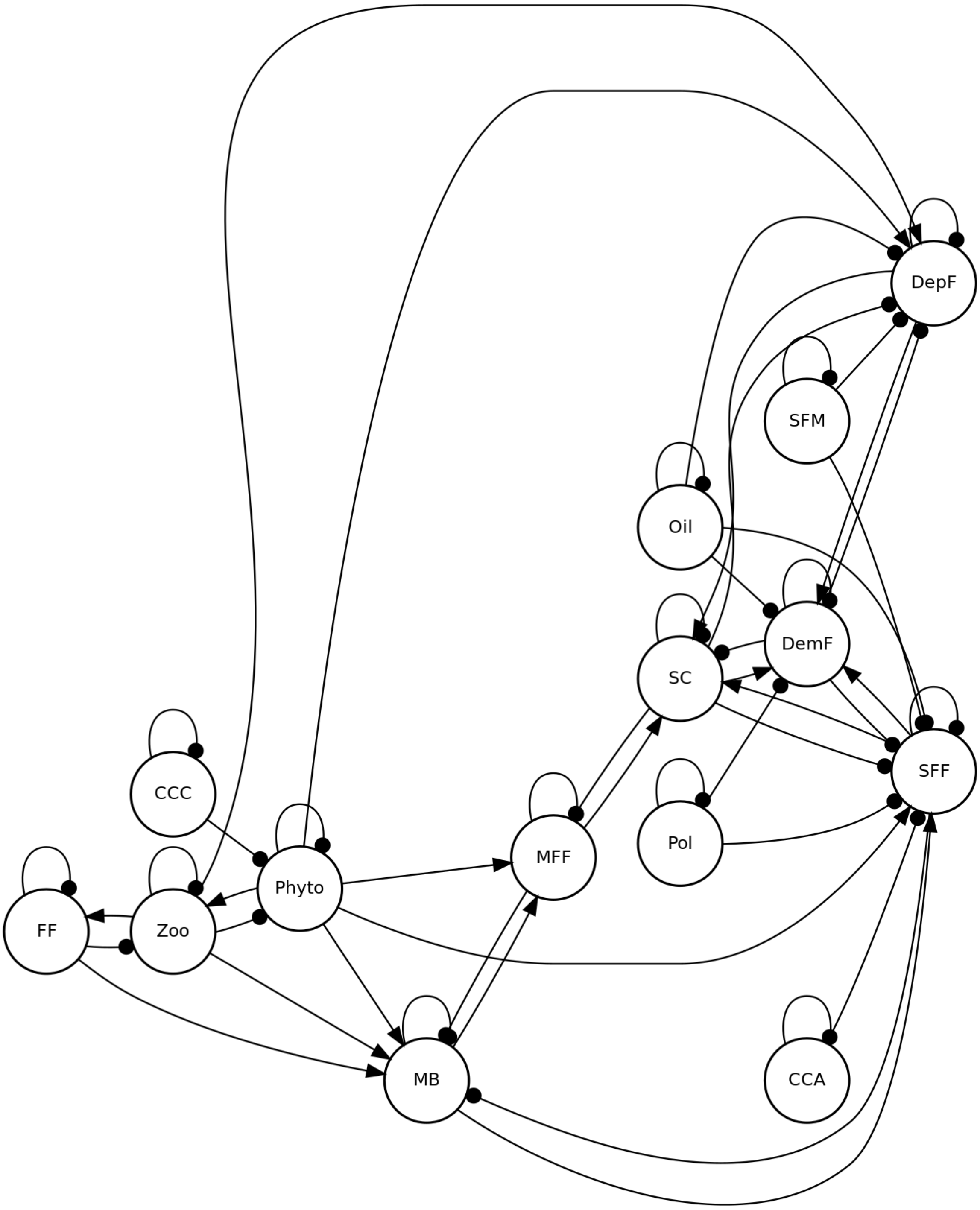
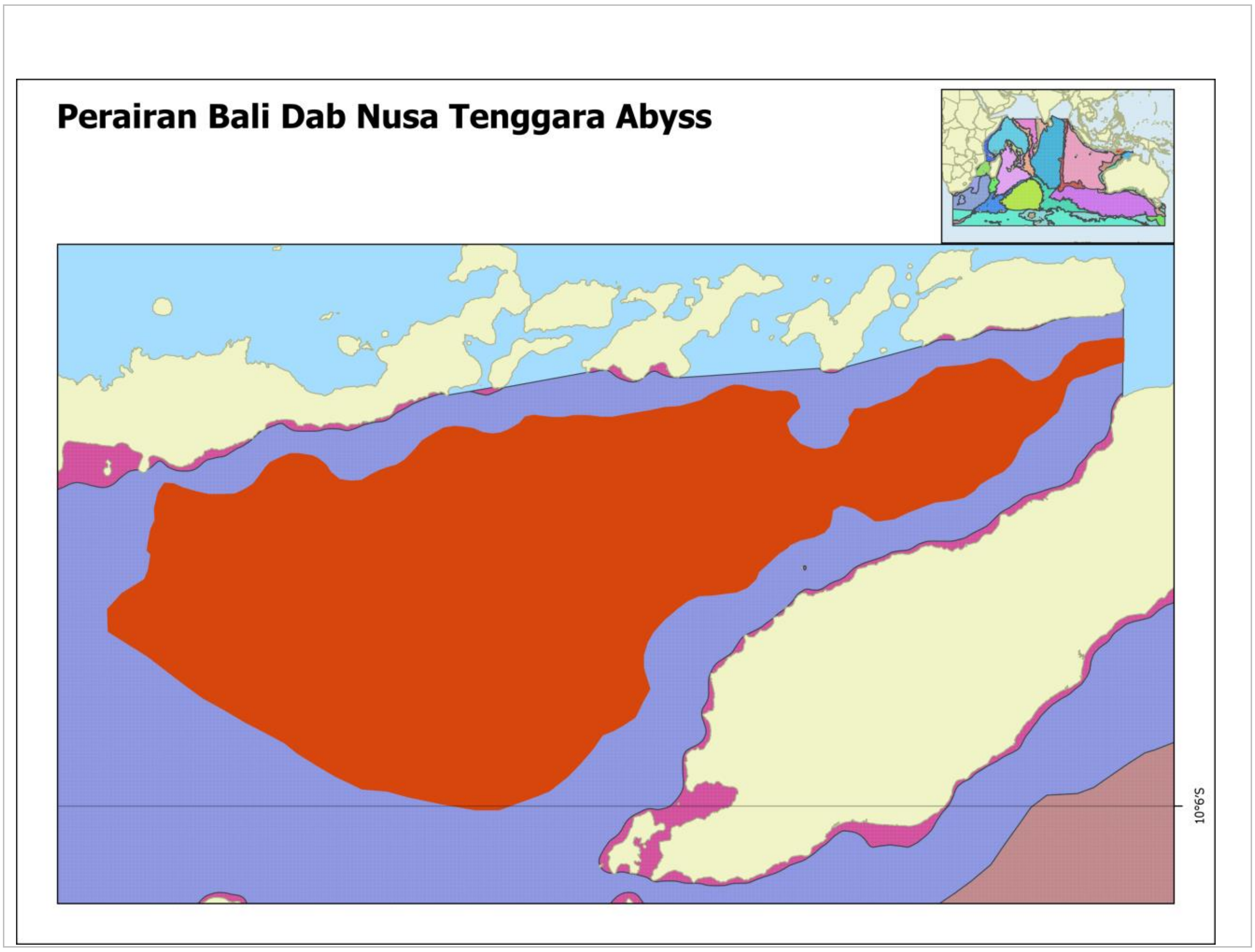


Figure 31: Ecosystem components in the qualitative model are: Food Falls (FF), Microbes (MB), Phytoplankton (Phyto), Zooplankton (Zoo), Deposit Feeders (DepF), Demersal Fishes (DemF), Scavengers (SC), Mobile Filter Feeders (MFF) . Pressures acting on the system are: Sessile Filter Feeders (SFF), Seafloor Mining (SFM), Climate Change Chlorophyll (CCC), Climate Change Acidification (CCA), OilSpills (Oil), Pollution (Pol)

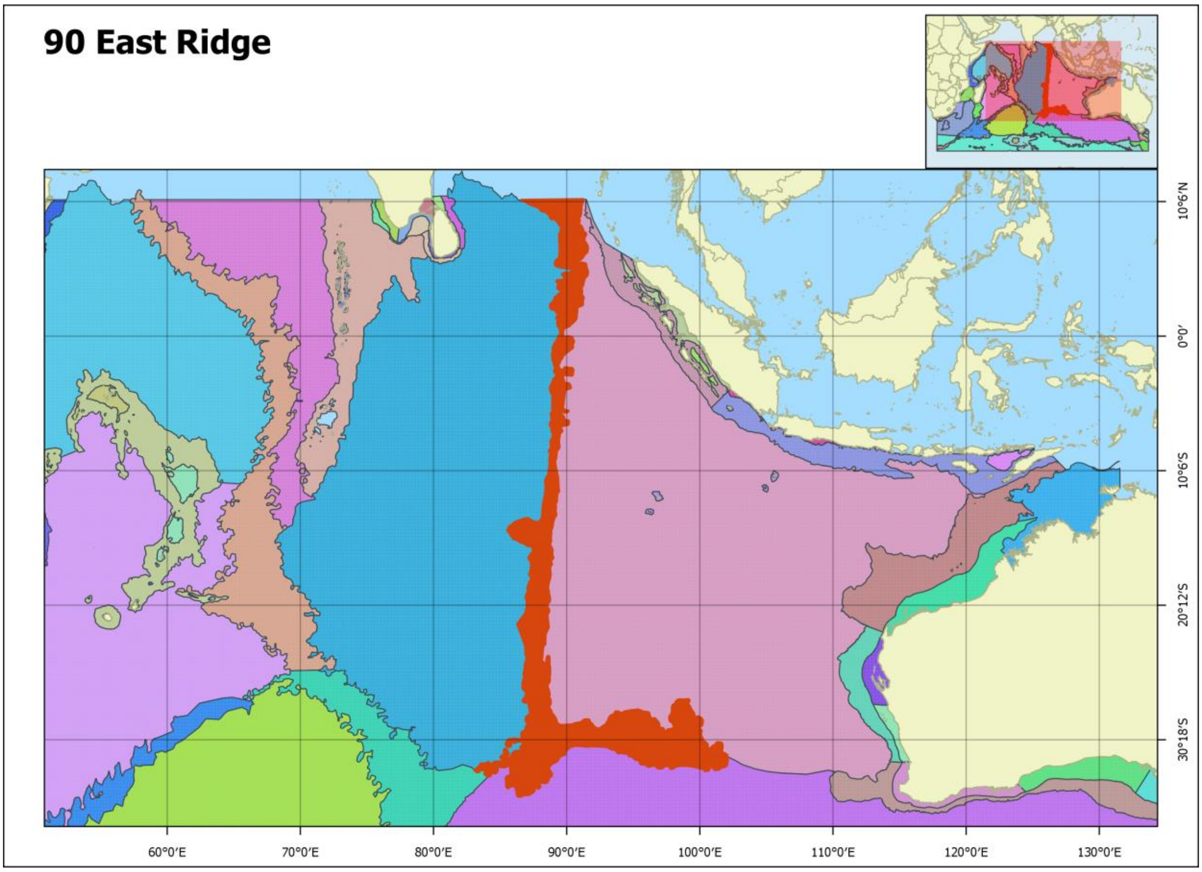
Figure 32: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.3.8 Perairan Bali Dab Nusa Tenggara Abyss



Hantoro et al. (2005) report a brittle star, foraminifera, and some shell of invertebrates and algae caught by sediment multi-corer in south of Flores and Sumba islands.

2.3.9 Ninety East Ridge Province



The Ninety East Ridge Province has the same boundaries and characteristics as described in Brewer et al (2015). Located at the south-eastern part of the Bay of Bengal, the Ninety East Ridge Province is a northern segment of an extensive ocean ridge system separating the Bay of Bengal Abyss from the Cocos Abyss. The northern boundary meets up with the Andaman Ridge. The primary distinction from the surrounding provinces is based on its geomorphology – a ridge feature dominated by plateau features – as well as depth, with most of the province raised well above the surrounding abyssal provinces. The Ninety East Ridge is a geologically separate feature to the Andaman and Nicobar Ridge feature which is dominated by slope, canyon and other geomorphological features. Hence, these two ridge systems are categorised as separate provinces.

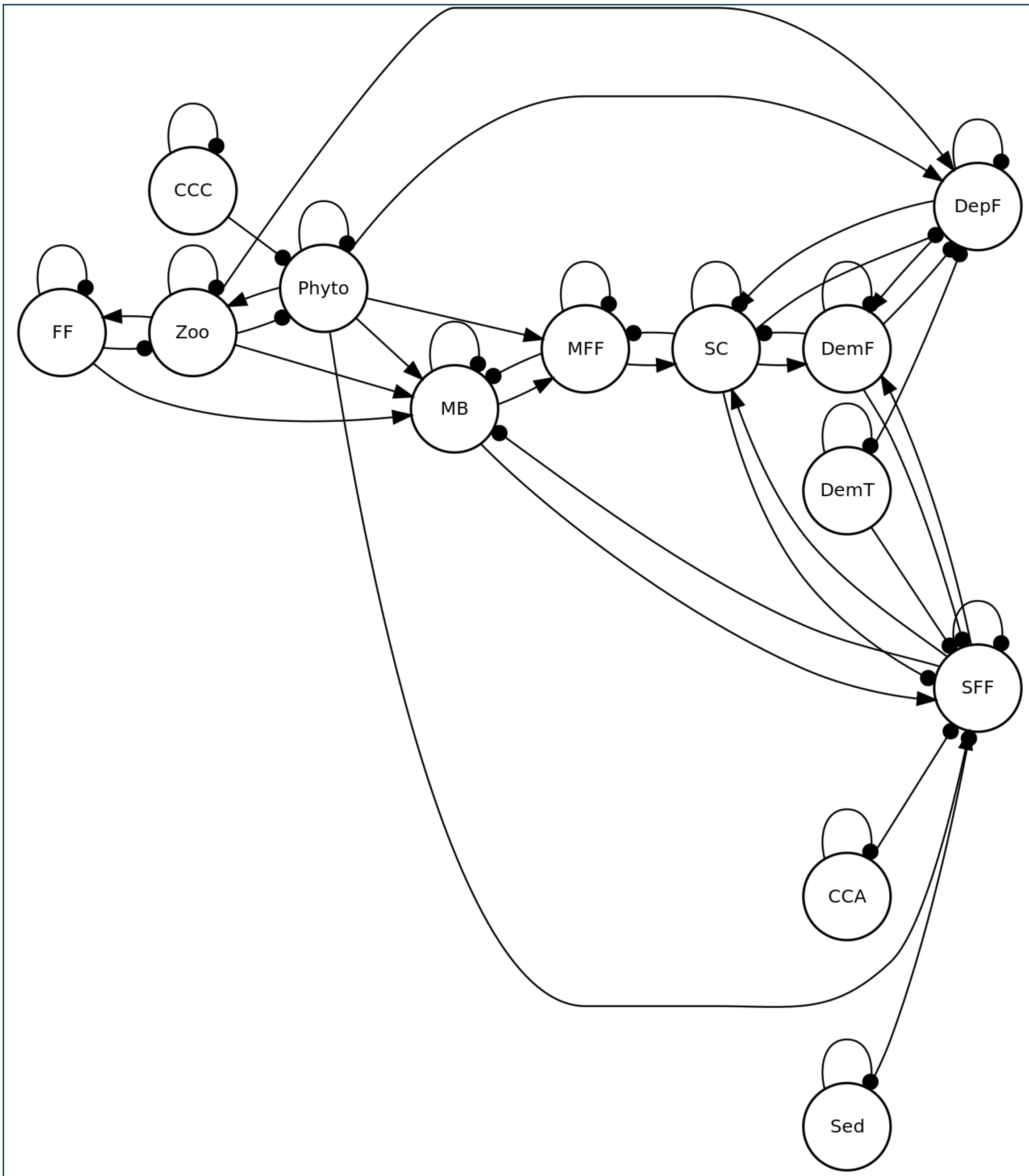


Figure 33: Ecosystem components in the qualitative model are: Food Falls (FF), Microbes (MB), Phytoplankton (Phyto), Zooplankton (Zoo), Deposit Feeders (DepF), Demersal Fishes (DemF), Scavengers (SC), Mobile Filter Feeders (MFF) . Pressures acting on the system are: Sessile Filter Feeders (SFF), Demersal Trawling (DemT), Climate Change Chlorophyll (CCC), Climate Change Acidification (CCA), Sedimentation (Sed)

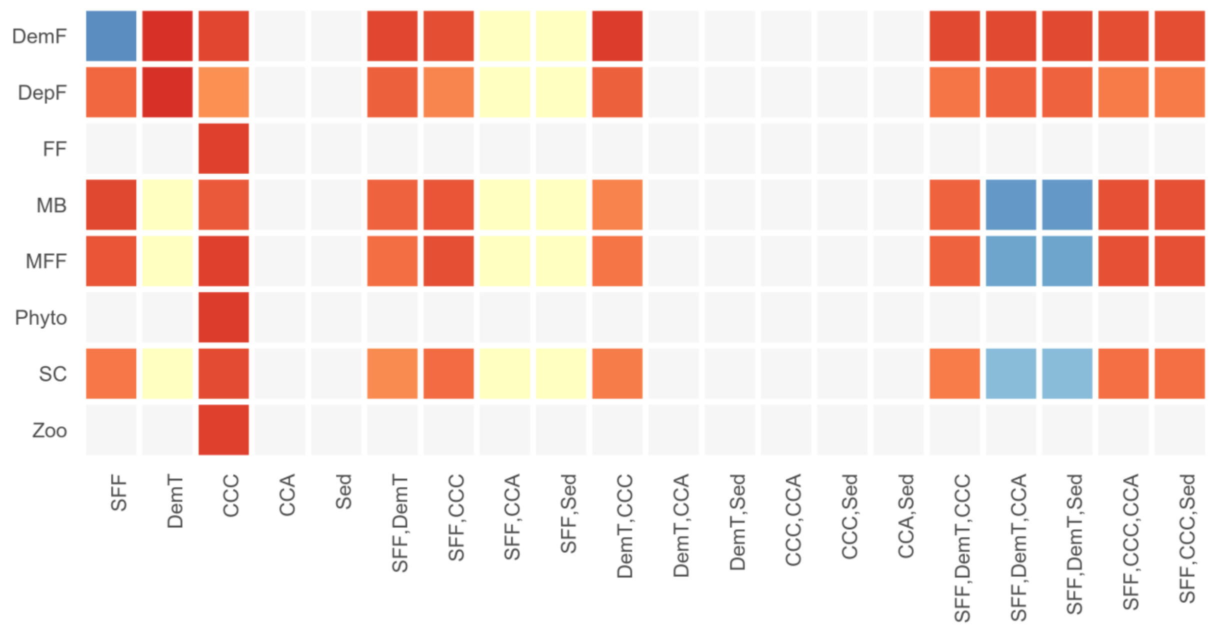
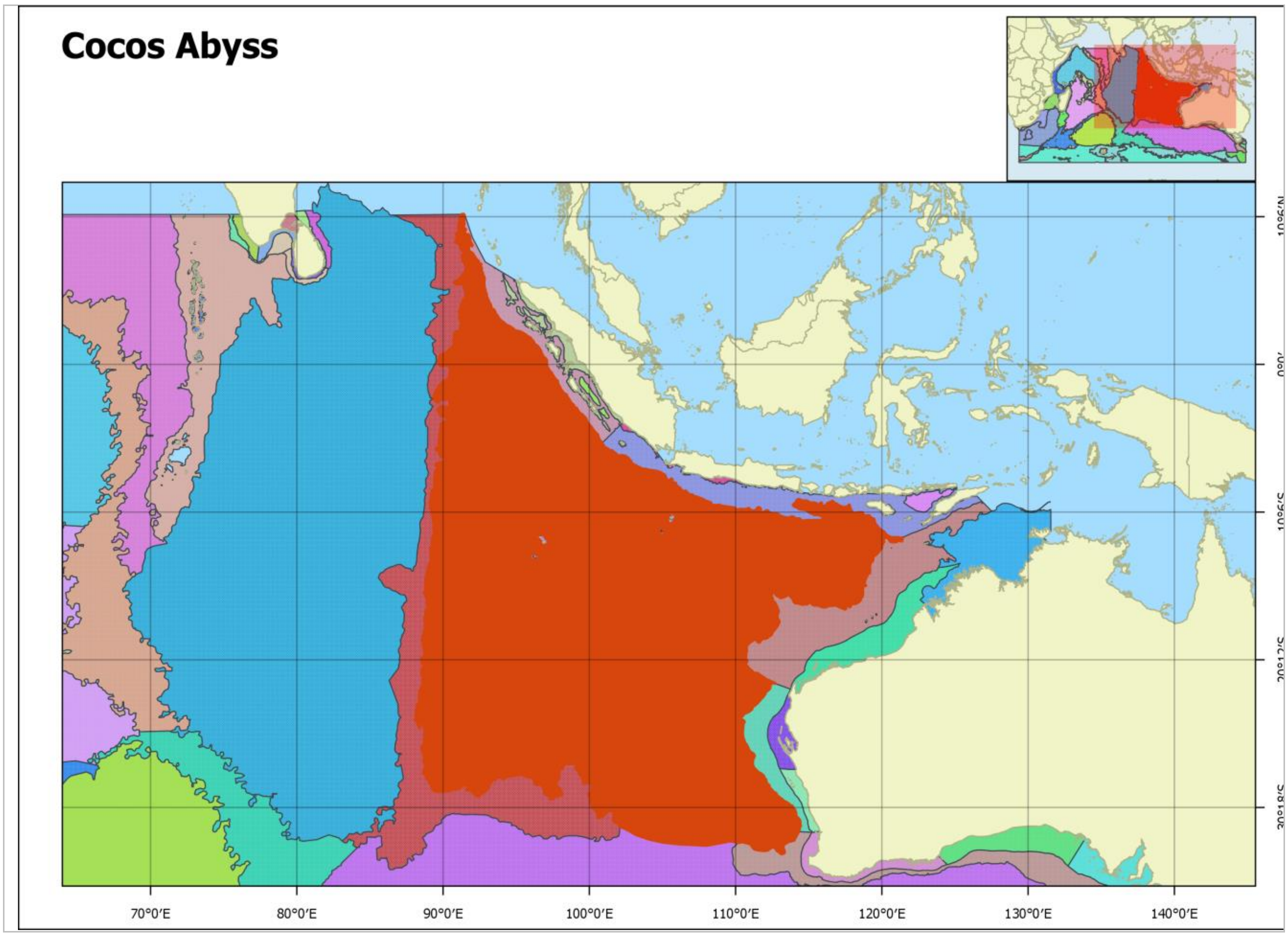


Figure 34: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.3.10 Cocos Abyss Province

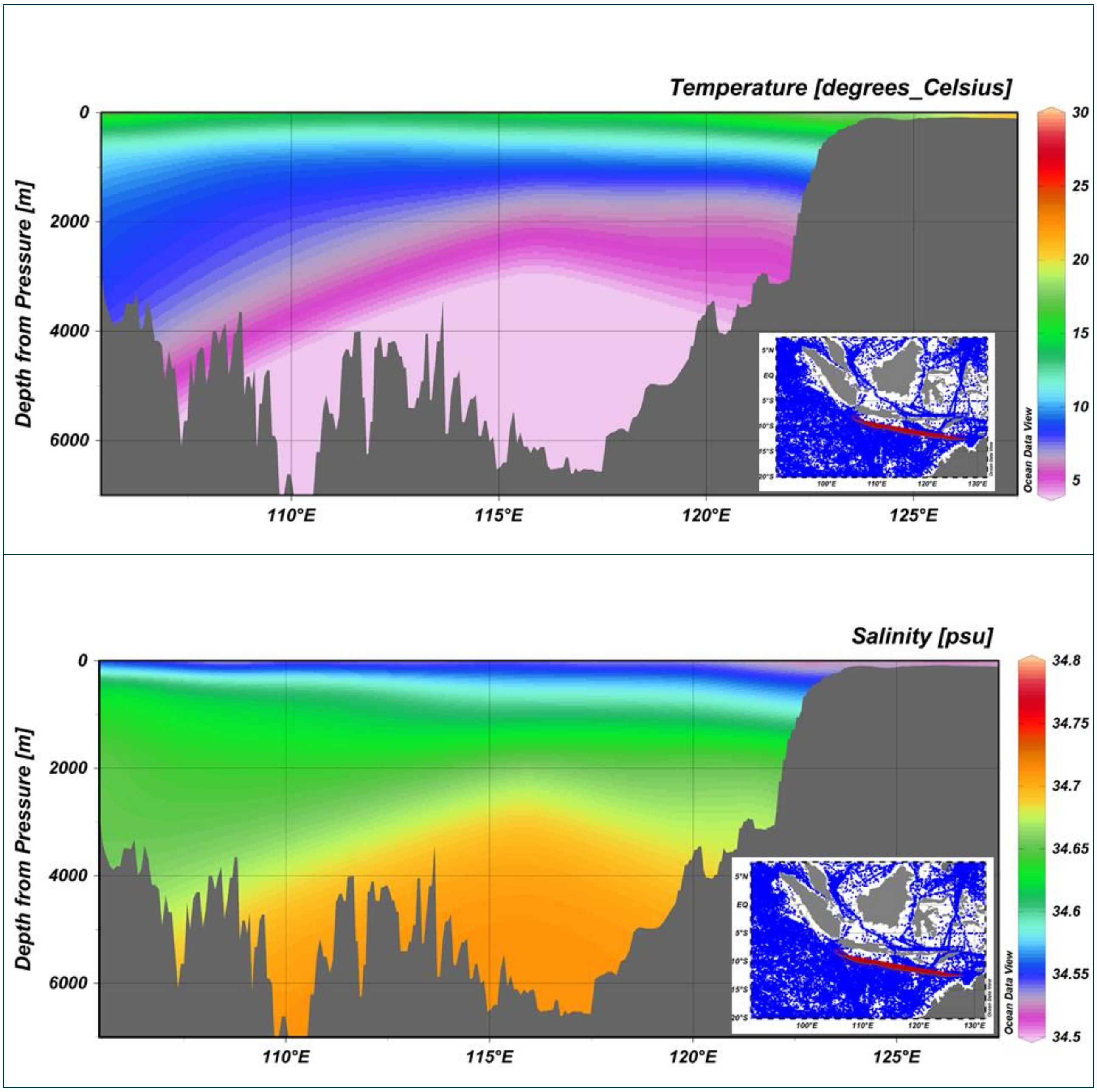


The Cocos Abyss Province has the same boundaries and characteristics as described in Brewer et al (2015). The Cocos Abyss Province is a part of a much larger province that just intrudes into the Bay of Bengal Large Marine Ecosystem (Brewer et al. 2009). The province is bounded by the Ninety East Ridge Province in the west and the Sunda Trench in the east (which is in the Andaman and Nicobar Ridge and South West Sumatran provinces). Depth is typically between 5000 and 6000 m. The semi-enclosed nature of this province suggests that the deep-ocean processes are likely to be partially confined compared to the broader scale Bay of Bengal Abyss that it neighbours. Being closer to the deep-sea topographic features (the ridges) also suggests that the seafloor processes are likely to be impacted by these features more so than the Bay of Bengal Abyss. The Andaman Ridge boundary restricts exchanges of deep-ocean waters with the Bay of Bengal Abyss, as discussed below. The seafloor and deep waters are likely to be influenced by geothermal processes, tectonic events and deep-ocean circulation and mixing. The province may contain resources and regions of unique and rare deep-ocean communities, particularly at the boundaries in the west, east and north where a number of provinces intersect.

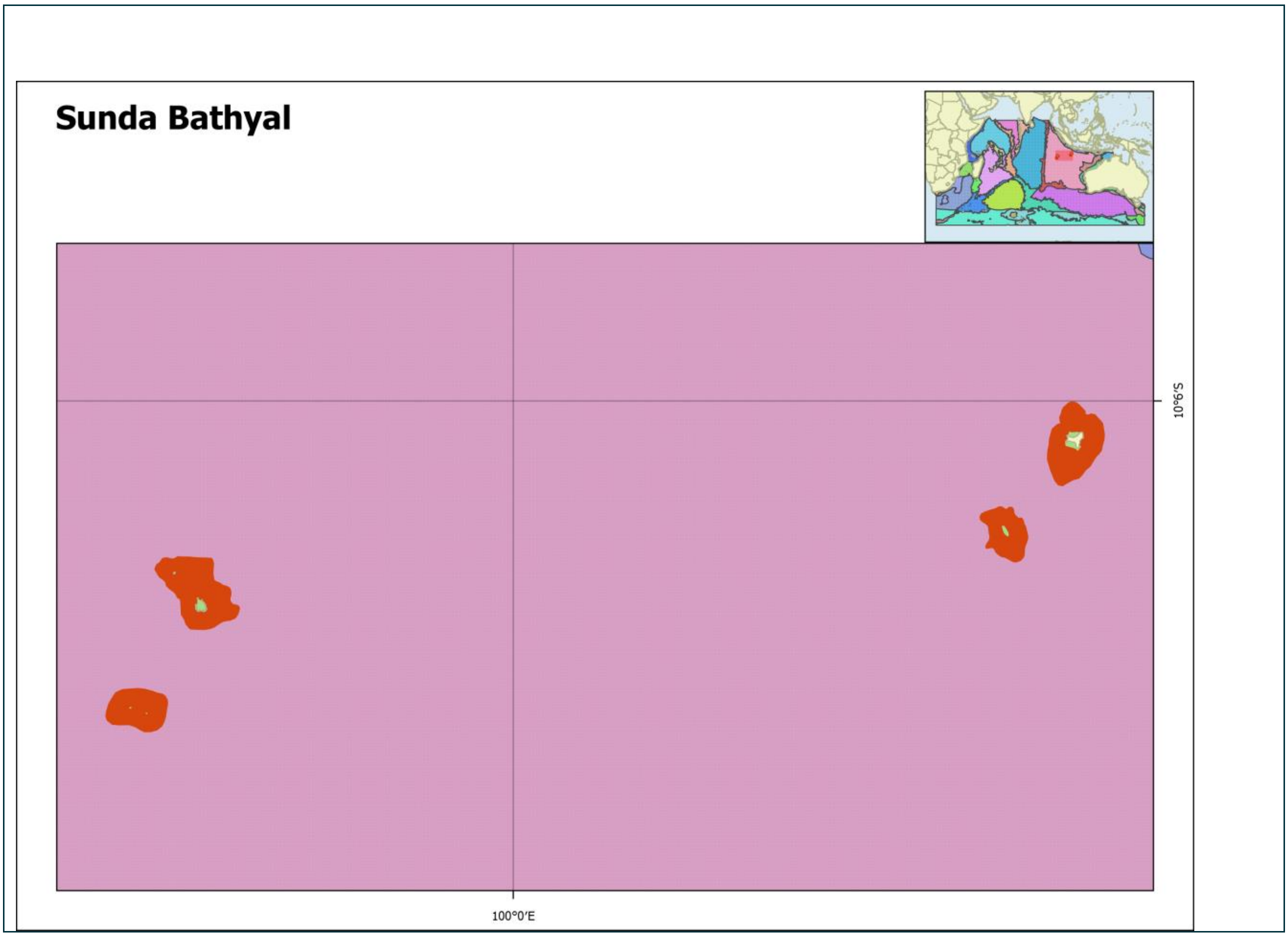
The deep sea above the abyssal plateau on the edge of the continent is potential for the commercial deep fisheries. The high biodiversity includes some species of fish, crustacea and squids (MoE RI, 2013). One of the shrimp found here is *Heterocarpus sp.*within depth of 950m.

In 2018 a joint expedition of South Java Deep Sea Biodiversity/SJADES had collected over 12.000 biota within fortnight in this part of Indian Ocean. More than a dozen of new species were found, coming from the kinds of prawns, lobsters, and hermit crabs (IIS, 2008).

Assimilation of various observation data such as ARGO, moorings, and research vessels in this region shows the temperature ranges from 7.5-5°C - 5°C from 3000m further down to 7000m. And 34.7 psu for salinity, as in figure below. The red line represents the station of data used.

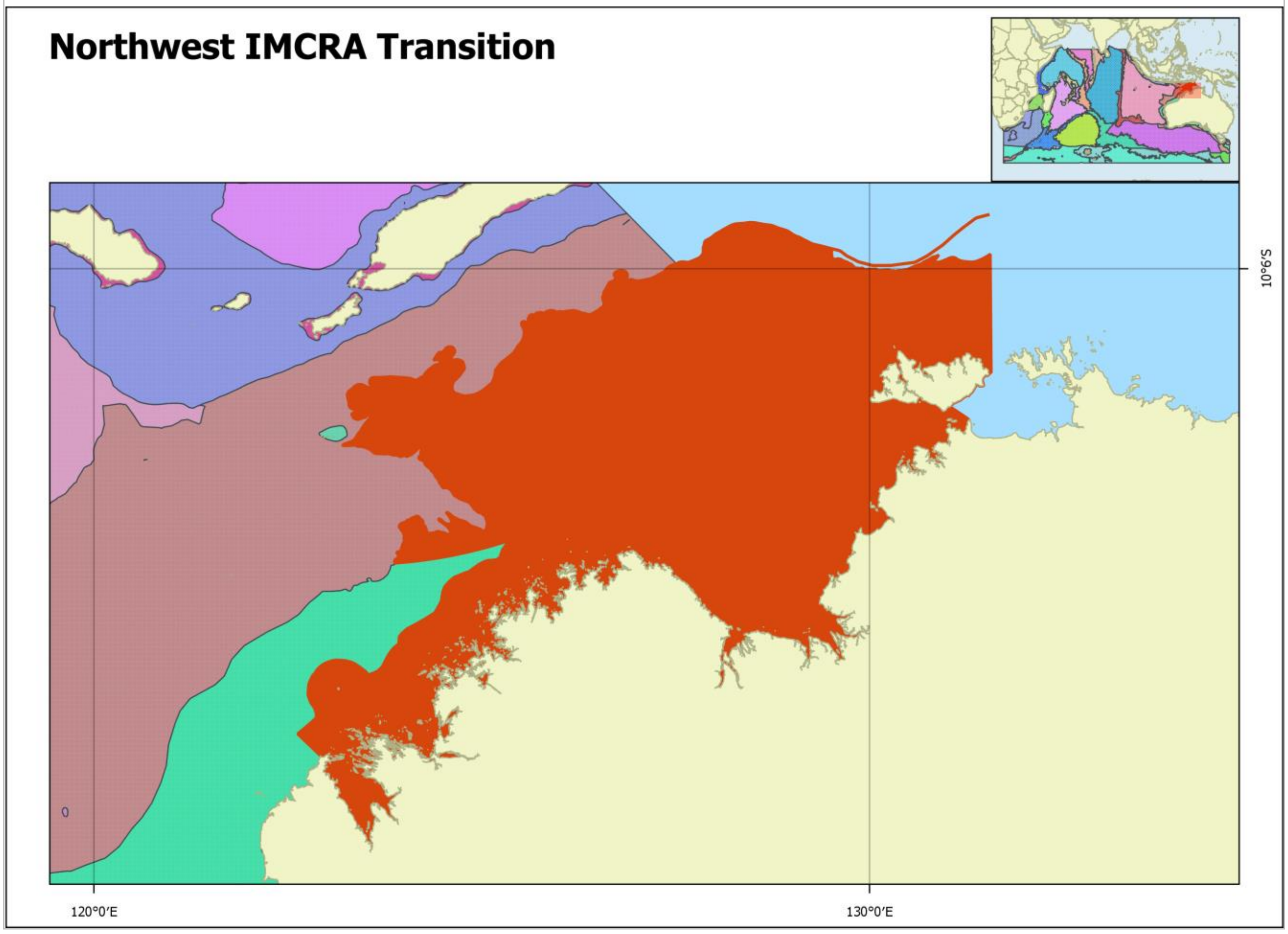


2.3.11 Sunda Shelf and Bathyal



The Sunda Shelf and Bathyal (including Cocos Keeling Islands) are a set of volcanic islands that are in the middle of the Cocos Abyss (Brewer et al. 2009). This province is strongly influence by the oligotrophic Indo-Pacific waters. There is high seasonal, biological productivity in the local region due to the presence of strong mid-oceanic currents that spawn chaotic eddies (Brewer et al. 2009). The province is geographically isolated but has a strong biological connection to the archipelagic islands to the north. More details can be found in Brewer et al. (2009).

2.3.12 Northwest IMCRA Transition



Extract from Benthic Marine Bioregionalisation of Australia's Exclusive Economic Zone (Heap et al. 2005)

This bioregion is the 2nd largest of all the IMCRA shelf bioregions.

• Class 1 includes units defined by the distribution and abundance of pinnacles, banks, and sand banks.

• This bioregion contains the 3rd largest area of Class 1 units for all of the IMCRA shelf bioregions.

• This bioregion contains the 2nd largest areas of Class 7 units of all IMCRA shelf bioregions, dominated by broad shelf terraces, and the shallow basin located in the Joseph Bonaparte Gulf.

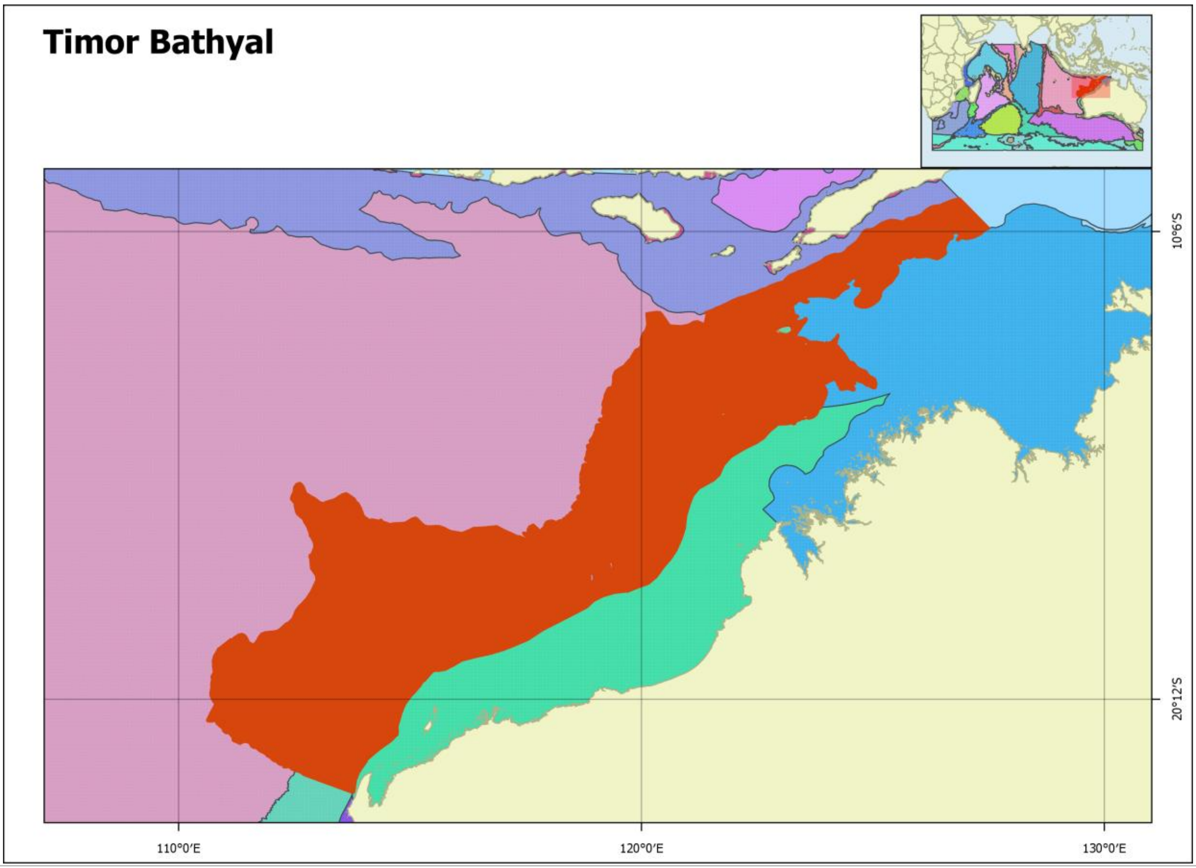
• This bioregion contains the largest area of Class 11 units of all IMCRA shelf bioregions, dominated by the extensive banks that make up the Sahul Banks and Van Diemen Rise.

• This bioregion also contains the 2nd largest area of Class 12 units of all IMCRA shelf bioregions.

• This bioregion is the only IMCRA shelf bioregions to contain seven classes of geomorphic units.

Qualitative models for this province can be found in Hosack et al (2012) and Dunstan et al. (2019).

2.3.13 Timor Bathyal Province



The Timor bathyal is a merging of the Northwest Slope and the Timor Bathyal Province (Benthic Marine Bioregionalisation of Australia's Exclusive Economic Zone (Heap et al. 2005)

This bioregion is one of 11 NBMB bioregions to cover two Primary Bathymetric Units, and one of only two to occur on the slope and rise.

• This bioregion contains the 2nd smallest area of rise of all the NBMB bioregions.

• This bioregion is one of 14 NBMB bioregions to contain all of the biome types.

• The ratio of endemic species to total species is the highest for all the NBMB bioregions.

• Biomes defined by the demersal fish depth structure are the 11th largest in terms of their total area and cover the 10th largest area as a percentage of the bioregion area.

This bioregion is one of seven NBMB bioregions to cover all three Primary Bathymetric Units.

• This bioregion contains the 5th largest area of rise of all the NBMB bioregions.

• This bioregion is the only NBMB bioregion to contain two biome types.

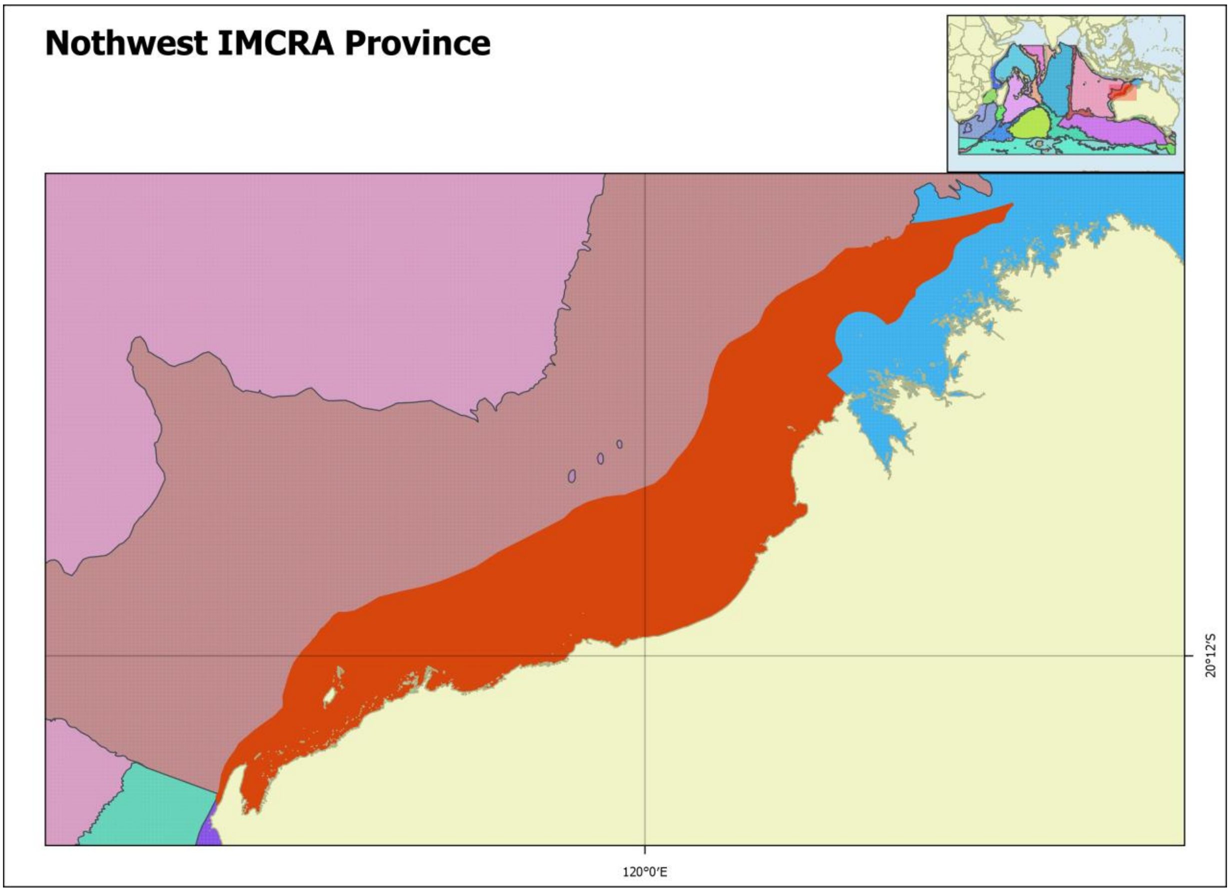
• The ratio of endemics to total species is the second highest for all the NBMB bioregions.

• The demersal fish fauna in this bioregion are linked to the Indonesian slope demersal fish fauna.

• Biomes defined by the demersal fish depth structure in this bioregion are the second largest in terms of area and cover the third largest area as a percentage of the area of the bioregion.

• This bioregion is the only NBMB bioregion to contain nine classes of geomorphic units.

2.3.14 Northwest IMCRA Shelf Province



Extract from Benthic Marine Bioregionalisation of Australia's Exclusive Economic Zone (Heap et al. 2005)

This bioregion is the 3rd largest of all the IMCRA shelf bioregions.

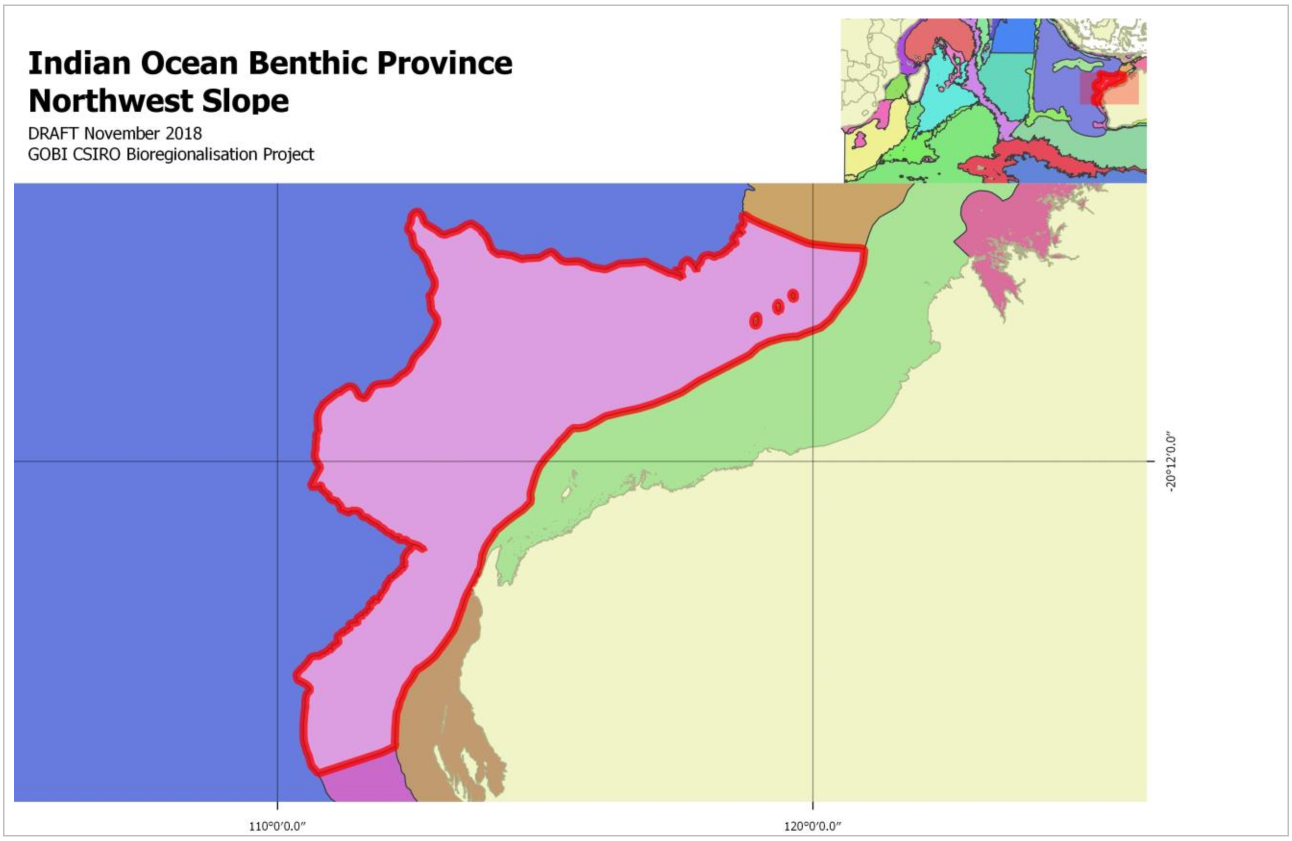
• Class 1 includes units defined by the distribution and abundance of pinnacles, banks, and sand banks.

• This bioregion contains the 2nd largest area of Class 1 units of all the IMCRA shelf bioregions.

• This bioregion is one of four IMCRA shelf bioregions to contain five classes of geomorphic units.

Qualitative models for this region can be found in Hosack et al (2012).

2.3.15 Northwest Slope

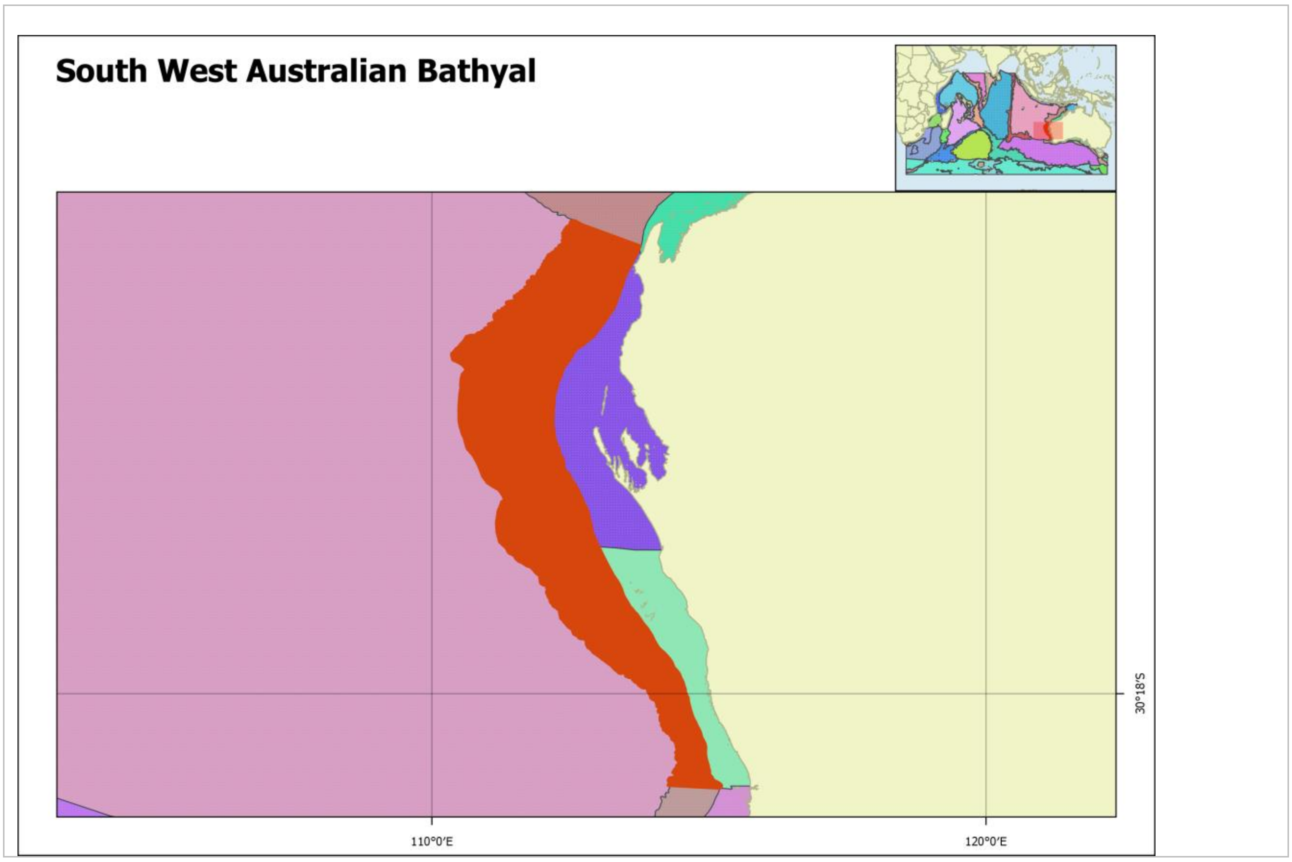


This bioregion is one of 11 NBMB bioregions to cover two Primary Bathymetric Units, and one of only two to occur on the slope and rise.

- This bioregion contains the 2nd smallest area of rise of all the NBMB bioregions.
- This bioregion is one of 14 NBMB bioregions to contain all of the biome types.
- The ratio of endemic species to total species is the highest for all the NBMB bioregions.
- Biomes defined by the demersal fish depth structure are the 11th largest in terms of their total area and cover the 10th largest area as a percentage of the bioregion area.

Qualitative models for this region can be found in Hosack et al. (2012).

2.3.16 Southwest Australian Bathyal



This bioregion is one of six NBMB bioregions to cover only one Primary Bathymetric Unit, and one of five to occur only on the slope.

• This bioregion is one of 14 NBMB bioregions to contain all of the biome types.

• Biomes defined by the demersal fish depth structure are the 6th largest in terms of their total area and cover the 7th largest area as a percentage of the bioregion area for all the NBMB bioregions.

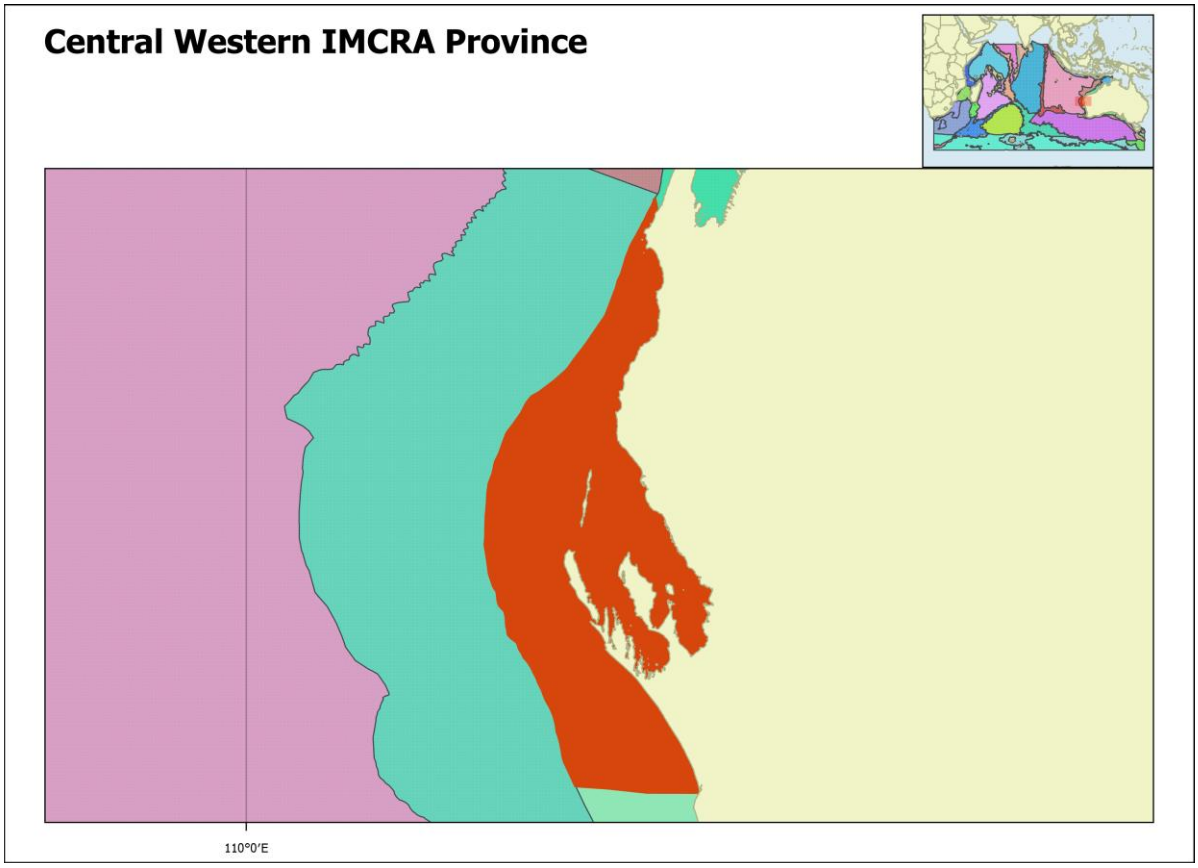
• This bioregion is one of four NBMB bioregions to contain three classes of geomorphic units.

• Class 2 includes units defined by the spacing of submarine canyons on the slope.

• This bioregion is centred on the Naturaliste Plateau, a 90,000 km submerged continental fragment that rises from water depths of >5000 m to 2,000 m and surrounded by deep ocean floor. This bioregion represents a completely different environment from the surrounding seabed and adjacent Provinces.

Qualitative models for this region can be found in Hosack et al. (2012) and Hayes et al. (2012).

2.3.17 Central Western IMCRA Shelf Province



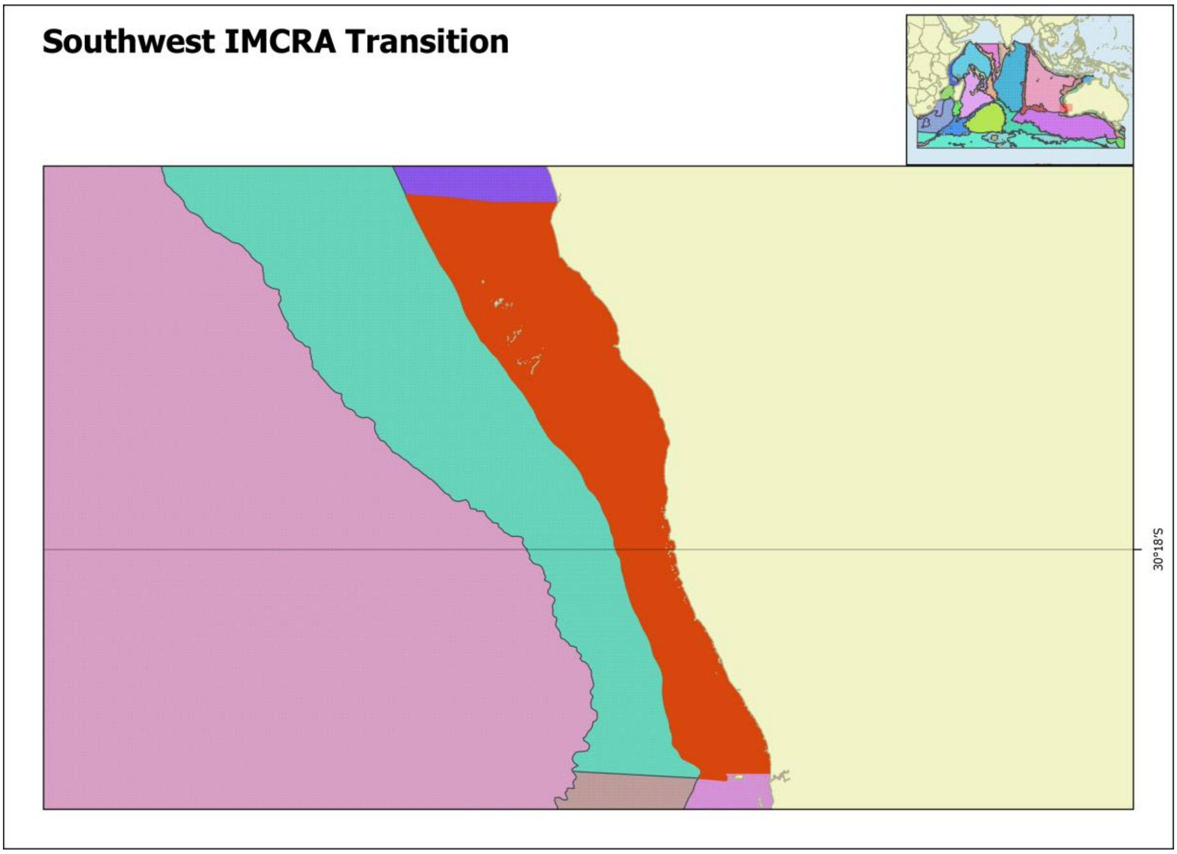
Extract from Benthic Marine Bioregionalisation of Australia's Exclusive Economic Zone (Heap et al. 2005)

This bioregion has the second shallowest mean water depth of all the IMCRA shelf bioregions.

- Class 1 units are overwhelmingly the dominant geomorphic class in this bioregion.
- This bioregion is one of six IMCRA shelf bioregions to contain two classes of geomorphic units.

Qualitative models for this region can be found in Hosack et al. (2012).

2.3.18 South West IMCRA Transition



Extract from Benthic Marine Bioregionalisation of Australia's Exclusive Economic Zone (Heap et al. 2005)

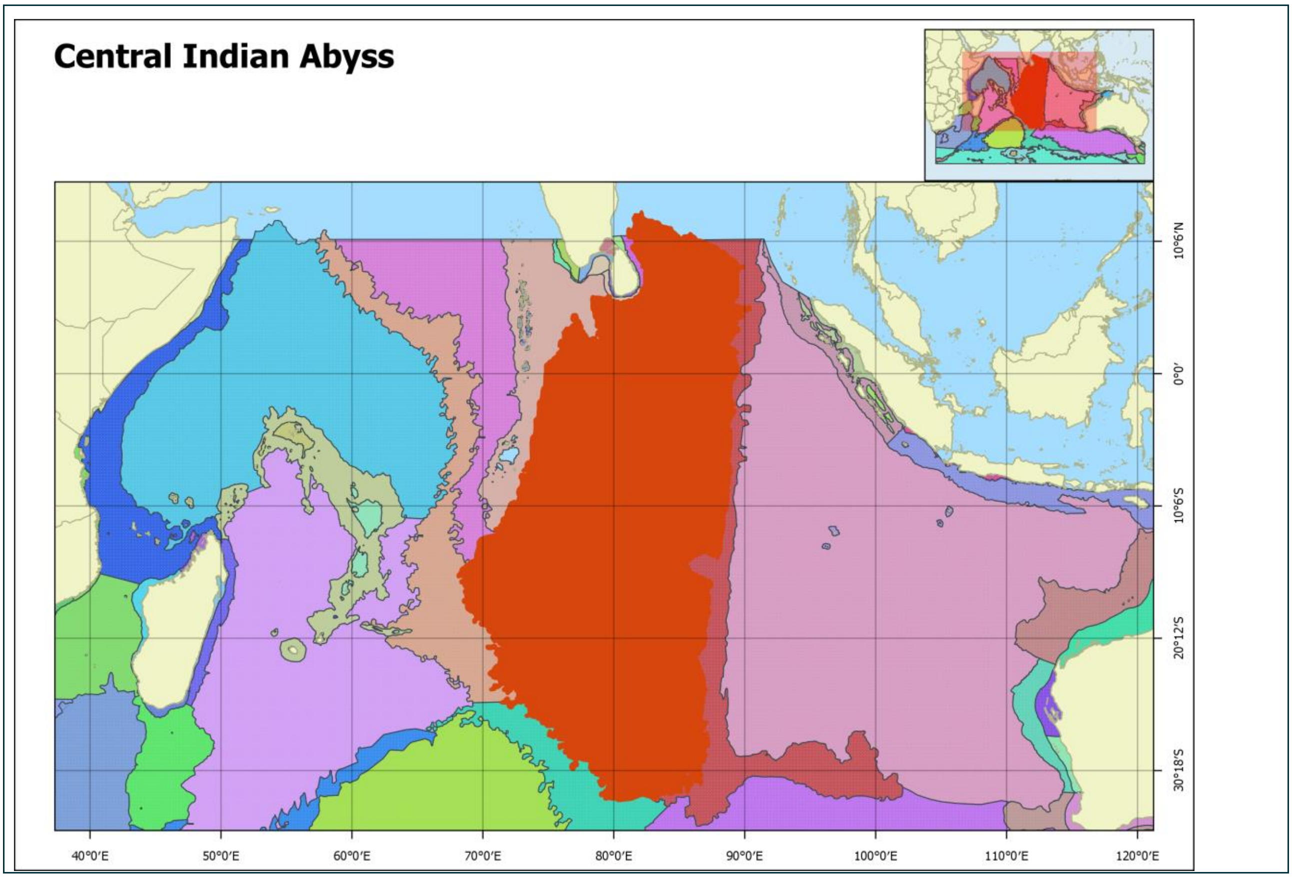
This bioregion is the smallest of the IMCRA shelf bioregions.

• Class 1 units are overwhelmingly the dominant geomorphic class in this bioregion.

• This bioregion is one of six IMCRA shelf bioregions to contain two classes of geomorphic units.

Qualitative models for this region can be found in Hayes et al. (2012).

2.3.19 Central Indian Abyss



The Northern end of the central Indian Abyss is a large very cold (~2°C) abyssal plan directly south of Sri Lanka. It is south of the Bay of Bengal Abyss and is separate from the Bengal Fan. To the east it abuts 90 East Ridge and the Central Indian Ridge Province in the West. The North East Indian Abyss is separated from the Central Indian Abyss by different groups of Squat Lobster and is characterised by slightly lower oxygen than central Indian abyss and belongs to EMU cluster 13 (Sayre et al 2017).

The southern end of the Central Indian Abyss Province is identified from the Ecological Marine Units (cluster 14) and the values of bathymetry and oxygen levels. The abyss has a mean temperate of 0.9C. The Squat lobster RCP2 suggests a separation from the North East Indian Abyss and approximately the latitude of the Chagos Archipelago (Appendix A). The Abyss is bounded by 90 East Ridge and the Central Indian Ridge and extends south to the southern ocean boundary.

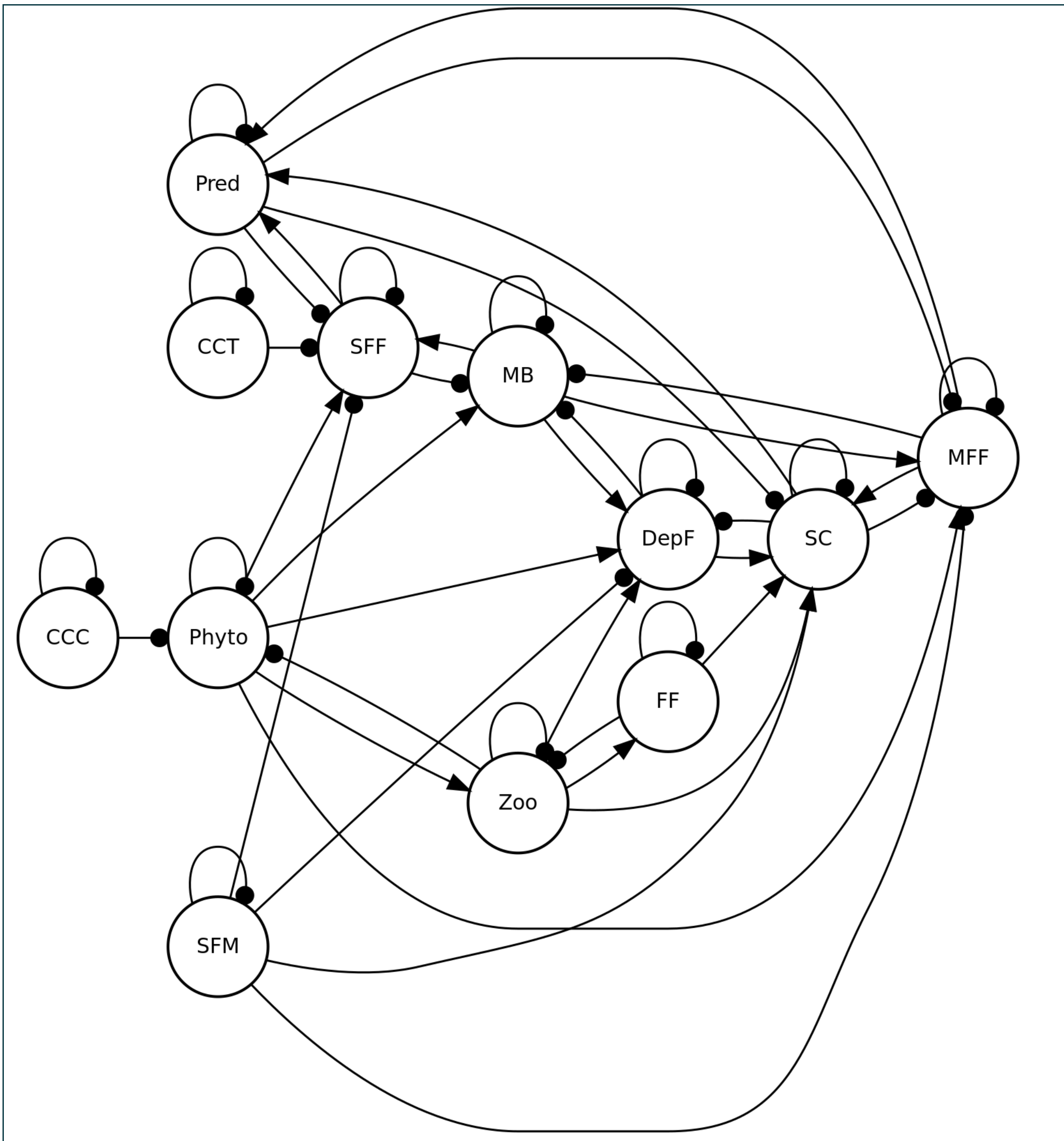


Figure 35: Ecosystem components in the qualitative model are: Predatory Fish (Pred), Sessile Filter Feeders (SFF), Mobile Filter Feeders (MFF), Scavengers (SC), Microbes (MB), Phytoplankton (Phyto), Zooplankton (Zoo), Food Falls (FF), Deposit Feeders (DepF) . Pressures acting on the system are: Seafloor Mining (SFM), Climate Change Chlorophyll (CCC), Climate Change Temperature (CCT)

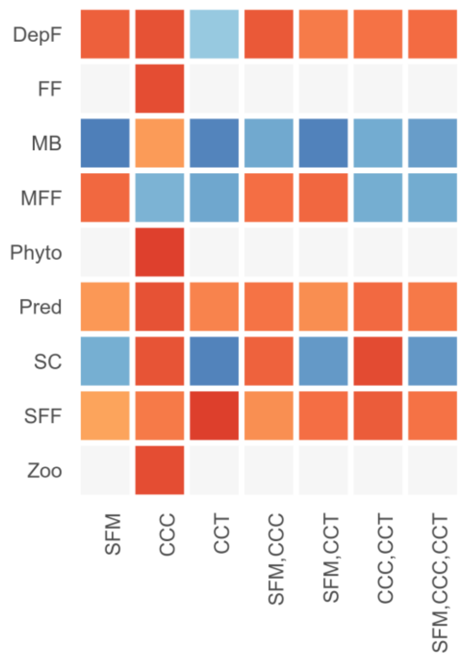
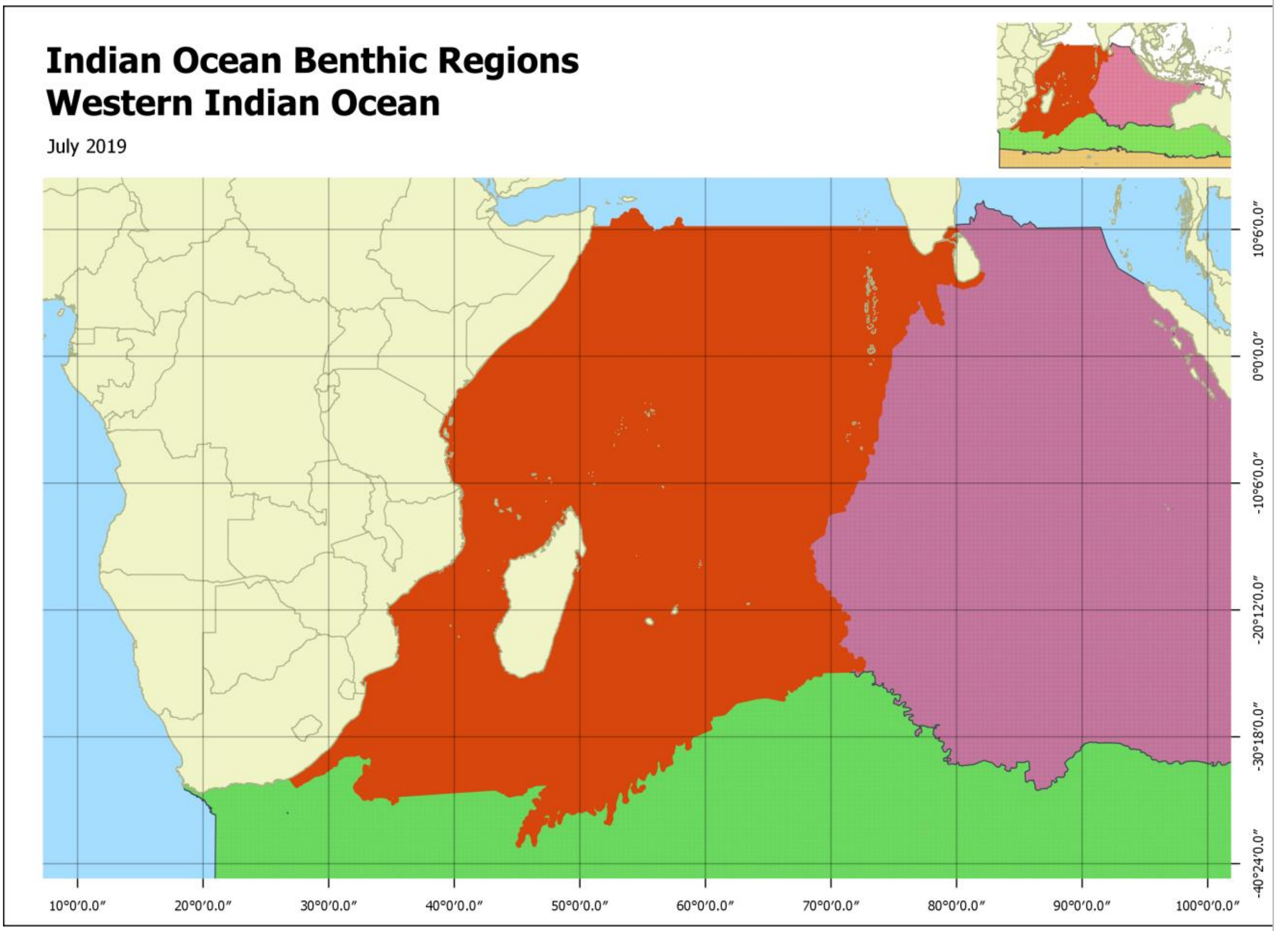
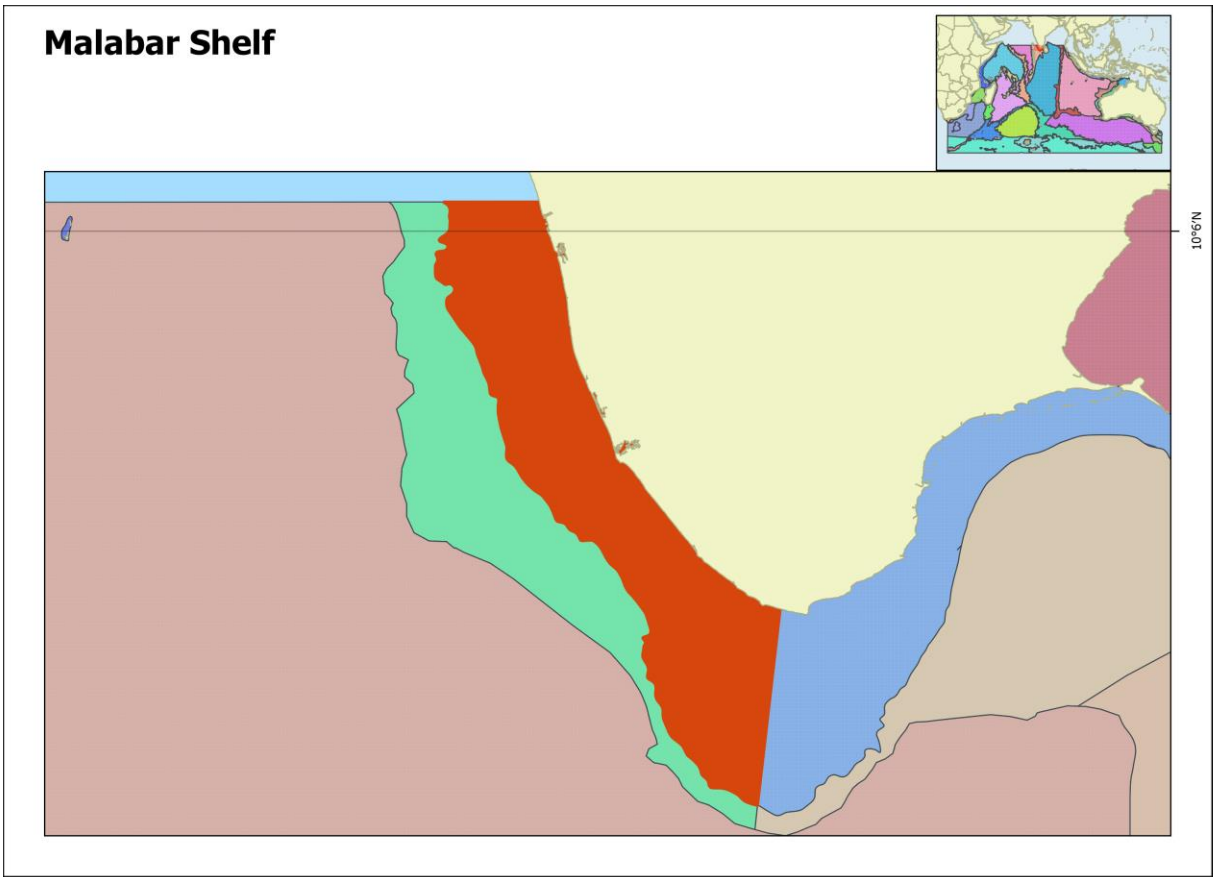


Figure 36: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4 Western Indian Ocean



2.4.1 Malabar Shelf (South West Indian Shelf) Province



The Malabar Shelf Province has the same boundaries and characteristics as described in Brewer et al (2015). This shallow shelf province extends from Kanyakumari at the southern tip of India to Ratnagiri (Angrea Bank) in Maharashtra State on the west coast of India, approximately 1000 km to the north-west. It is a relatively wide shelf ranging from 50 km in the southern parts to 120 km in the north. The southern boundary coincides with the end of the Indian subcontinent and feature called the Wadge Bank; and the northern boundary is where the shelf widens and comes under the influence of larger northern Indian rivers such as the Narmada River. The terrestrial border comprises unique Western and Southern Ghats and associated small river systems but with very large pulse flows during the south-west monsoon. The outer limit is the South West Indian Slope Province and the unique Wadge Bank and Laccadive Sea, where the Maldive Ridge intersects the Indian continental margin and the major northern Indian Ocean currents are forced closer to the coast.

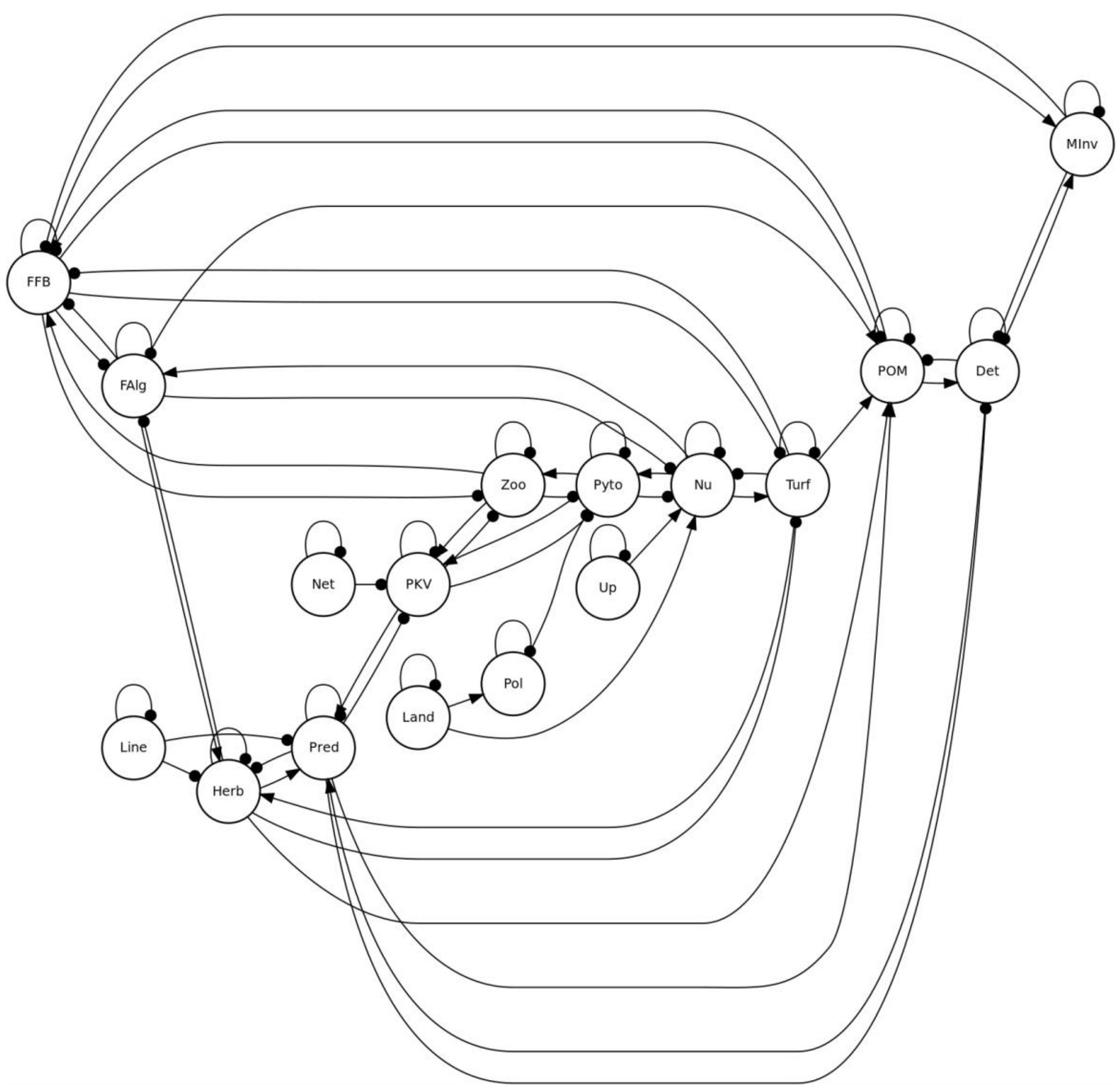


Figure 37: Ecosystem components in the qualitative model are: Filter Feeder Benthic (FFB), Fleshy Algae (FAlg), Turf Algae (Turf), Particulate Organic Matter (POM), Nutrients (Nu), Phytoplankton (Pyto), Zooplankton (Zoo), Predatory Fish (Pred), Herbivorous Fish (Herb), Detritivores (Det), Planktivores (PKV), Mobile Invertebrates (MInv) . Pressures acting on the system are: Line Fishing (Line), Net Fishing (Net), Upwelling (Up), Pollution (Pol), Land Use Change (Land)"

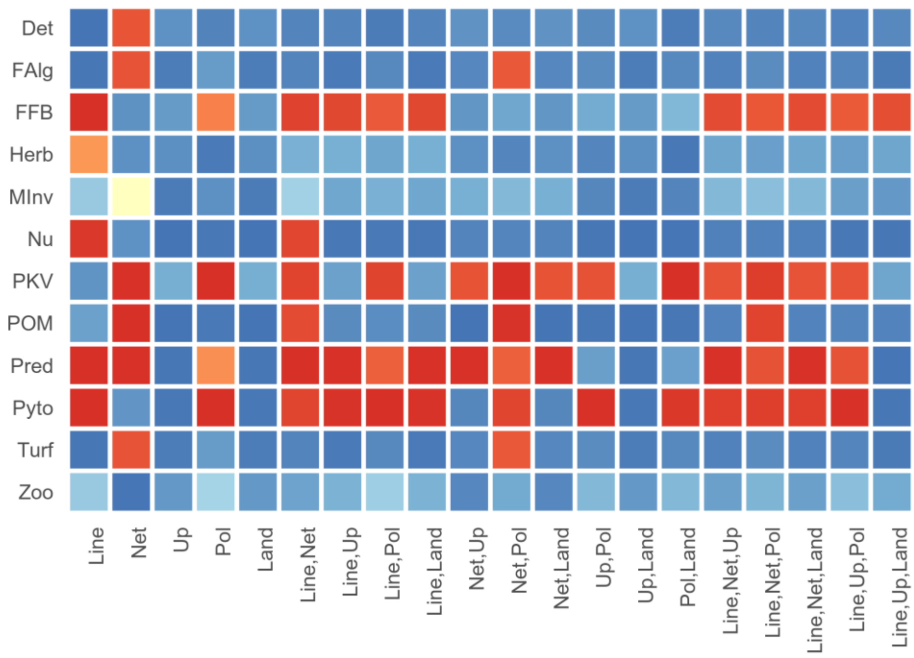
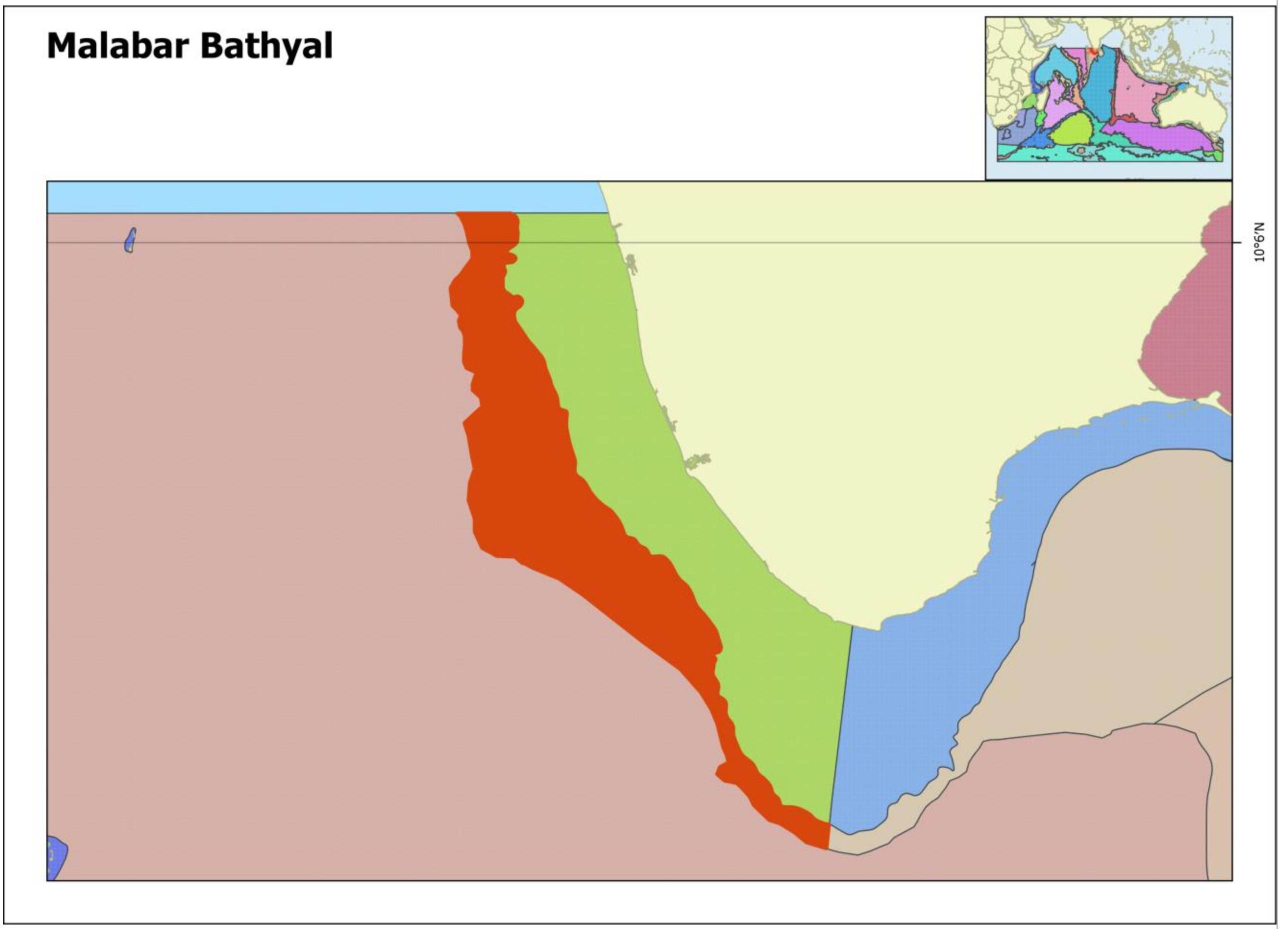


Figure 38: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.2 Malabar Bathyal (South West Indian Slope) Province



The South West Indian Bathyal Province has the same boundaries and characteristics as described in Brewer et al (2015). This slope province extends form Kanyakumari at the southern tip of India to Mangalore on the west coast, approximately 600 km to the north-west. It is widest in the south at ~150 km wide, and narrows in the north at about 50 km wide. The southern boundary coincides with the end of the Indian subcontinent and feature called the Wadge Bank. The northern boundary is where the Lakshadweep archipelago meets the shelf and the Coral Island Ridge ends. The outer limit is the Indian Ocean abyss and the Lakshadweep archipelago. The high runoff and freshwater inputs combine with the abrupt escarpments and complex topography to define the boundaries.

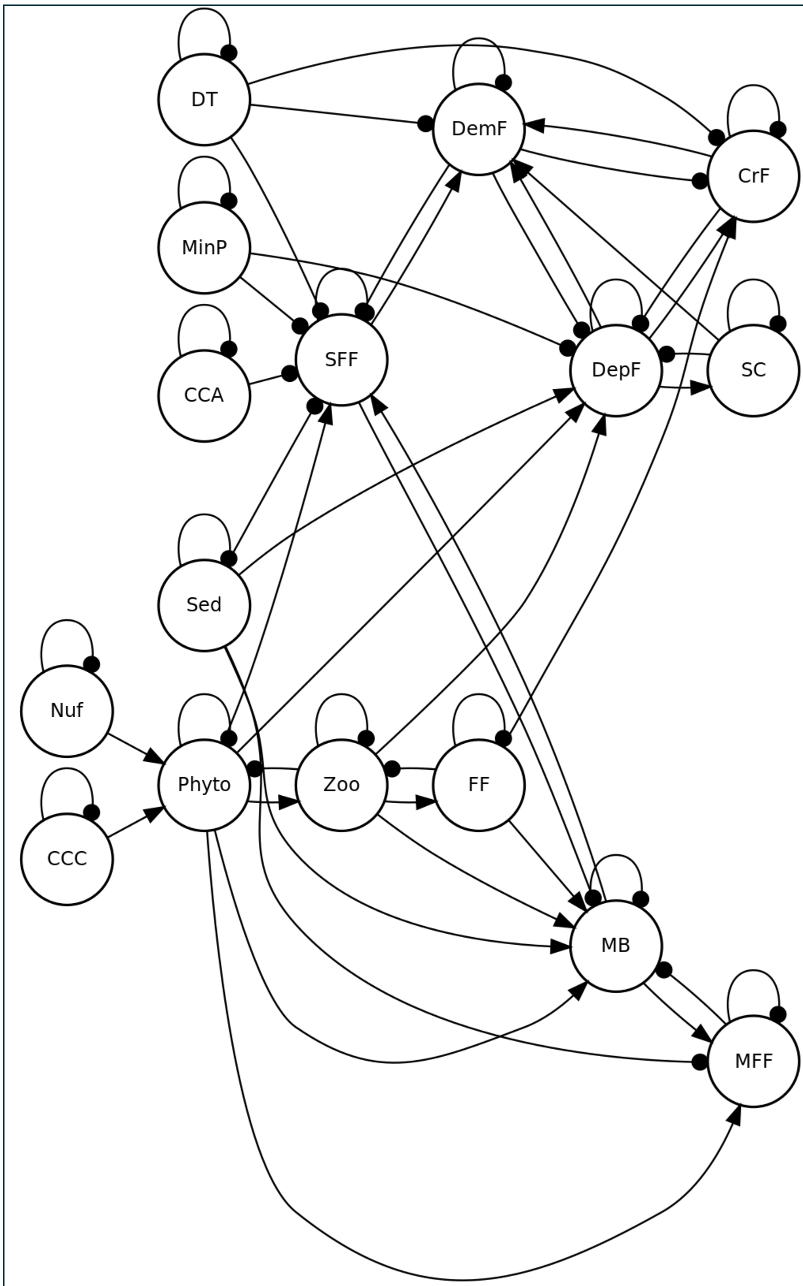


Figure 39: Ecosystem components in the qualitative model are: Sessile Filter Feeders (SFF), Food Falls (FF), Crustacean Fishery (CrF), Microbes (MB), Phytoplankton (Phyto), Zooplankton (Zoo), Deposit Feeders (DepF), Demersal Fishes (DemF), Scavengers (SC), Mobile Filter Feeders (MFF) . Pressures acting on the system are: Nutrification (Nuf), Sediment (Sed), Demersal Trawling (DT), Mining Prospecting (MinP), Climate Change Chlorophyll (CCC), Climate Change Acidification (CCA)

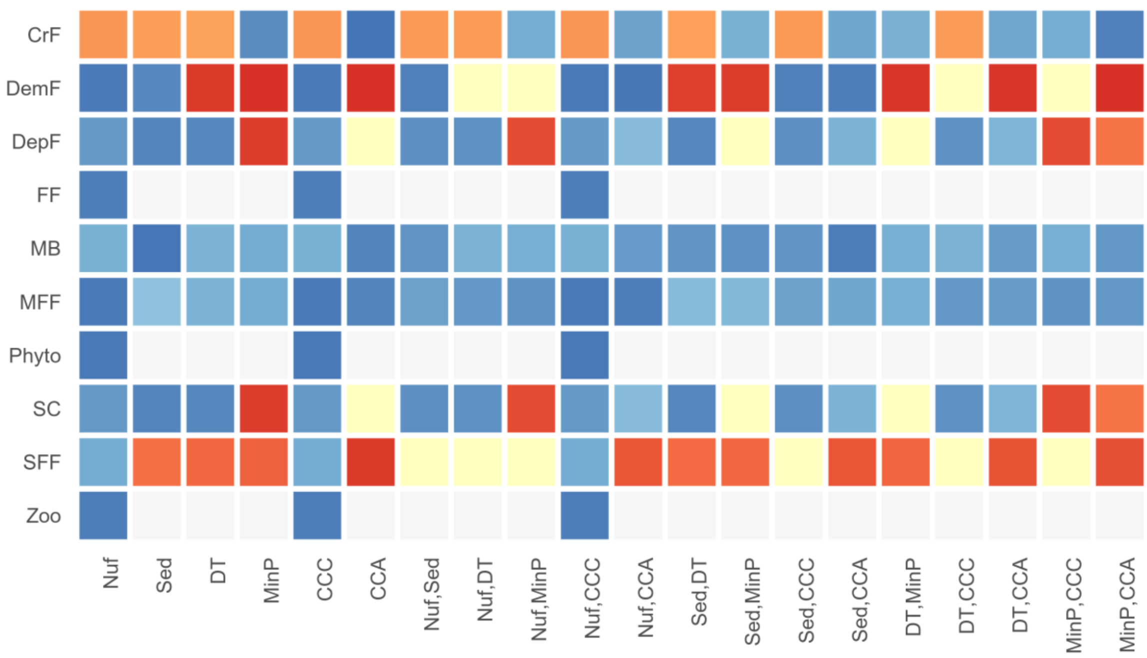
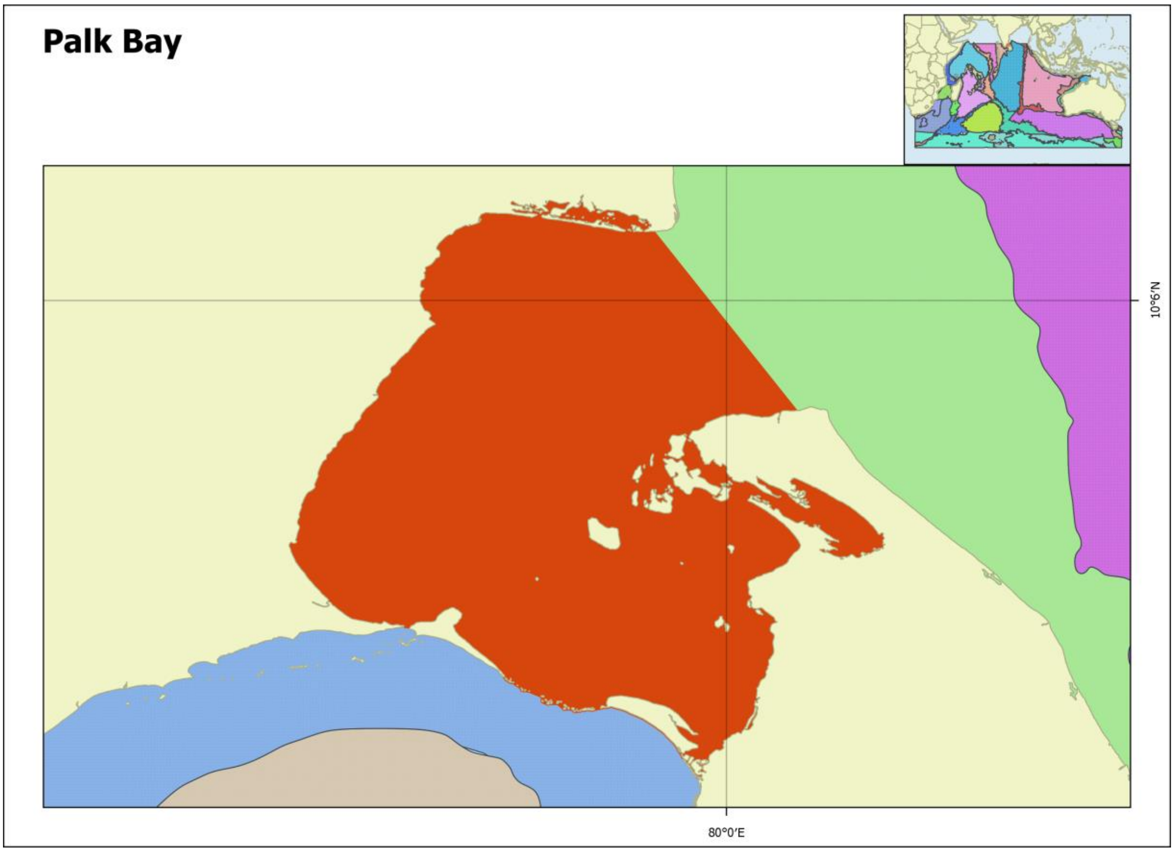


Figure 41: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.3 Palk Bay



Palk Bay Shelf Province is made up of Palk Bay and Palk Strait (together known as Sethusamudram) which are features of the isthmus that connects India to Sri Lanka. It is a unique feature of the BOBLME region. It extends from Mannar in northwest Sri Lanka to Point Calimere in the north, a distance of approximately 280 km. On the southern side it is separated from the Gulf of Mannar shelf by the 30 km long Adam's Bridge (also known as Rama's Bridge or Rama Setu), which is a chain of limestone shoals between the south-eastern coast of Tamil Nadu, India, and the north-western coast of Sri Lanka. These geomorphic features restrict water movements and help create a unique range of ecosystems within the bay.

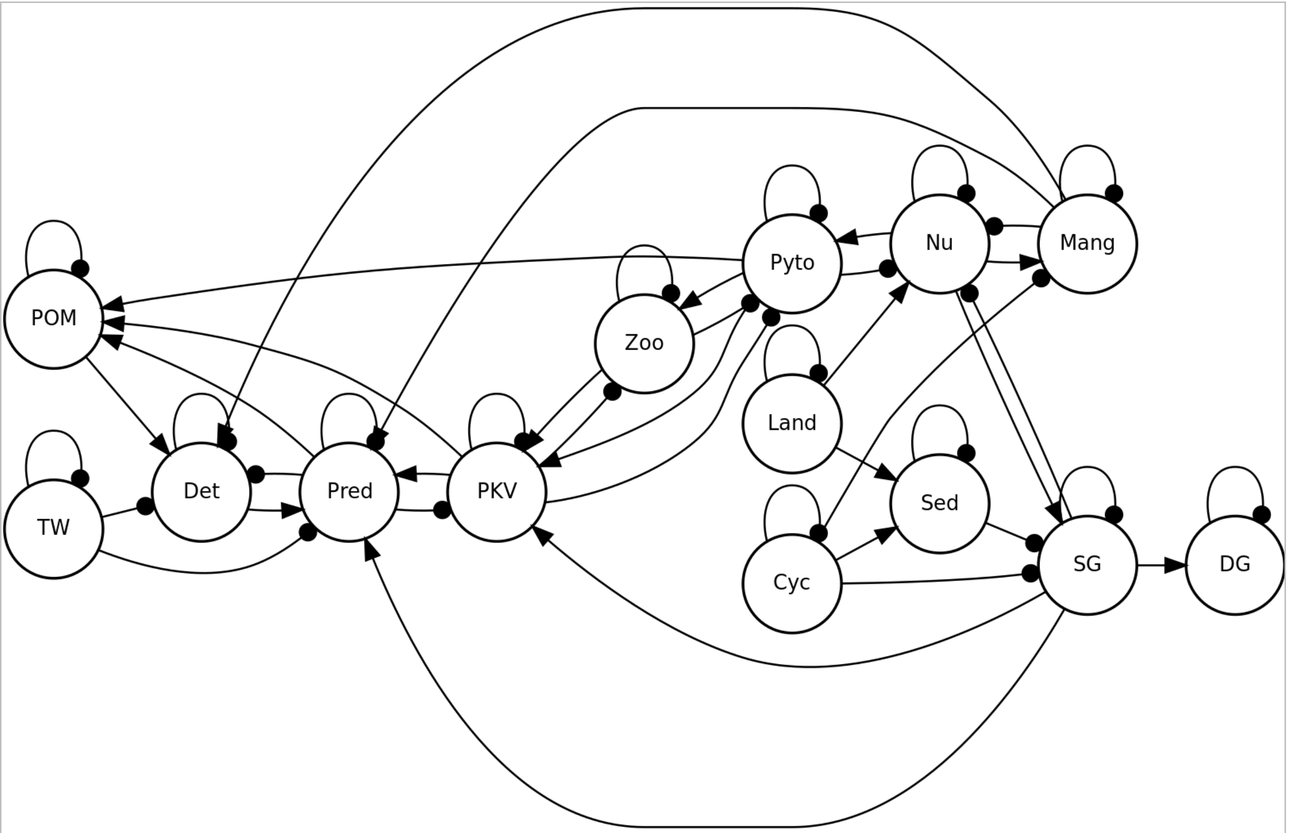


Figure 42: Ecosystem components in the qualitative model are: Particulate Organic Matter (POM), Nutrients (Nu), Phytoplankton (Pyto), Zooplankton (Zoo), Predatory Fish (Pred), Detritivors (Det), Planktivores (PKV), Mangroves (Mang), Seagrass (SG), Dugong (DG) . Pressures acting on the system are: Land Use Change (Land), Trawl (TW), Cyclones (Cyc), Sediment (Sed)

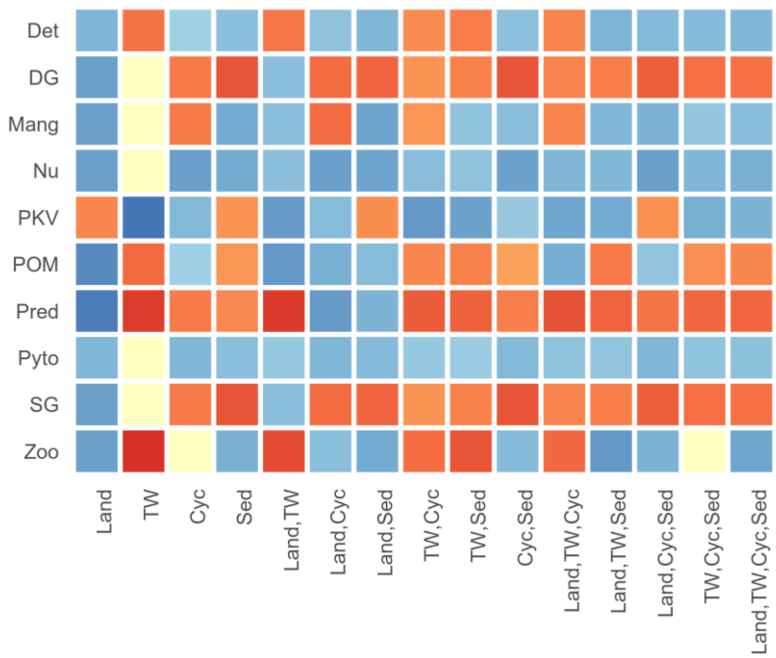
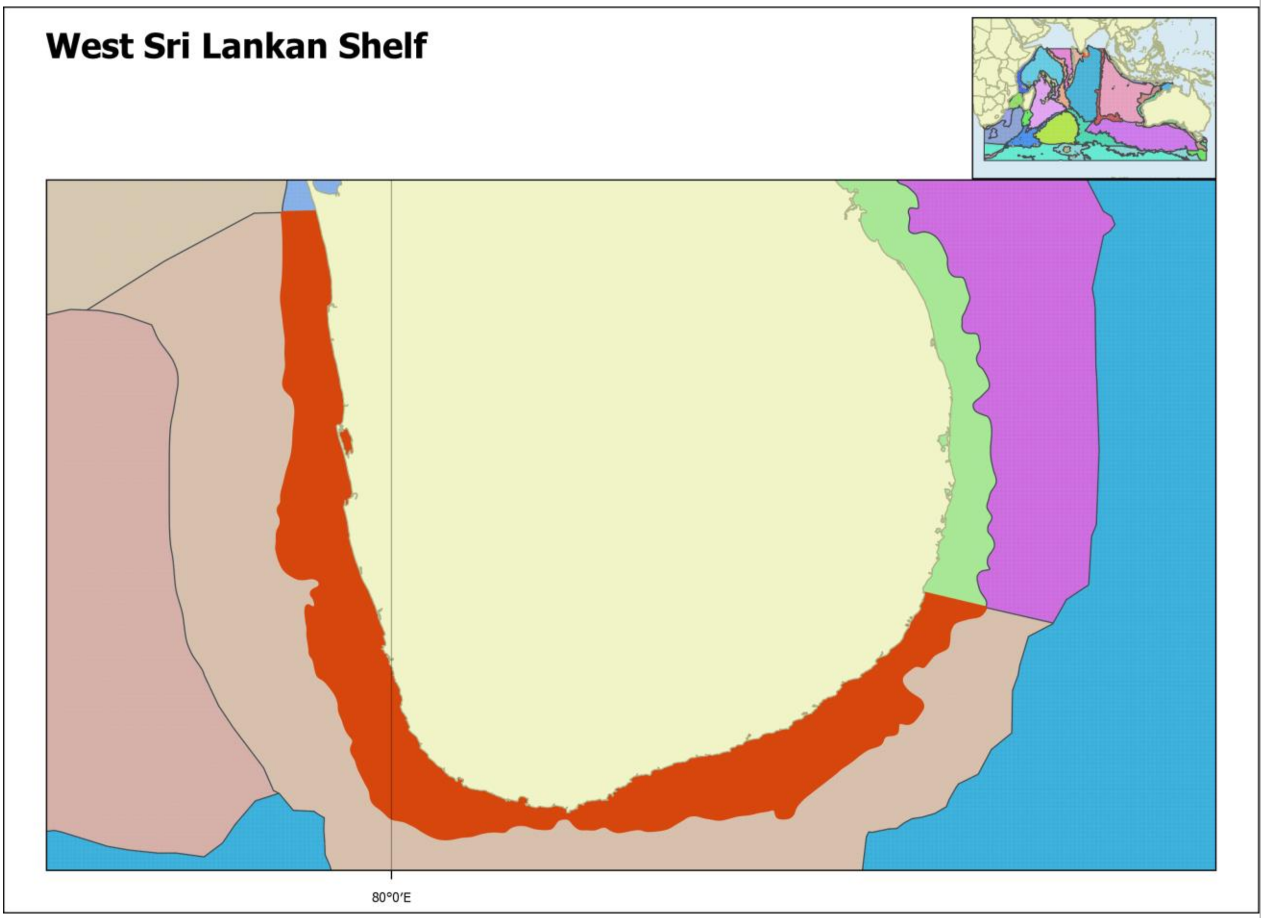


Figure 43: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.4 West Sri Lanka Shelf Province



The Sri Lanka Shelf Province has the same boundaries and characteristics as described in Brewer et al (2015). The Sri Lankan Shelf Province comprises the shelf waters (coastline to 200 m depth) encompassing most of Sri Lanka. However, in the north-west of Sri Lanka, the shelf environment is segregated into the Palk Bay Province and the Gulf of Mannar Shelf Province. The Palk Bay Shelf Province is a unique shallow sandy environment with a high proportion of basin habitats, substantial terrestrial and freshwater input from the Indian mainland and unique ecological communities. To the south of Palk Bay and forming the north-western boundary of the Sri Lankan Shelf Province is the eastern extent of the Gulf of Mannar Shelf Province. This is a deeper shelf separated from Palk Bay by chain of low islands and reef shoals known as Adams's bridge or the Bridge of Rama. It forms the north-eastern boundary of the Sri Lankan Shelf Province and is differentiated by its connection to terrestrial inputs, productivity dynamics and the influence of steeper depth gradient. The very north-eastern boundary of the province butts against the Coromandel Shelf Province. This boundary is based on the influences of major physical drivers including the various sources of terrestrial input, the influence of different current systems and substantial differences in productivity dynamics. The Sri Lankan Shelf Province is bounded on its deepest margin by the Sri Lankan Slope Province, a steeply grading continental slope habitat surrounding most of Sri Lanka.

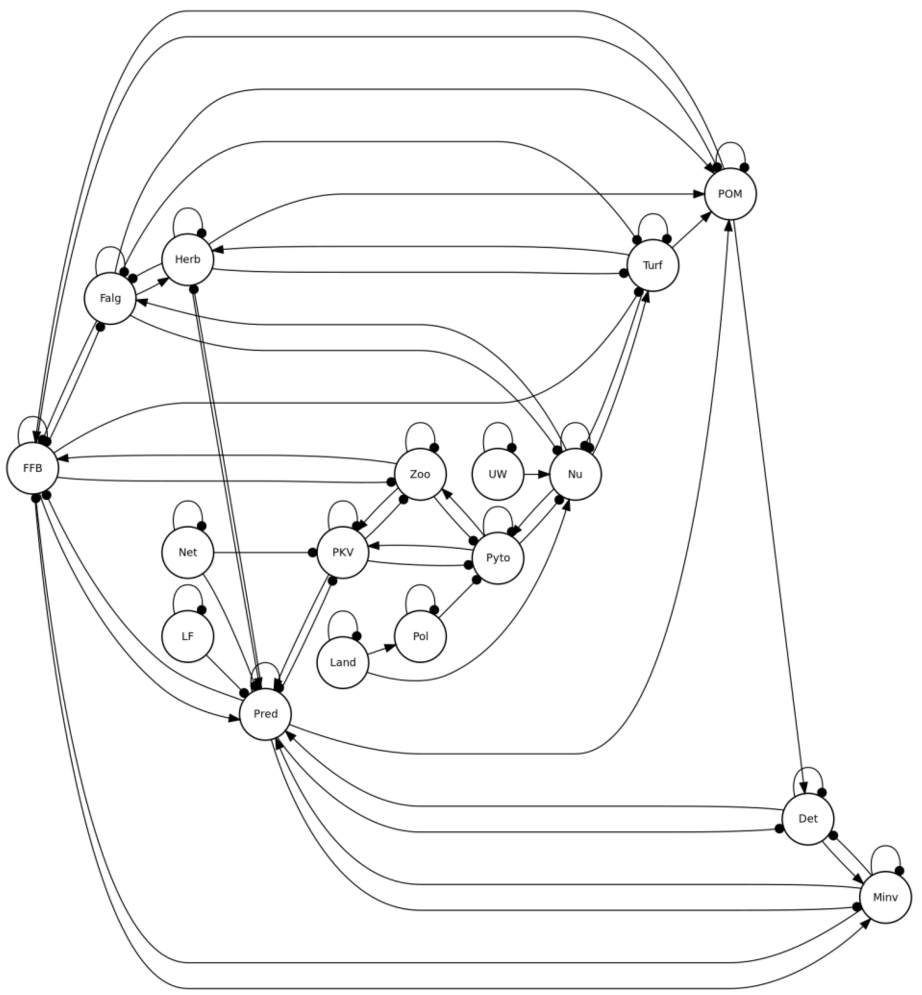


Figure 44: Ecosystem components in the qualitative model are: Filter Feeder Benthic (FFB), Fleshy Algae (Falg), Turf Algae (Turf), Particulate Organic Matter (POM), Nutrients (Nu), Phytoplankton (Pyto), Zooplankton (Zoo), Predatory Fish (Pred), Herbivorous Fish (Herb), Detritivores (Det), Planktivores (PKV), Mobile Invertebrates (Minv), Land Use Change (Land) . Pressures acting on the system are: Line Fishing (LF), Net fishing (Net), Upwelling (UW), Pollution (Pol)

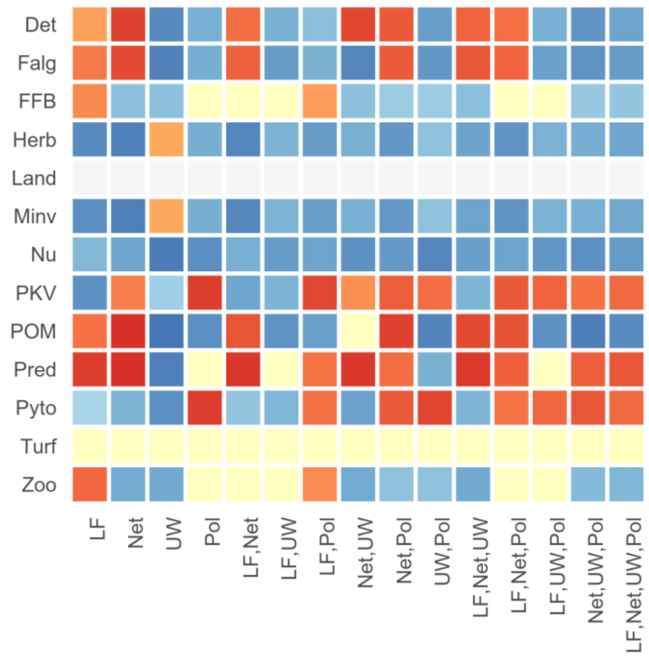
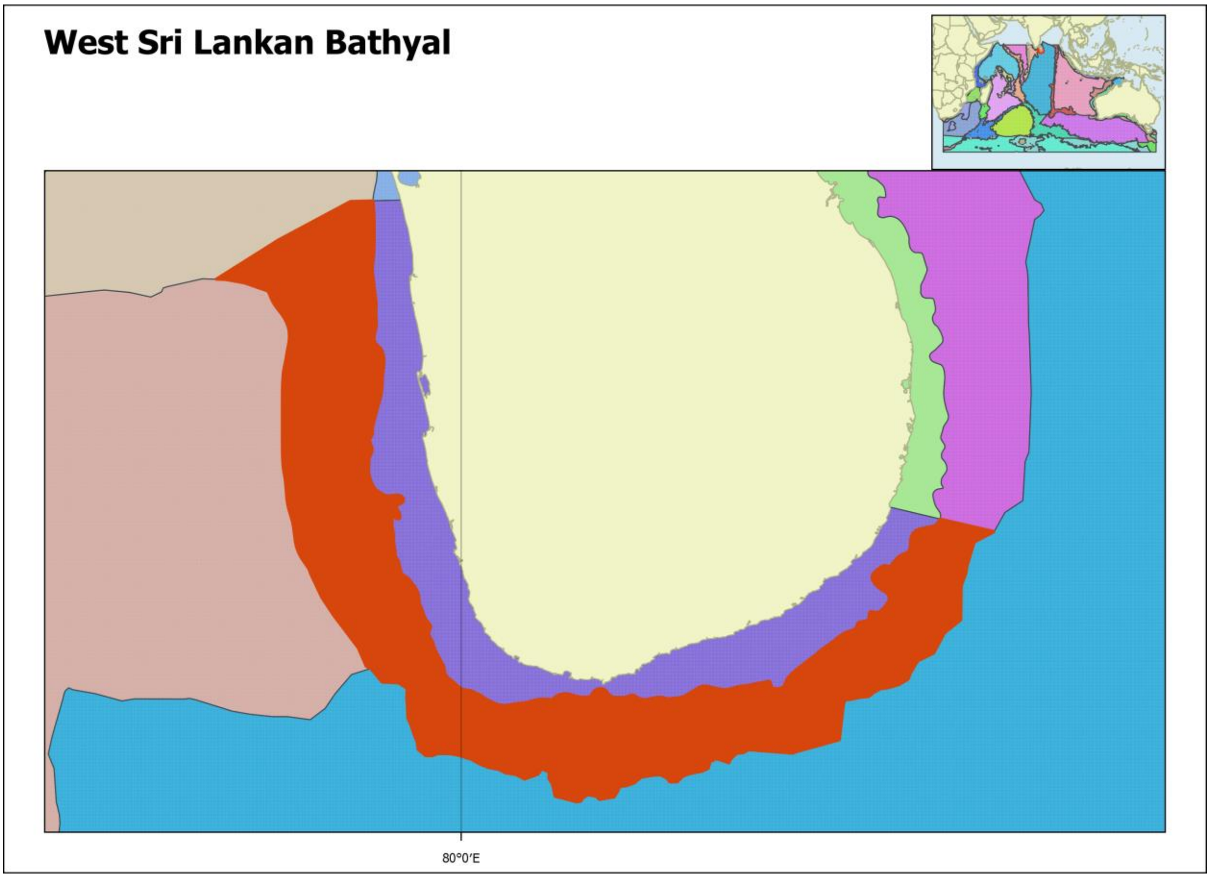


Figure 45: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.5 West Sri Lanka Bathyal Province



The Sri Lanka Bathyal Province has the same boundaries and characteristics as described in Brewer et al (2015). The Sri Lankan Slope Province encompasses the Sri Lankan Shelf Province and hence uses some of the same justification for the boundaries. Throughout most of its extent it is a narrow and steep sloping province. The north-western boundary butts against the Gulf of Mannar Slope Province where the slope widens substantially, the gradient decreases and the influence of the Indian continent increases. The deeper extent of the slope joins the Bay of Bengal Abyss Province to the east, the abyssal ocean within the Laccadive Sea to the west and the deep abyssal Indian Ocean environment to the south.

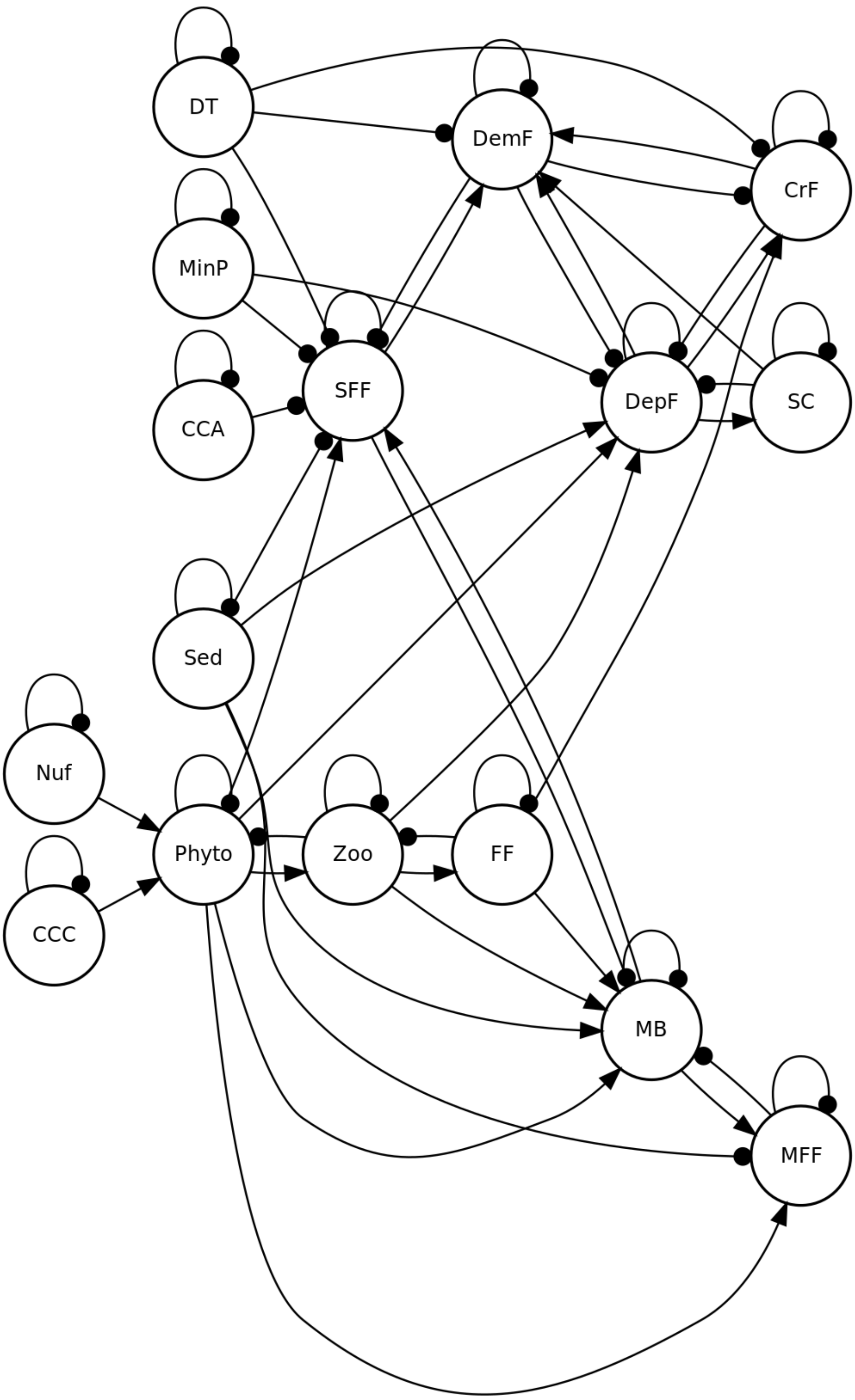


Figure 46: Ecosystem components in the qualitative model are: Sessile Filter Feeders (SFF), Food Falls (FF), Crustacean Fishery (CrF), Microbes (MB), Phytoplankton (Phyto), Zooplankton (Zoo), Deposit Feeders (DepF), Demersal Fishes (DemF), Scavengers (SC), Mobile Filter Feeders (MFF) . Pressures acting on the system are: Nutrification (Nuf), Sediment (Sed), Demersal Trawling (DT), Mining Prospecting (MinP), Climate Change Chlorophyll (CCC), Climate Change Acidification (CCA)

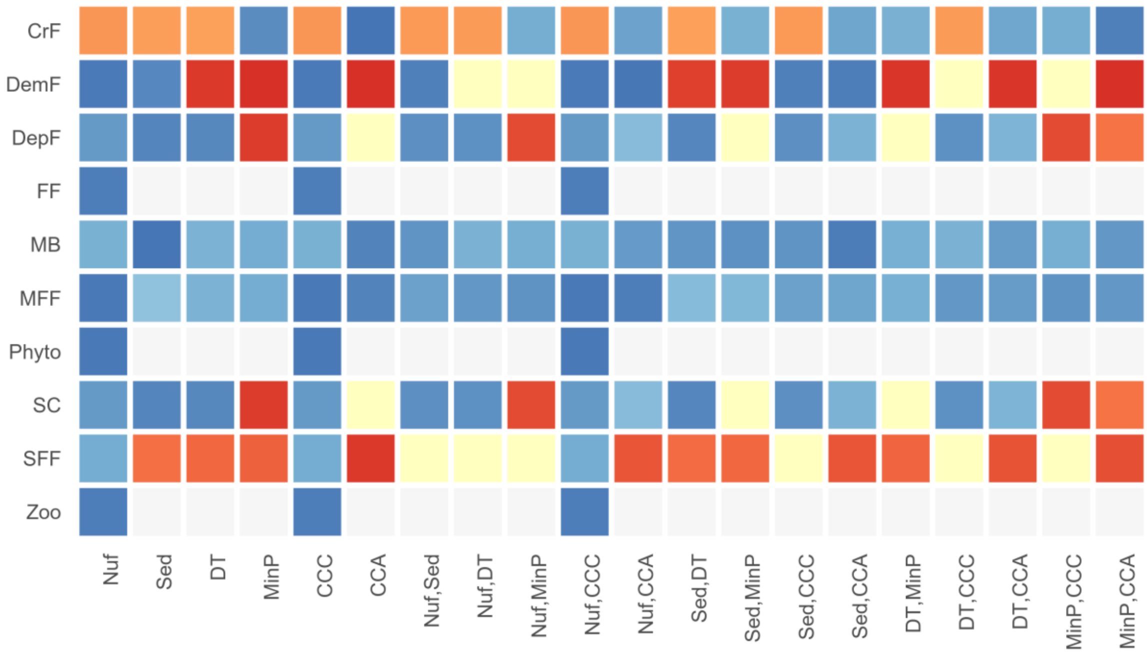
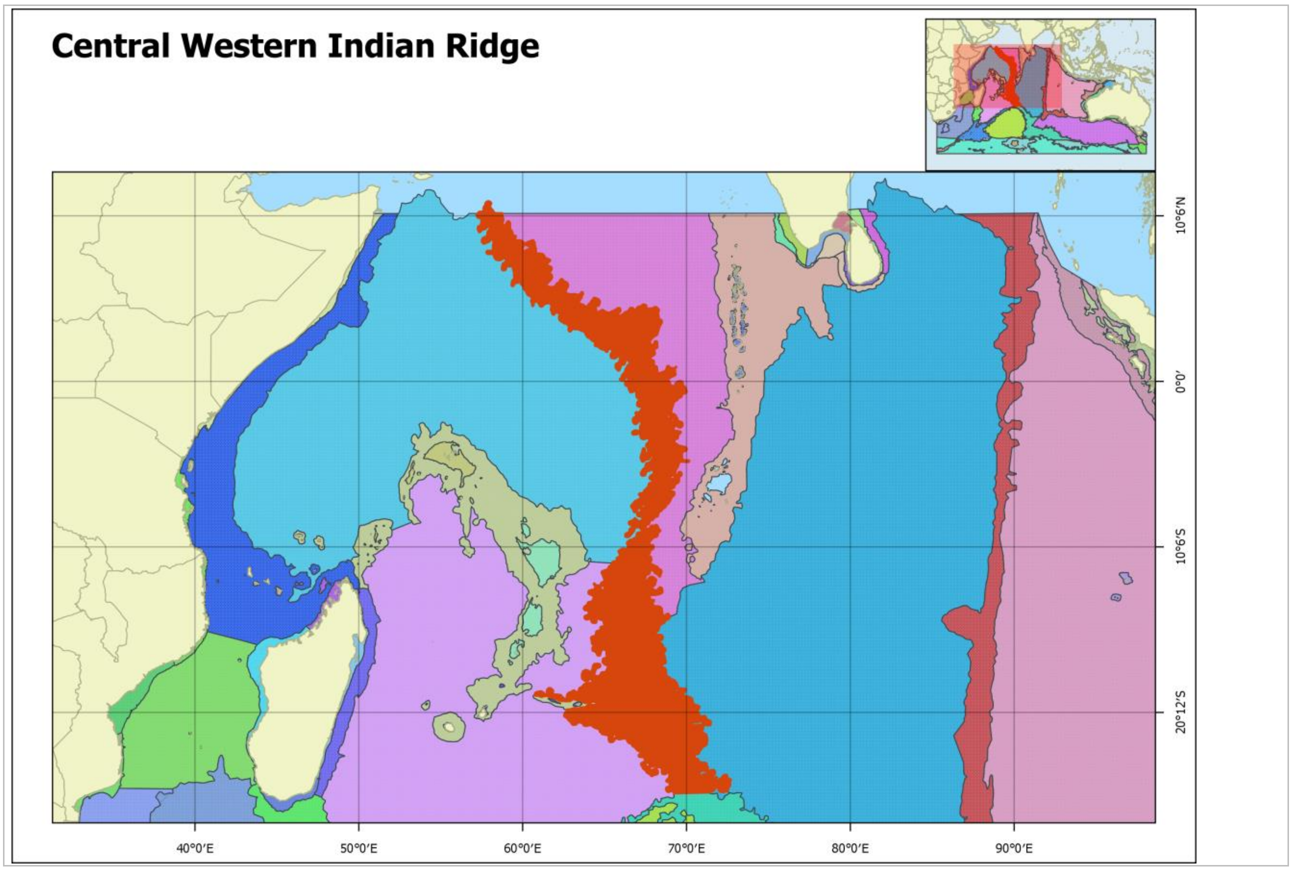


Figure 47: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.6 Central Western Indian Ridge Province



The Central Western Indian Ridge is a large spreading ridge that separates the benthic eastern and western Indian Oceans. The ridge is separated from the Del Cano and South East Indian Ridge Provinces and appears to have different communities of squat lobsters. It is a combination of EMU clusters 13 & 14 (Sayre et al. 2017). It is at similar depths to many of the coastal lower bathyal provinces and is surrounded by abyssal provinces to the east, west and south.

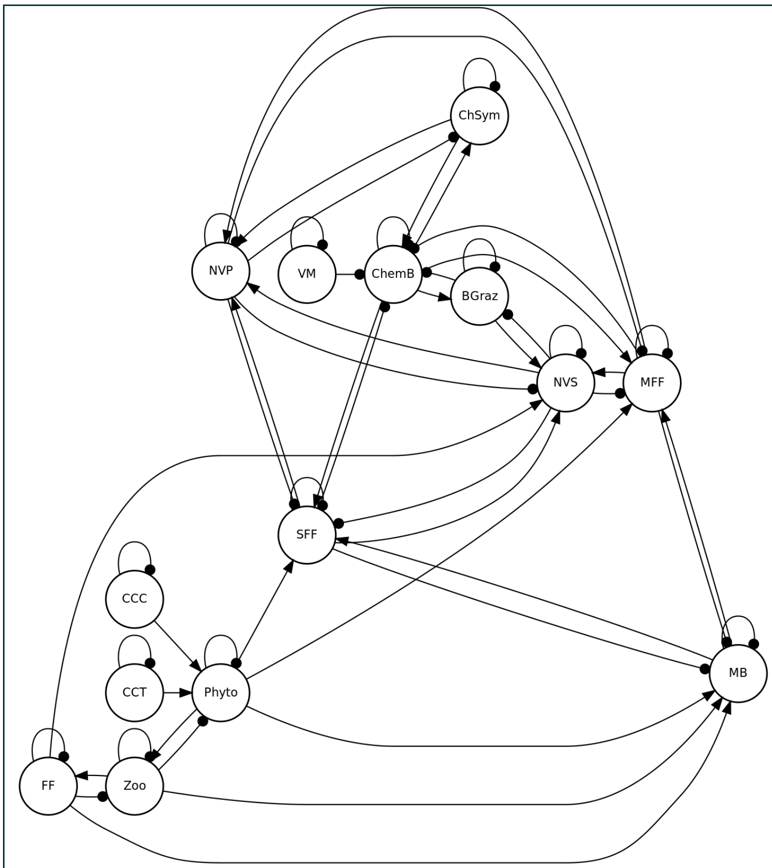


Figure 48: Ecosystem components in the qualitative model are: Non-Vent Predators (NVP), Sessile Filter Feeders (SFF), Mobile Filter Feeders (MFF), Food Falls (FF), Microbes (MB), Phytoplankton (Phyto), Zooplankton (Zoo), Chemosynthetic Bacteria (ChemB), Bacteria Graziers (BGraz), Non-Vent Scavengers (NVS), Chemosynthetic Symbionts (ChSym) . Pressures acting on the system are: Vent Mining (VM), Climate Change Chlorophyll (CCC), Climate Change Temperature (CCT)

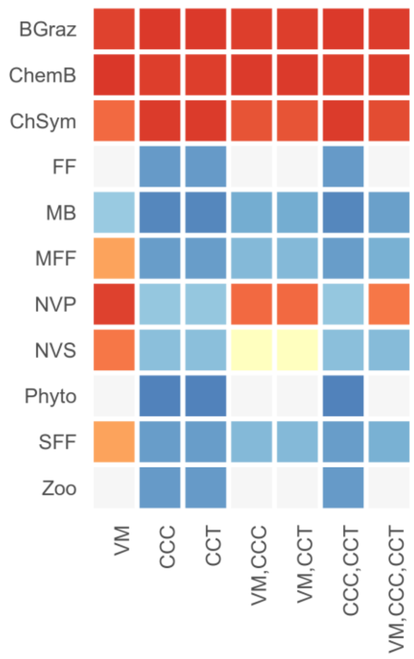
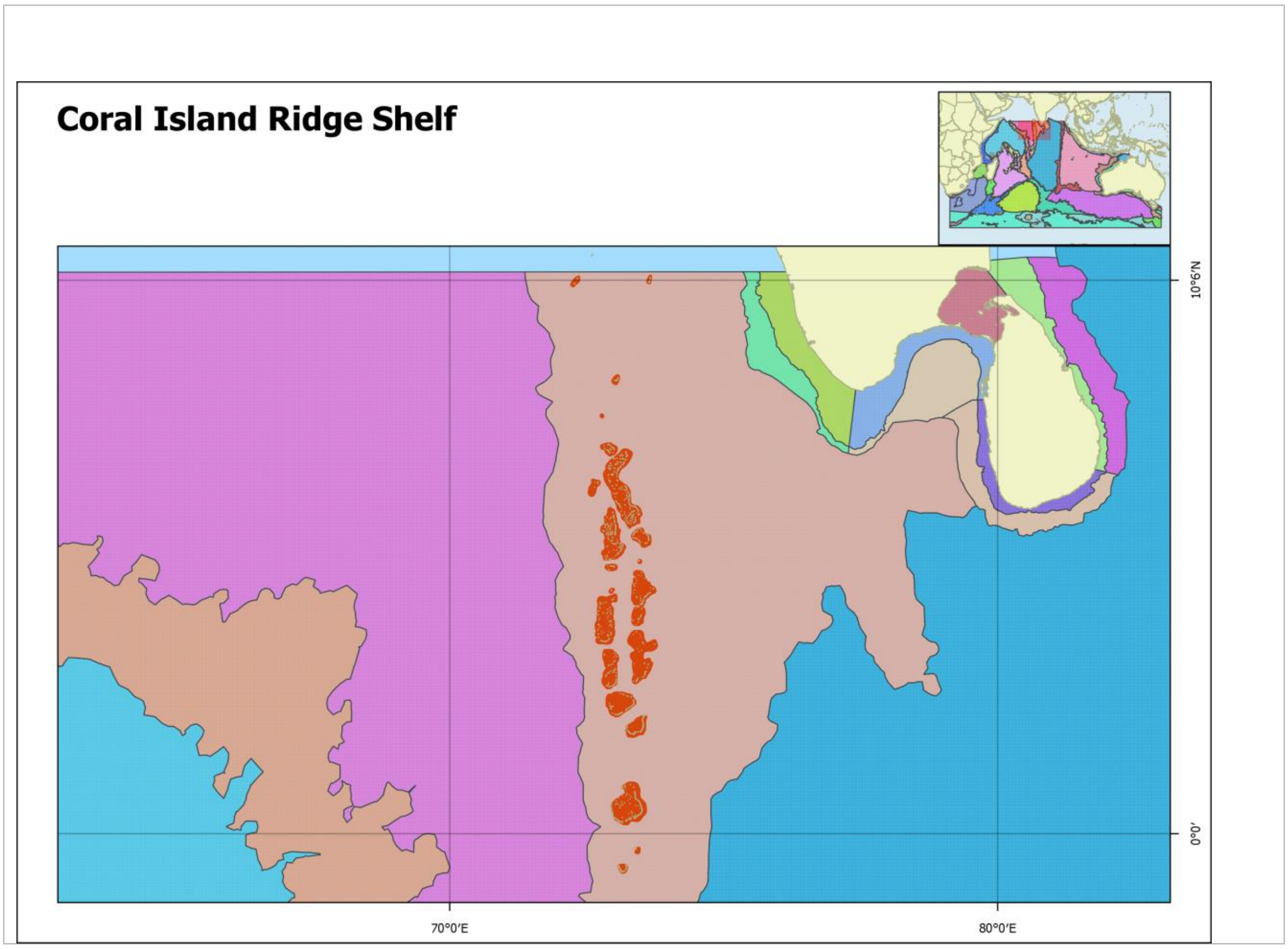


Figure 49: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.7 Coral Island Ridge Shelf Province



The Coral Island Ridge Province has the same boundaries and characteristics as described in Brewer et al (2015). The Coral Island Ridge Province lies on a prominent volcanic ridge and oceanic plateau extending between the Northern and the Central Indian Ocean. The ridge extends northward from 1° S at the southern end of the Maldivian Archipelago to 14° N at the northern end of Lakshadweep. It forms a sub-surface barrier between the western and eastern Indian Ocean so many of its ecological features are strongly influenced by the major currents in the northern Indian Ocean such as the East Arabian Current and the Northern Equatorial Current.

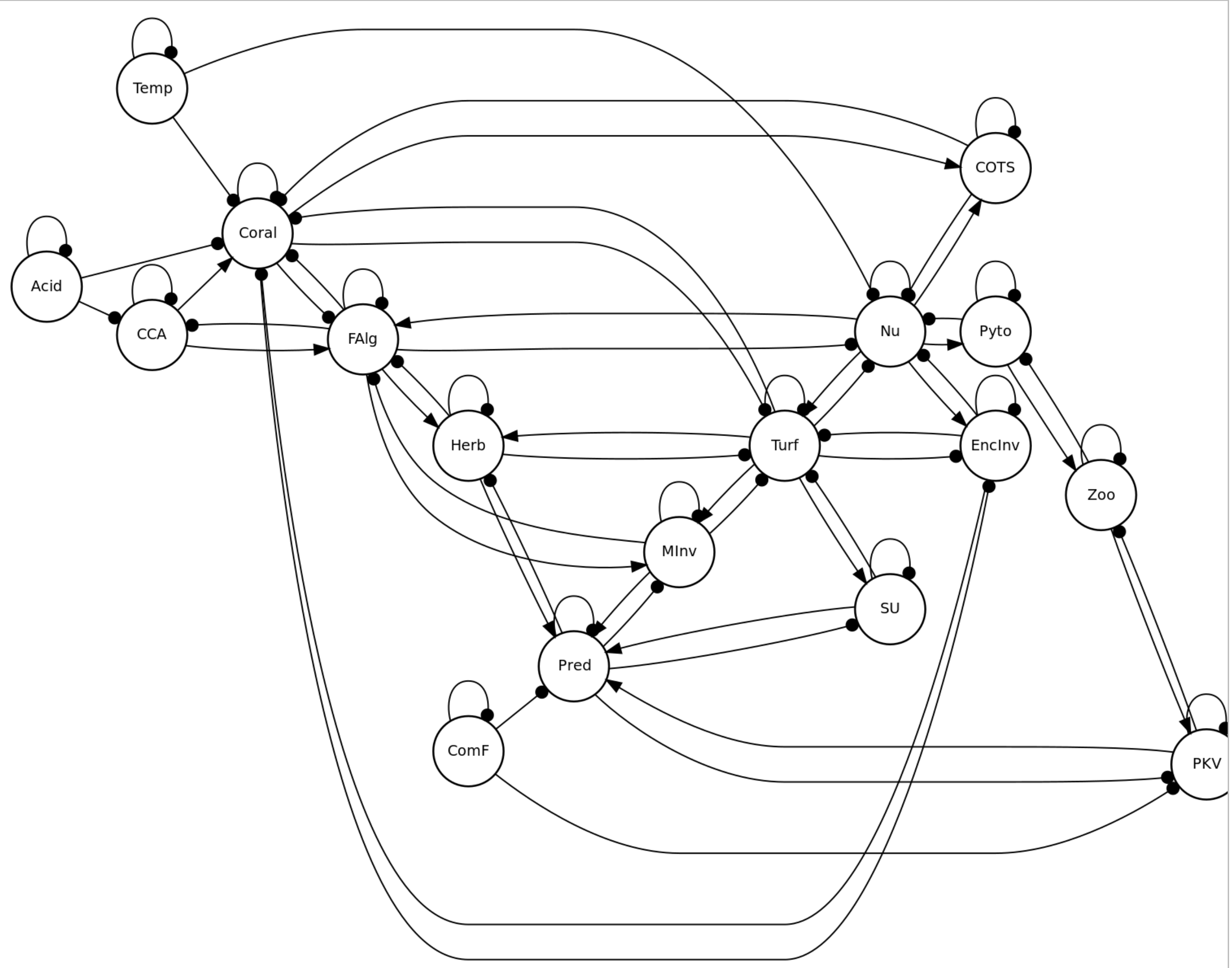


Figure 50: Ecosystem components in the qualitative model are: CCA (CCA), Coral Predators (COTS), Coral (Coral), Fleshy Algae (FAlg), Mobile Invertebrates (MInv), Predatory Fish (Pred), Planktivores (PKV), Herbivorous Fish (Herb), Sea Urchins (SU), Encrusting Invertebrates (EncInv), Turf Algae (Turf), Nutrients (Nu), Commercial Fisheries (ComF), Phytoplankton (Pyto), Zooplankton (Zoo) . Pressures acting on the system are: Temperature (Temp), Acidification (Acid)

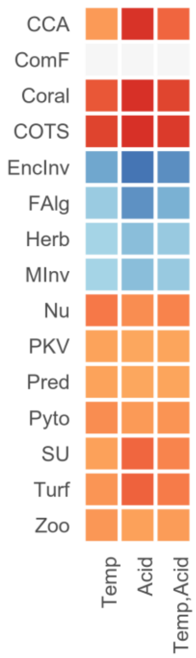
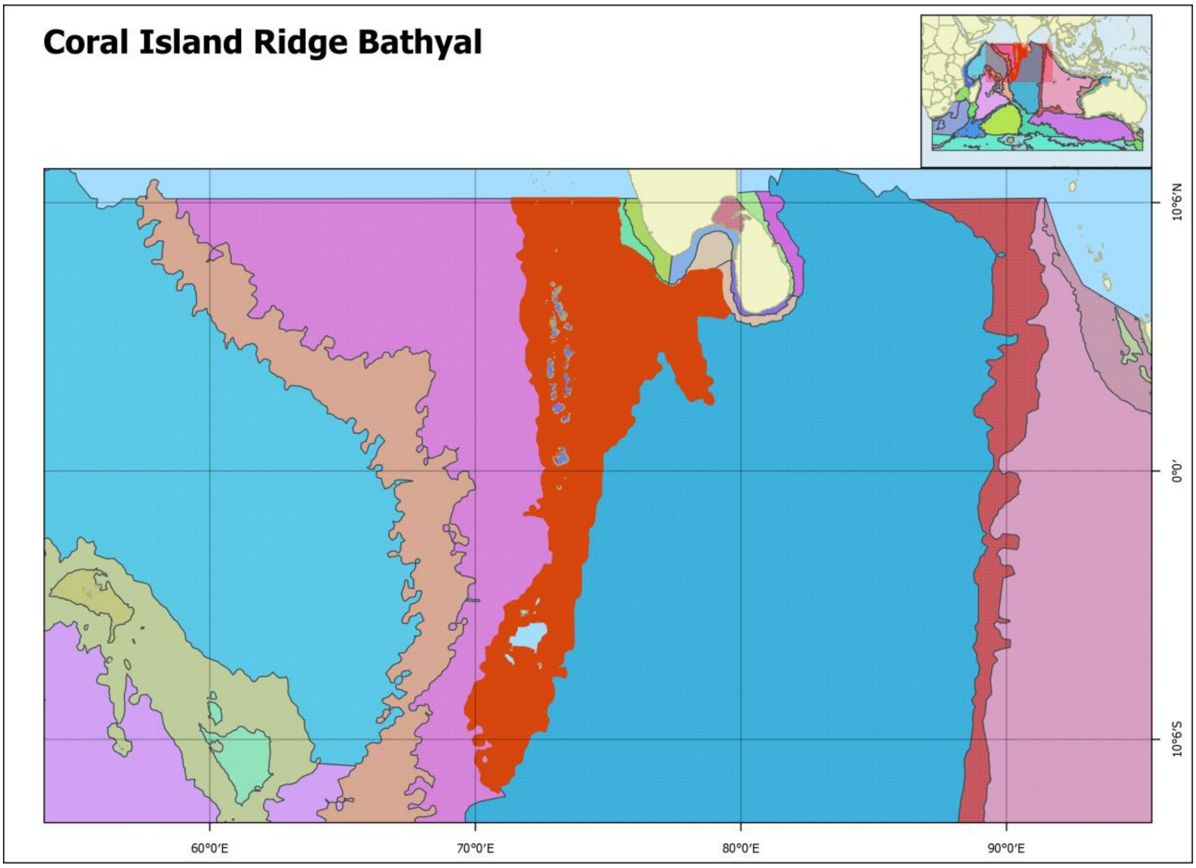


Figure 51: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.8 Coral Island Ridge Bathyl



The Coral Island Ridge Province has the same boundaries and characteristics as described in Brewer et al (2015). The Coral Island Ridge Province lies on a prominent volcanic ridge and oceanic plateau extending between the Northern and the Central Indian Ocean. The ridge extends northward from 1° S at the southern end of the Maldivian Archipelago to 14° N at the northern end of Lakshadweep. It forms a sub-surface barrier between the western and eastern Indian Ocean so many of its ecological features are strongly influenced by the major currents in the northern Indian Ocean such as the East Arabian Current and the Northern Equatorial Current

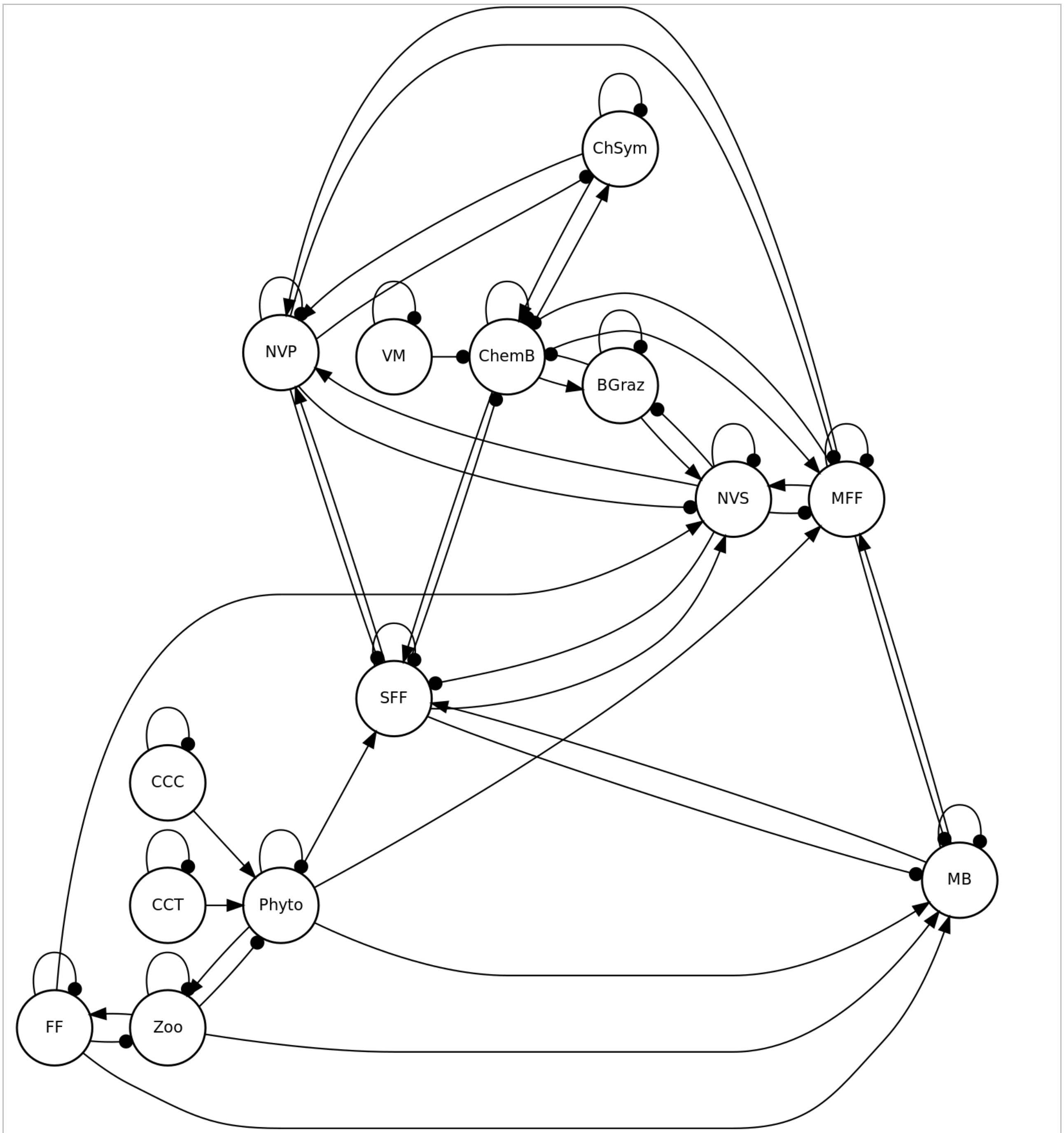


Figure 52: Ecosystem components in the qualitative model are: Non-Vent Predators (NVP), Sessile Filter Feeders (SFF), Mobile Filter Feeders (MFF), Food Falls (FF), Microbes (MB), Phytoplankton (Phyto), Zooplankton (Zoo), Chemosynthetic Bacteria (ChemB), Bacteria grazers (BGraz), Non-Vent Scavengers (NVS), Chemosynthetic Symbionts (ChSym) . Pressures acting on the system are: Vent Mining (VM), Climate Change Chlorophyll (CCC), Climate Change Temperature (CCT)

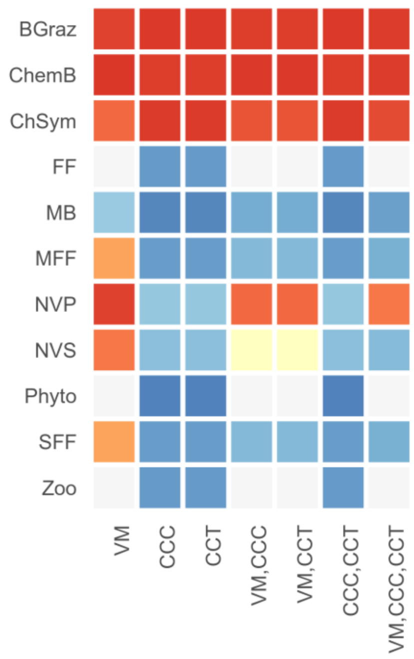
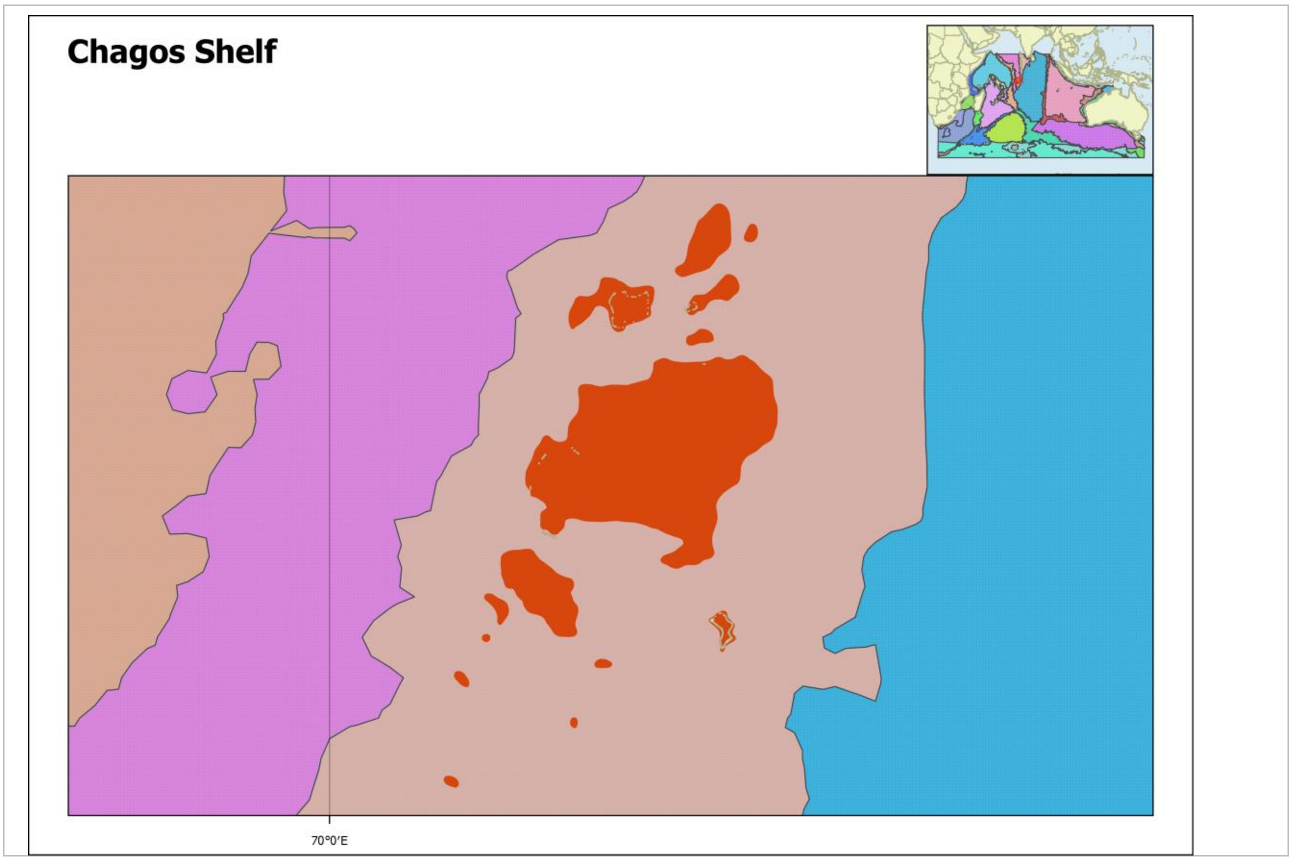


Figure 53: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.9 Chagos Shelf Province



The Chagos province is separated from the Coral Islands province due to the composition of the coral communities (Obura 2012). The coral communities are more similar to Northern Mozambique Channel than to Coral Islands or India.

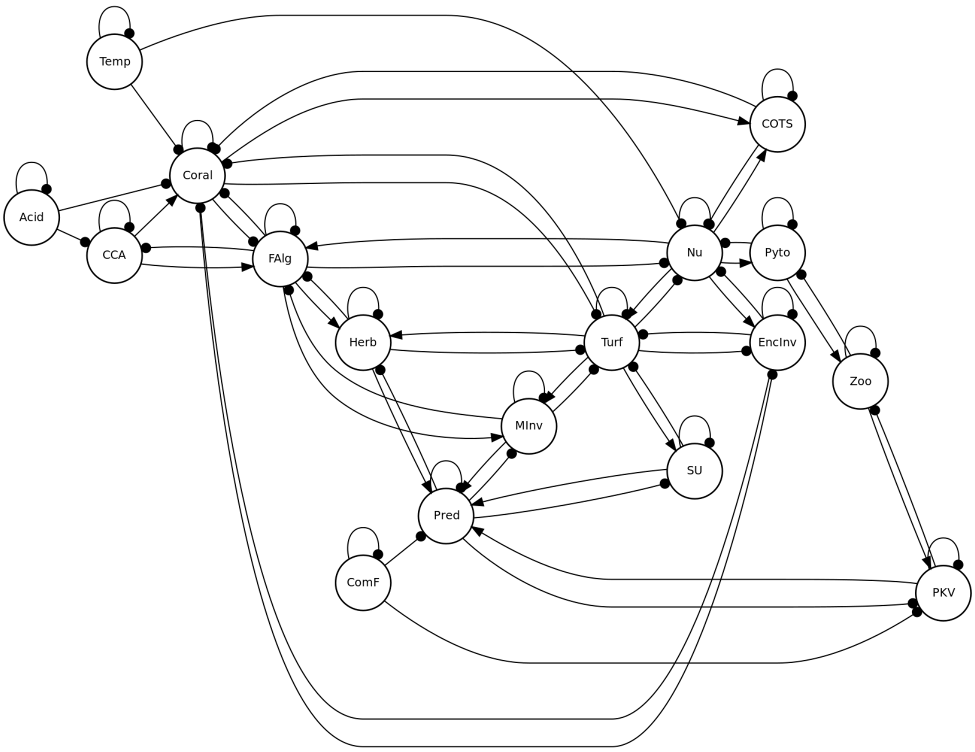


Figure 54: Ecosystem components in the qualitative model are: CCA (CCA), Coral Predators (COTS), Coral (Coral), Fleshy Algae (FAlg), Mobile Invertebrates (MInv), Predatory Fish (Pred), Planktivores (PKV), Herbivorous Fish (Herb), Sea Urchins (SU), Encrusting Invertebrates (EncInv), Turf Algae (Turf), Nutrients (Nu), Commercial Fisheries (ComF), Phytoplankton (Pyto), Zooplankton (Zoo) . Pressures acting on the system are: Temperature (Temp), Acidification (Acid)

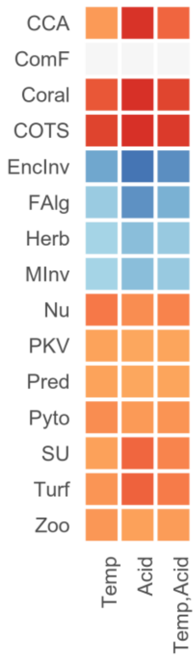
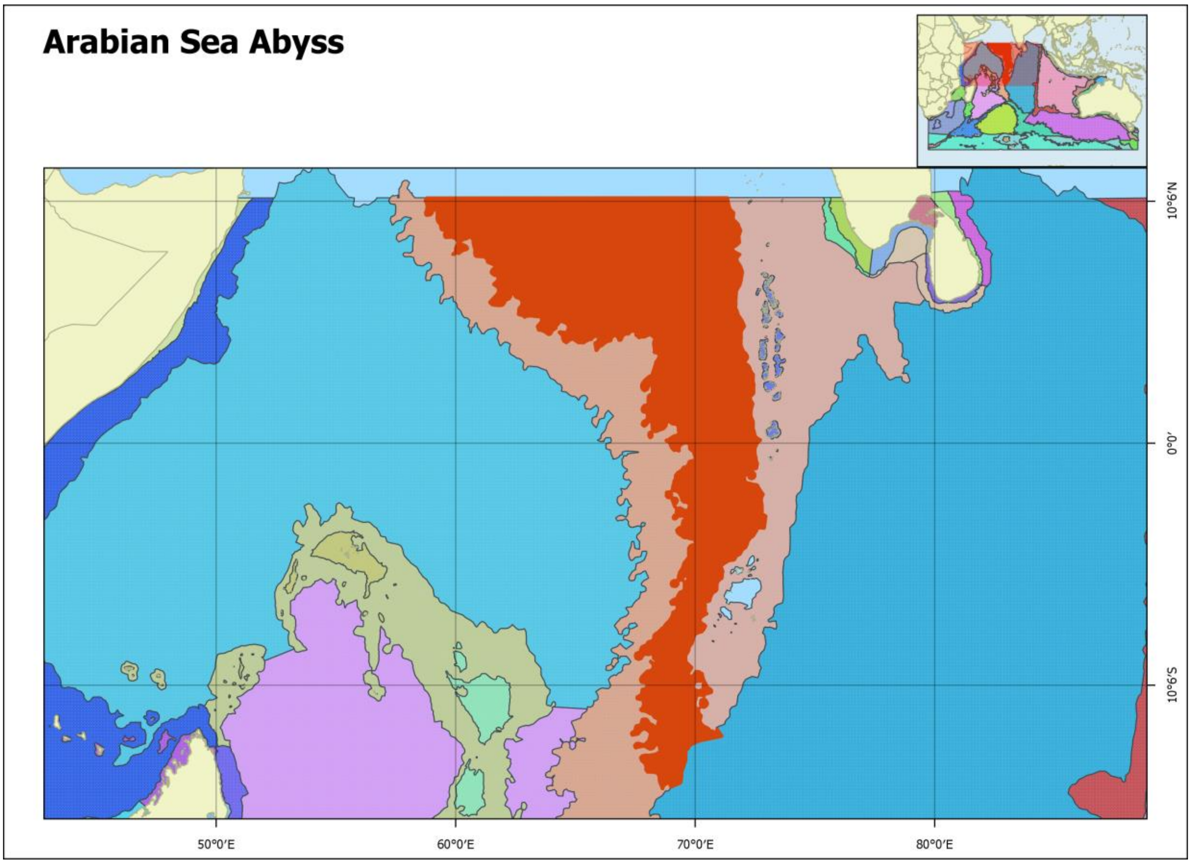


Figure 55: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.10 Arabian Sea Abyss



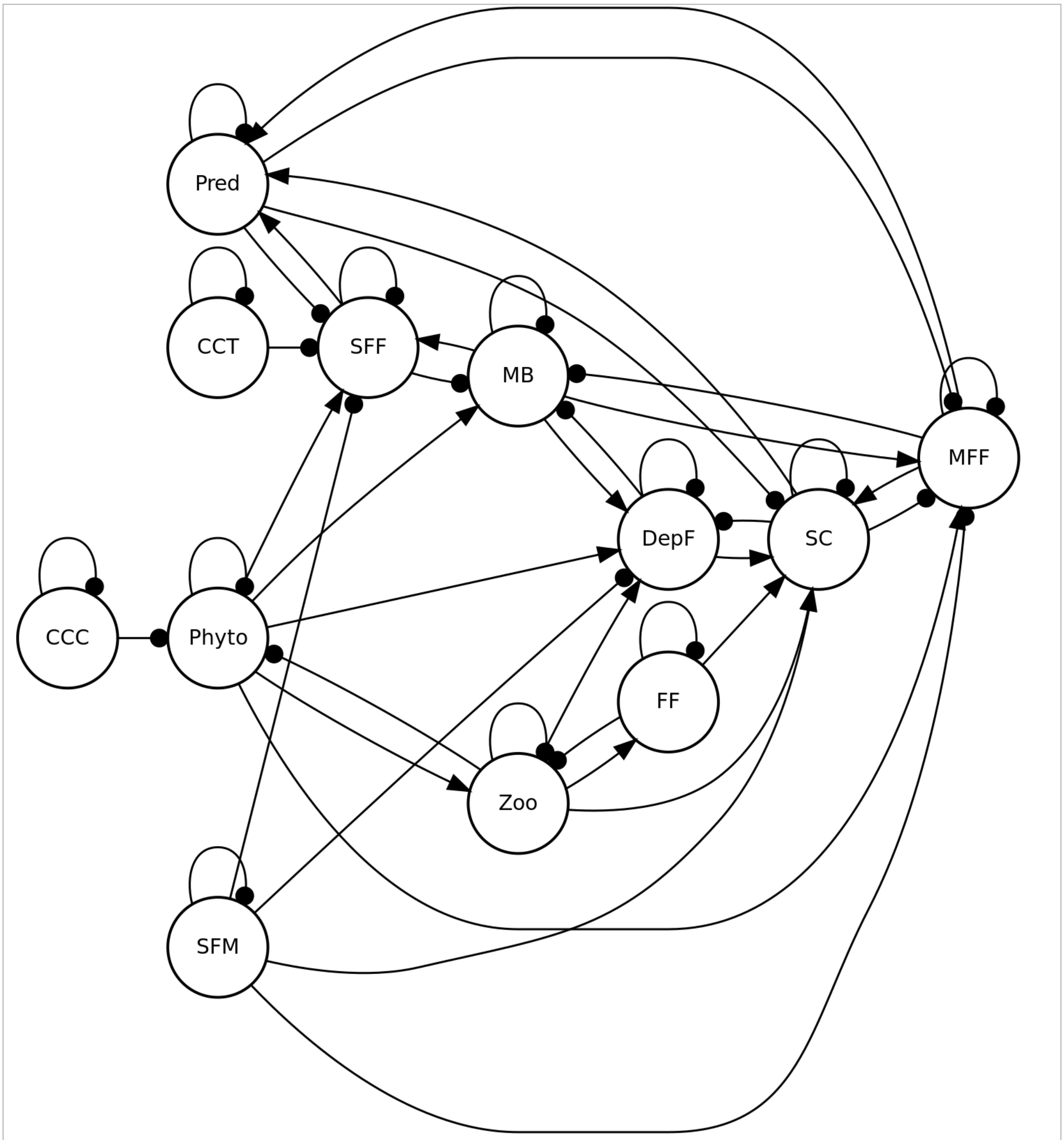


Figure 56: Ecosystem components in the qualitative model are: Predatory Fish (Pred), Sessile Filter Feeders (SFF), Mobile Filter Feeders (MFF), Scavengers (SC), Microbes (MB), Phytoplankton (Phyto), Zooplankton (Zoo), Food Falls (FF), Deposit Feeders (DepF) . Pressures acting on the system are: Seafloor Mining (SFM), Climate Change Chlorophyll (CCC), Climate Change Temperature (CCT)

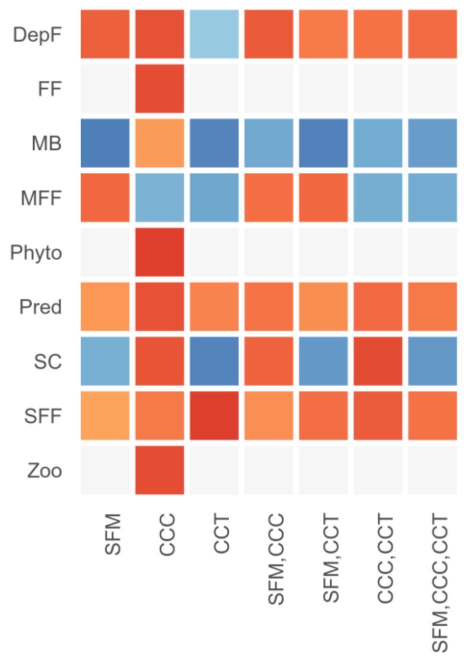
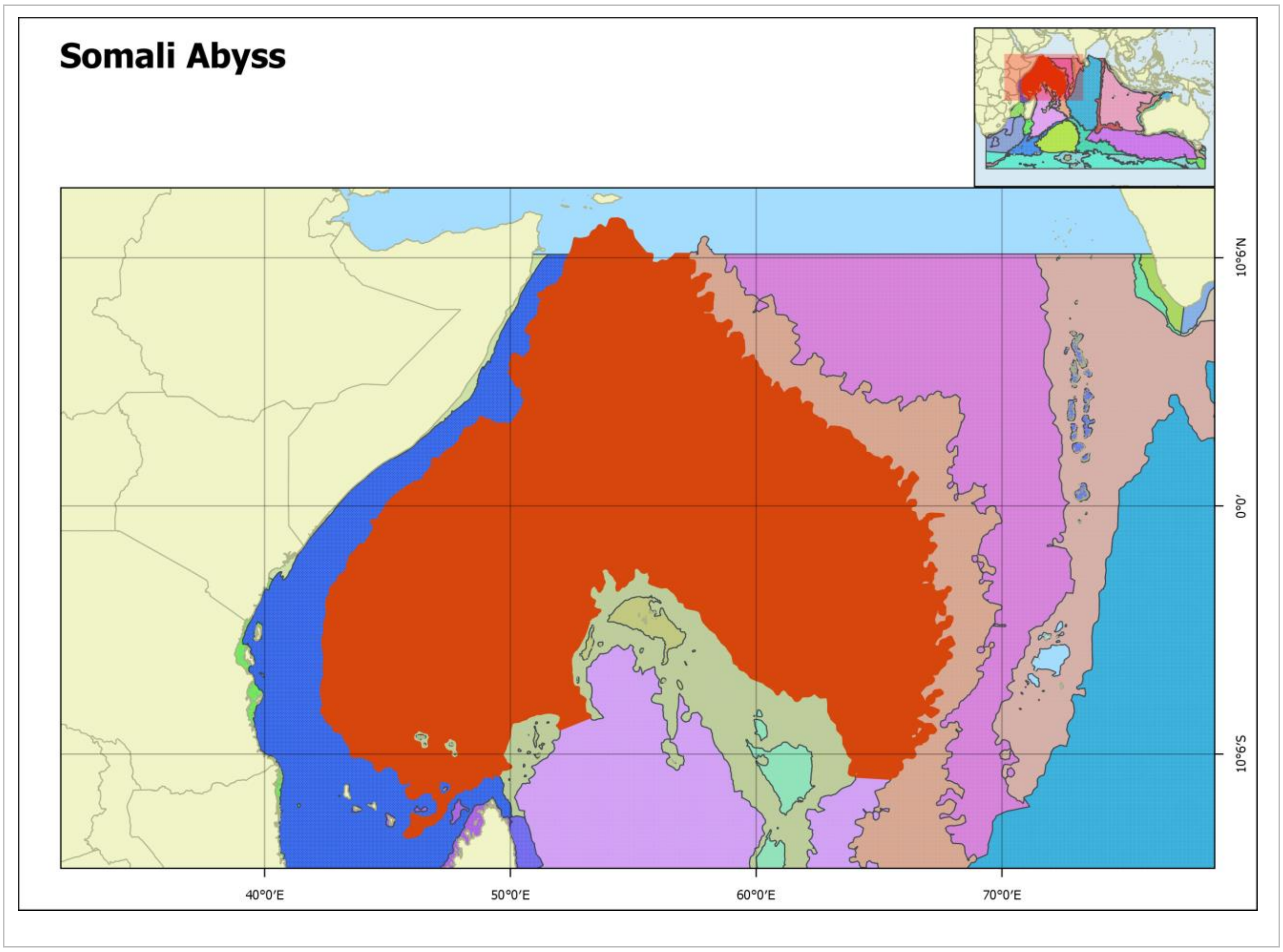


Figure 57: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.11 Somali Abyss



The Somali Abyss is the large abyssal plain between the coast of Africa and the Central Indian Ridge Province. This is separated from the South West Indian Abyss by the Mozambique Channel and is presumed to contain a distinct fauna. There may be connections with the fauna in the Arabian Sea. Analysis of squat lobster assemblages (Appendix A) suggests that this is separate from the surrounding abyssal plains and belongs to EMU cluster 14 (Sayre *et al.,* 2017).

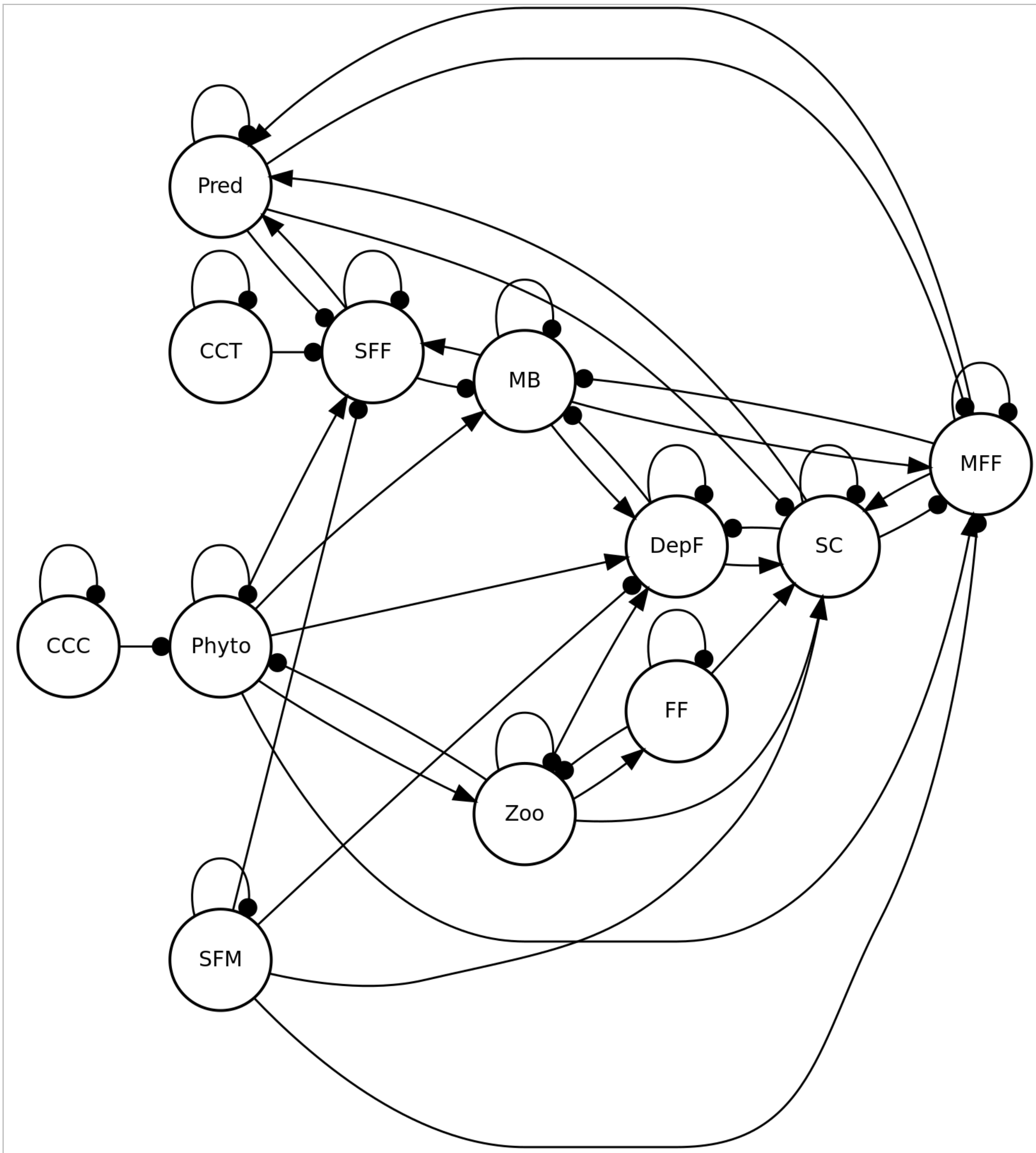


Figure 58: Ecosystem components in the qualitative model are: Predatory Fish (Pred), Sessile Filter Feeders (SFF), Mobile Filter Feeders (MFF), Scavengers (SC), Microbes (MB), Phytoplankton (Phyto), Zooplankton (Zoo), Food Falls (FF), Deposit Feeders (DepF) . Pressures acting on the system are: Seafloor Mining (SFM), Climate Change Chlorophyll (CCC), Climate Change Temperature (CCT)

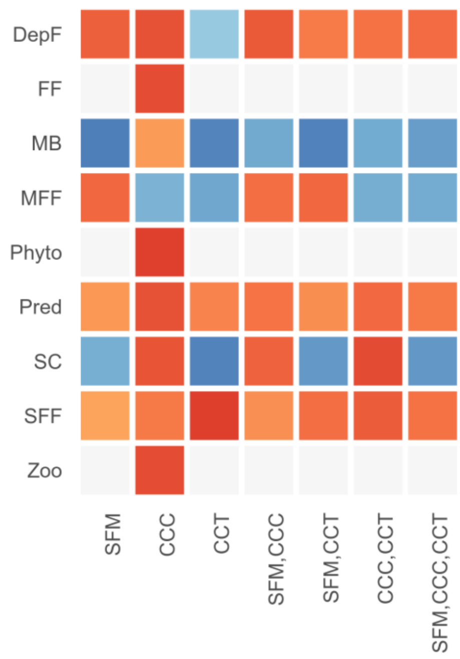
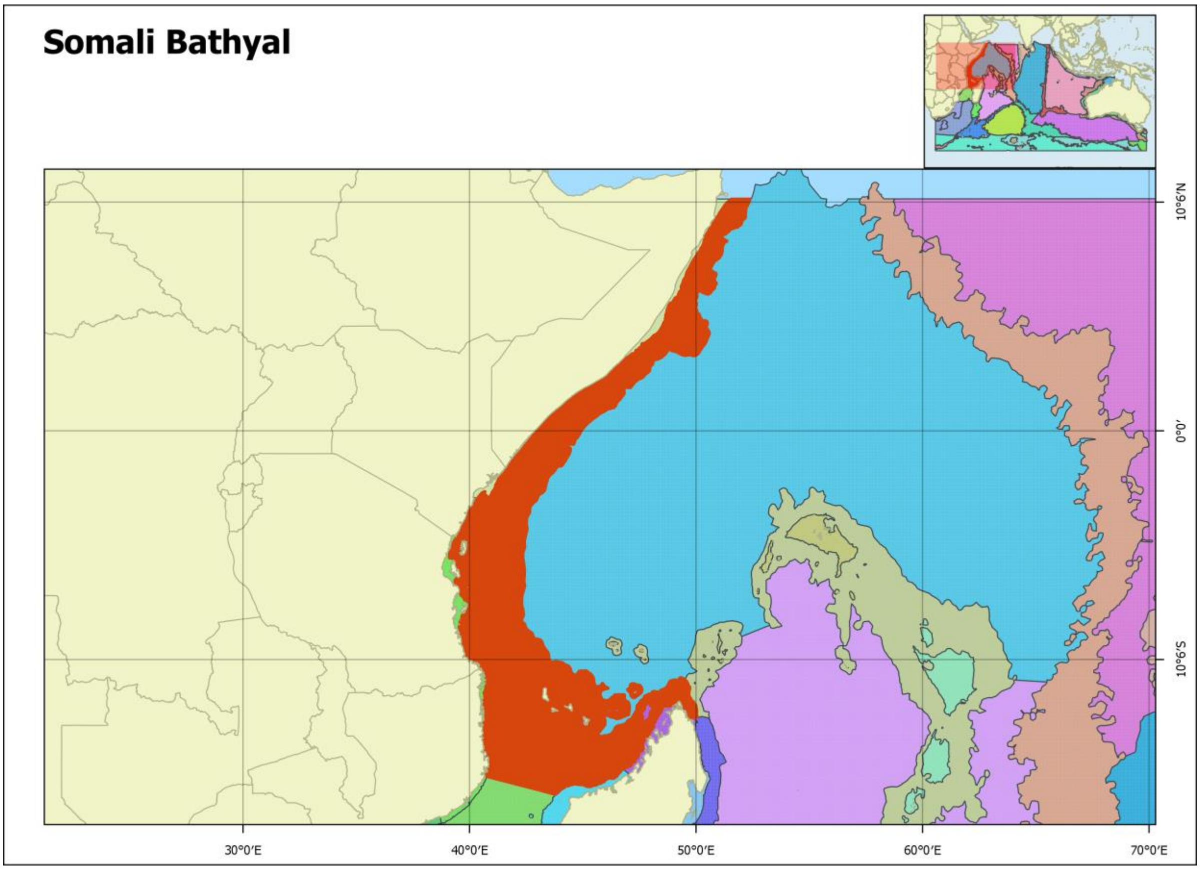


Figure 59: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.12 Somali Bathyal



The Somali Bathyal is the large coastal Inferred from bathymetry and the fact the abysal habitat is not connected through the Mozambique channel; See also Woolley et al squat lobsters (Appendix A). EMU bottom layer cluster 13 matches bathyal (Sayre et al., 2017). The Great Whirl Eddy forms above this feature on the Somali coast and the basin is bounded by the South Equatorial Current, East African Coastal Current and Somalia Current. Basin extends from shelf to tip of Madagascar. The Analysis of Squat lobsters highlights difference between Mozambique Channel and Somali Basin. The bathyal province is characterised by unique Corals (Santini & Winterbottom 2002, Samyn & Tallon 2005) and Holothurians (McClanahan 1988; Di Marco et al. 2002).

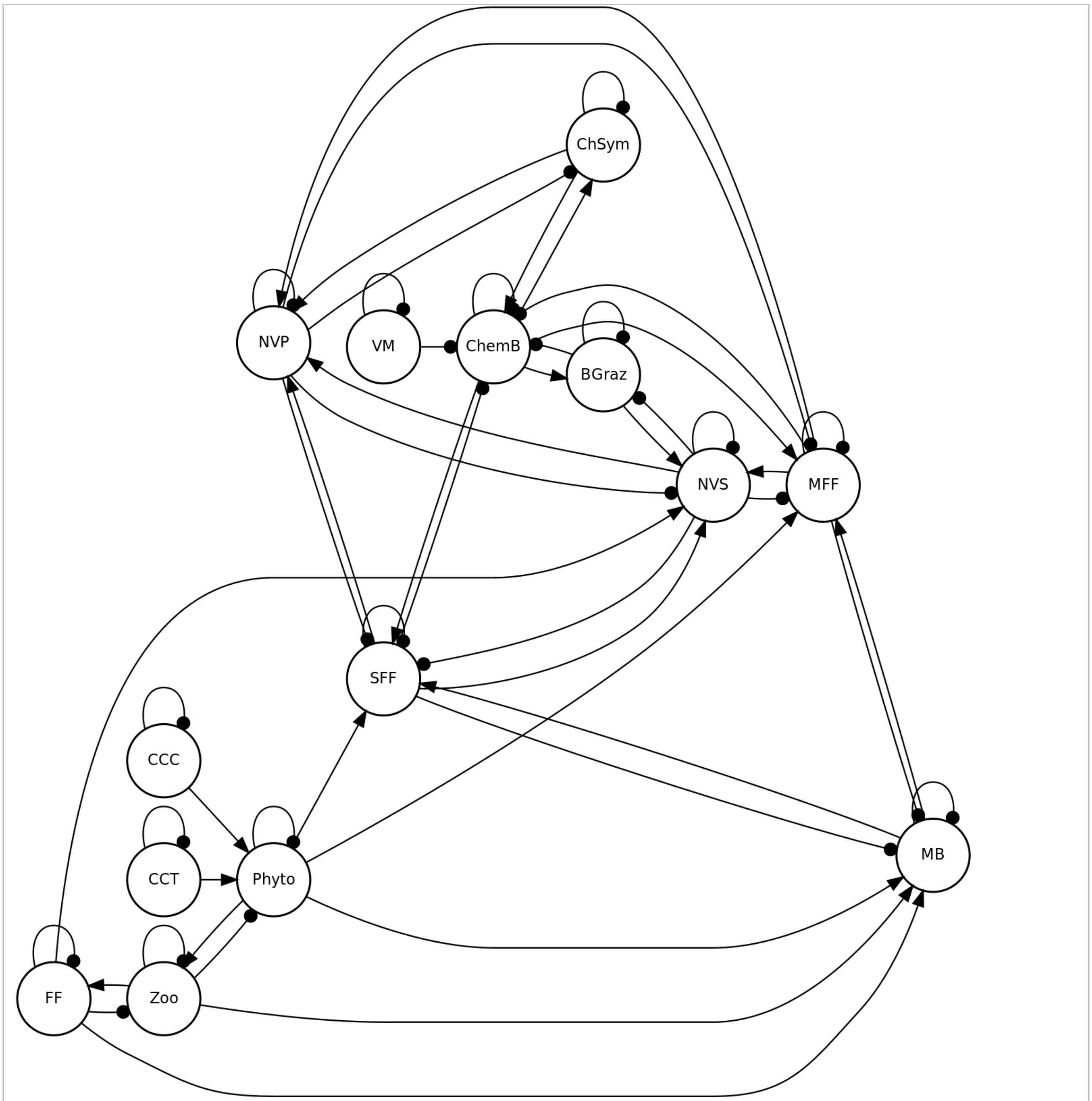


Figure 60: Ecosystem components in the qualitative model are: Non-Vent Predators (NVP), Sessile Filter Feeders (SFF), Mobile Filter Feeders (MFF), Food Falls (FF), Microbes (MB), Phytoplankton (Phyto), Zooplankton (Zoo), Chemosynthetic Bacteria (ChemB), Bacteria grazers (BGraz), Non-Vent Scavengers (NVS), Chemosynthetic Symbionts (ChSym) . Pressures acting on the system are: Vent Mining (VM), Climate Change Chlorophyll (CCC), Climate Change Temperature (CCT)

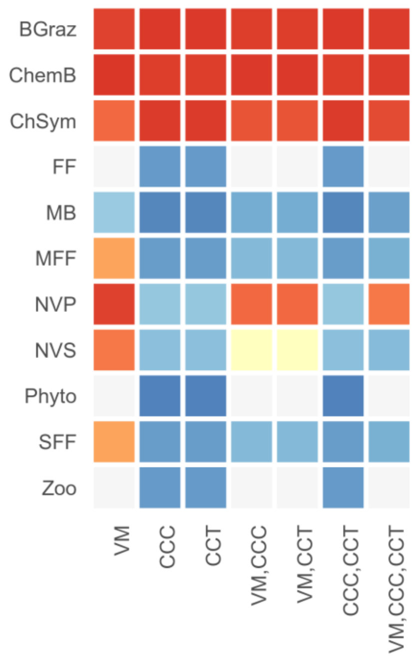
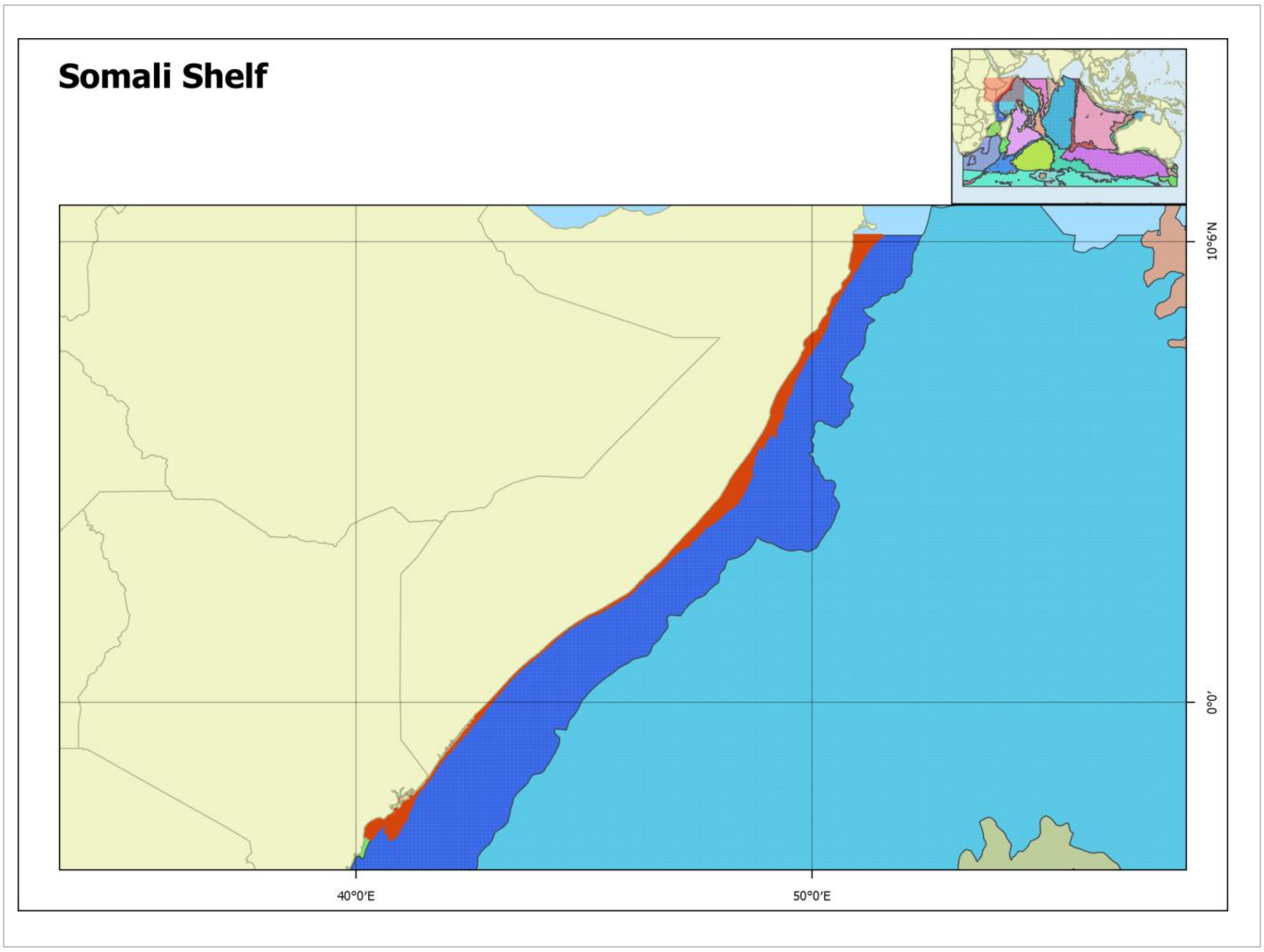


Figure 61: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.13 Somalia Shelf Province



The Central Somalia province extends from the northern boundary of the monsoon coast to the extent of the region studied. Obura (2012) located the northern extent as south of the Socotra Islands. This region is characterised by the Somali-Arabian sea upwelling associated with Somali current that run south to north and feeds into the Gulf of Aden. The Great Whirl eddy forms offshore in April and drives the seasonal upwelling that can be seen on the coasts. This upwelling commences in May and decreases through August-September (Beal and Donohue 2013). There is very little biological data, but records of catch suggest that there region can support large catches, primarily *Dussumieria acuta*, *Etrumeus teres* and *Sardinella longiceps, Decapterus macrosoma*, *D. russelli* and *Scomber japonicus* (FAO 1999).

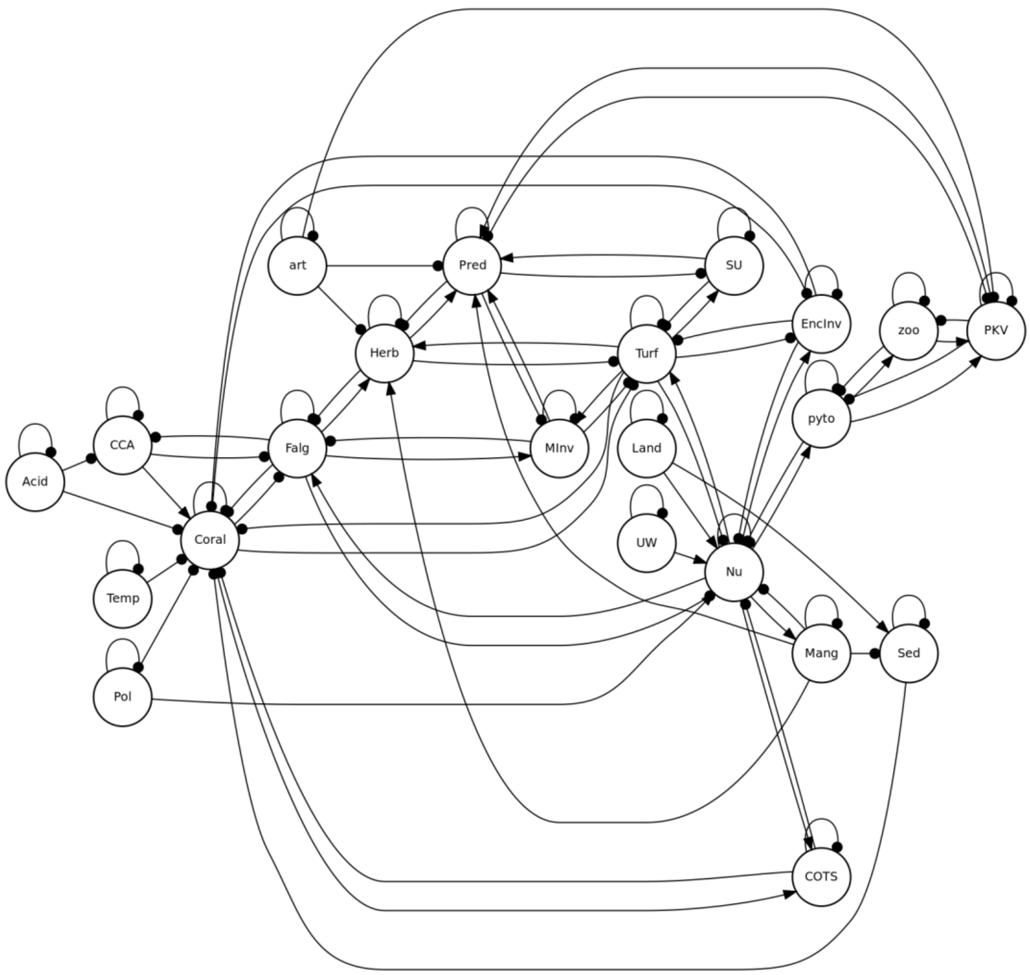


Figure 62: Ecosystem components in the qualitative model are: CCA (CCA), Coral Predators (COTS), Coral (Coral), Fleshy Algae (Falg), Mobile Invertebrates (MInv), Predatory Fish (Pred), Planktivores (PKV), Herbivorous Fish (Herb), Sea Urchins (SU), Encrusting Invertebrates (EncInv), Turf Algae (Turf), Nutrients (Nu), Phytoplankton (pyto), Mangrove (Mang), Zooplankton (zoo) . Pressures acting on the system are: Sediment (Sed), Pollution (Pol), Artisanal Fisheries (art), Temperature (Temp), Acidification (Acid), Land Use Change (Land), Upwelling (UW)

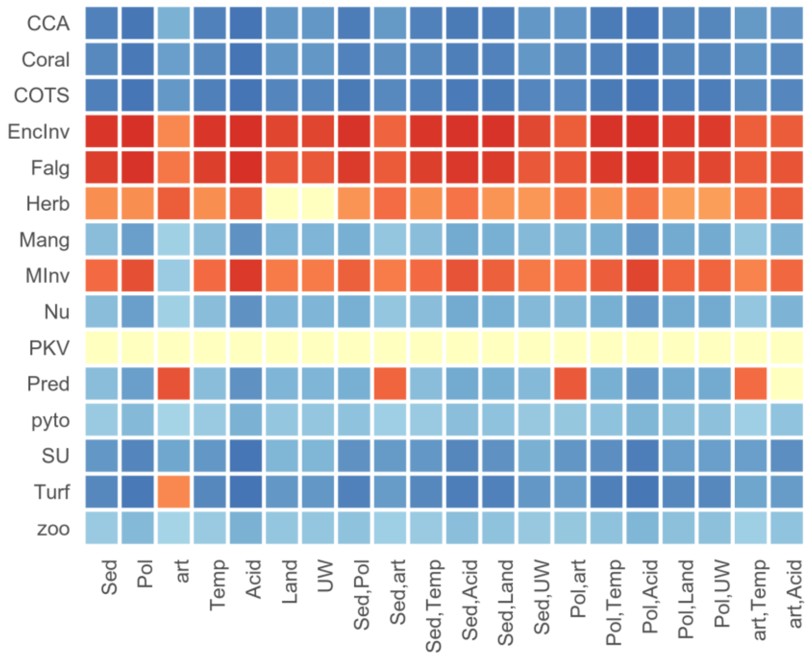
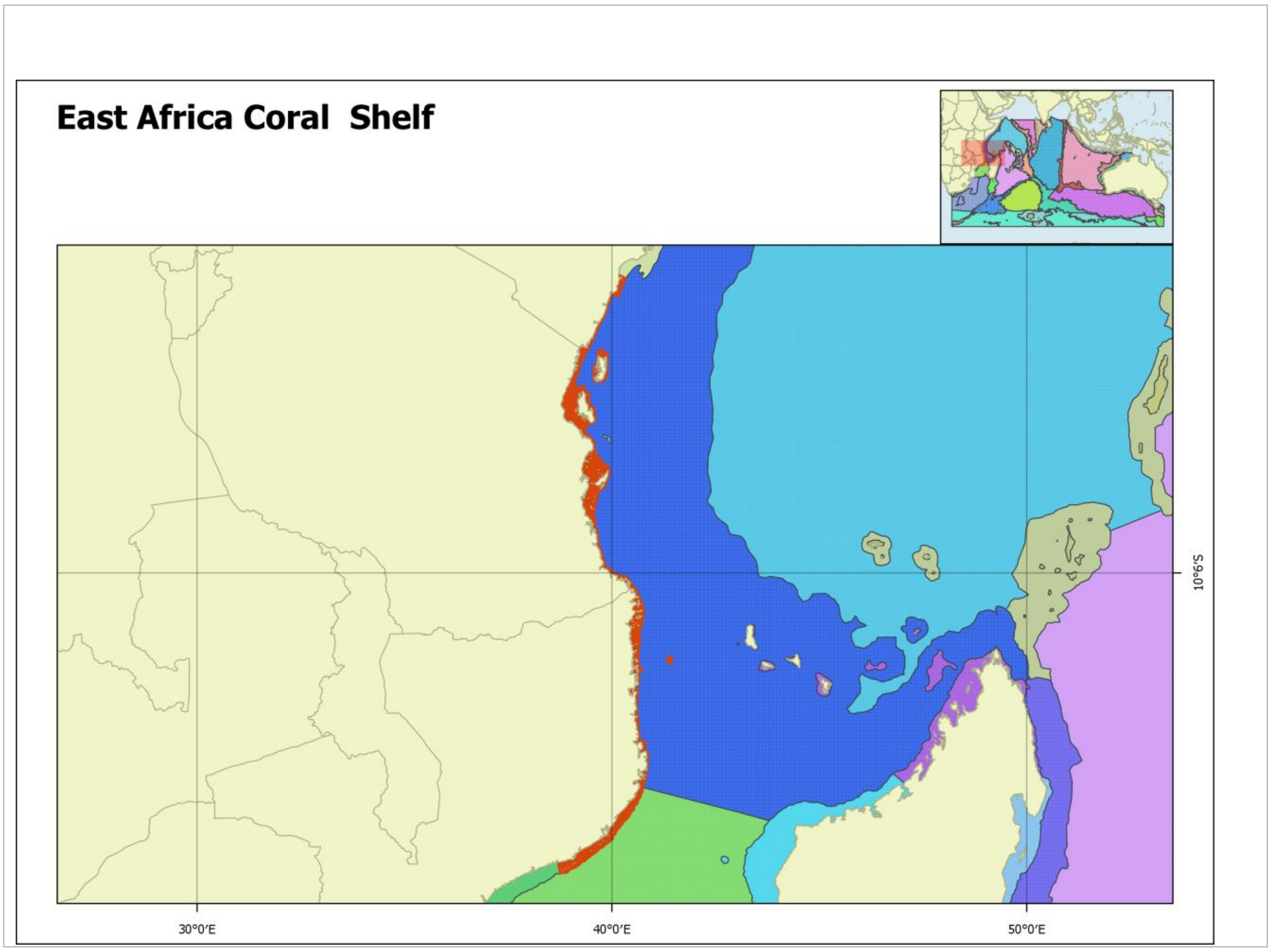


Figure 63: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.14 East Africa Coral Shelf Province



The East Africa Coral Shelf province is characterised by low nutrient waters, with pronounced seasonal upwelling (Anderson and Andrew 2016). There is strong seasonal (monsoon) input into the shelf from river discharge. The higher levels of productivity are associated with the monsoon season's upwelling. (Samoilys et al. 2014.). This province was identified in Marine Ecoregions of the World and further validated by (Obura 2012).

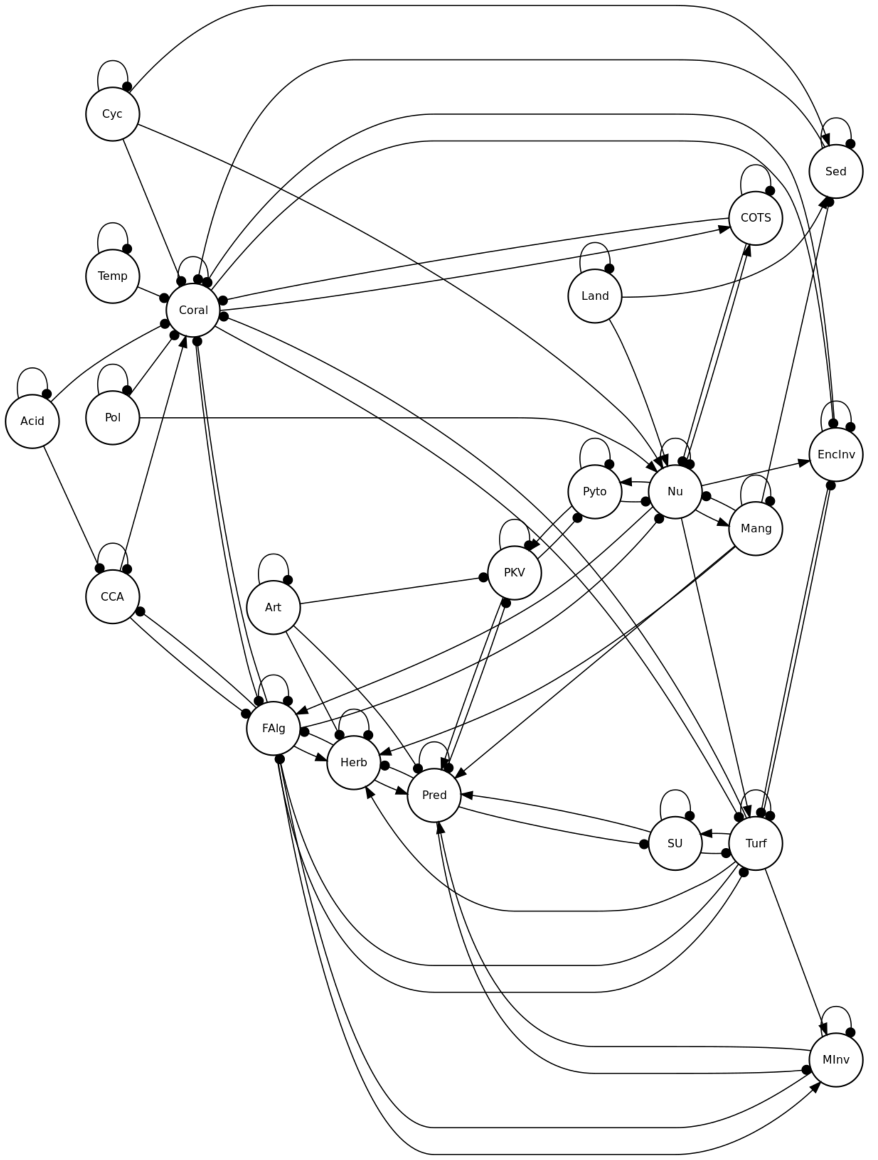


Figure 64: Ecosystem components in the qualitative model are: CCA (CCA), Coral Predators (COTS), Coral (Coral), Fleshy Algae (FAlg), Mobile Invertebrates (MInv), Predatory Fish (Pred), Planktivores (PKV), Herbivorous Fish (Herb), Sea Urchins (SU), Encrusting Invertebrates (EncInv), Turf Algae (Turf), Nutrients (Nu), Phytoplankton (Pyto), Mangrove (Mang) . Pressures acting on the system are: Sediment (Sed), Pollution (Pol), Artisanal Fisheries (Art), Temperature (Temp), Acidification (Acid), Land Use Change (Land), Cyclones (Cyc)

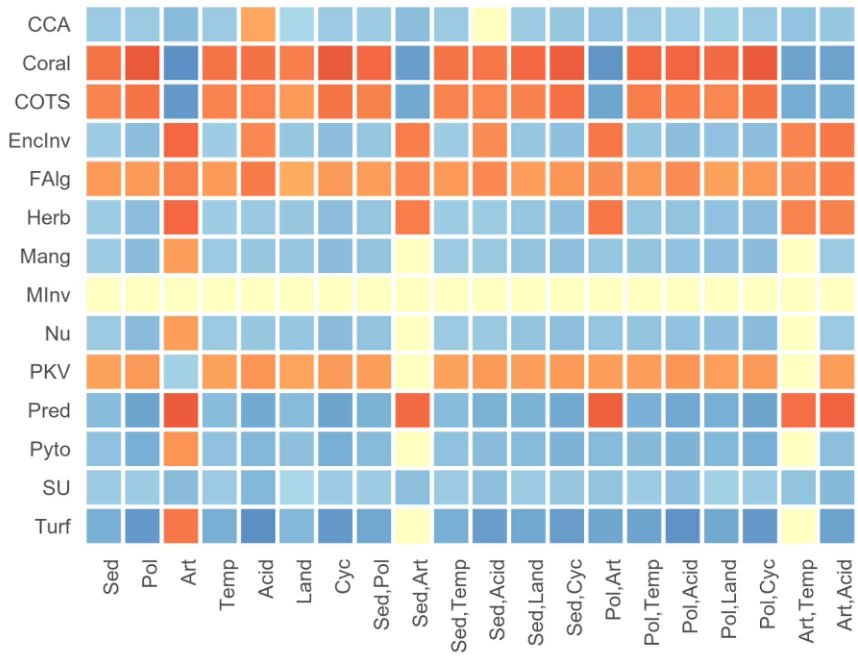
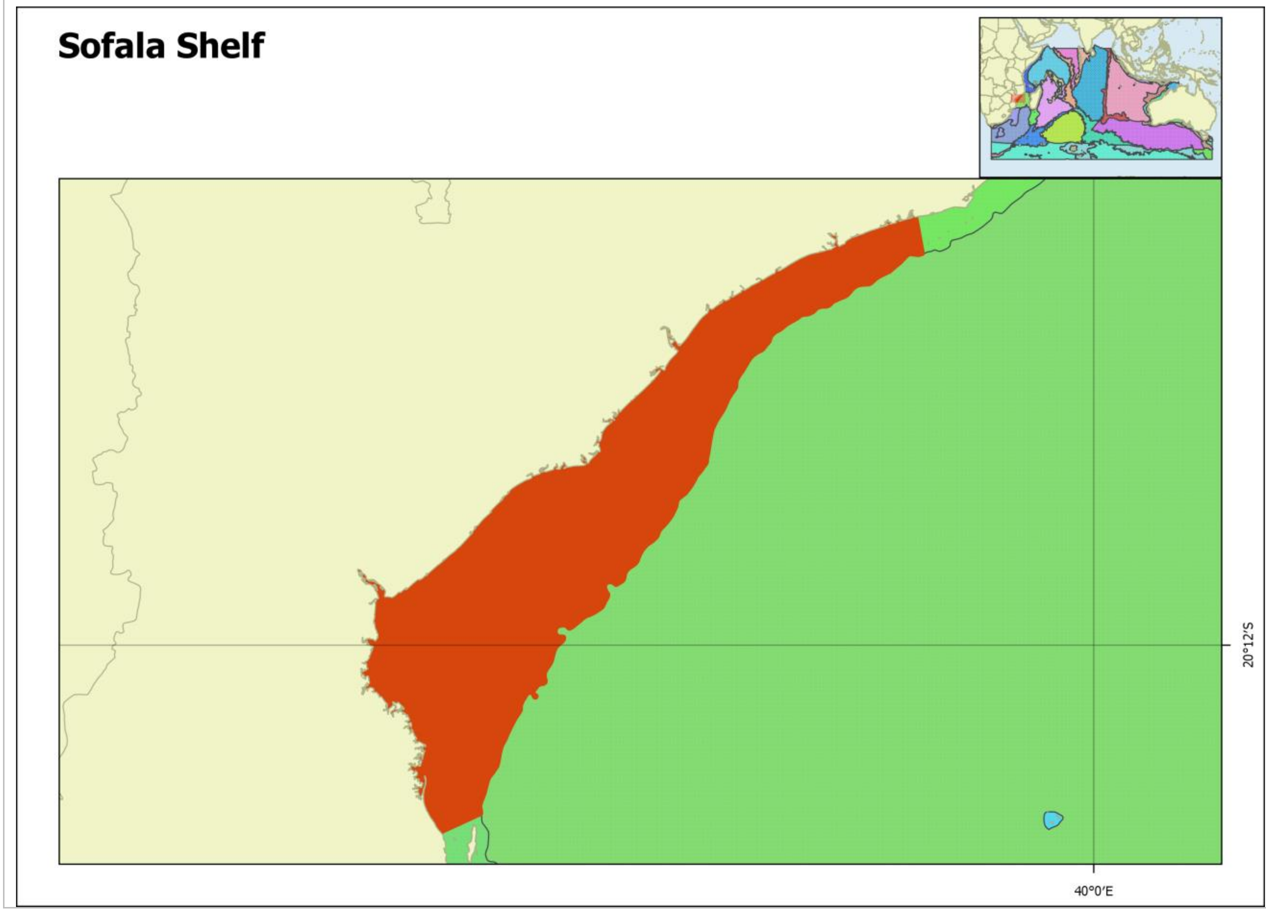


Figure 65: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.15 Sofala Shelf Province



The Sofala Shelf Channel is a large region the south west Mozambique Channel. The taxa are described in Obura, Church & Gabriel (2012) and Samoilys et al. (2014). The Sofala shelf has a significant number of commercially significant fish stocks (Groeneveld and Koranteng 2017). The similarity between both sides of the channel was also identified in the WWF RAMP-COI (2011) report.

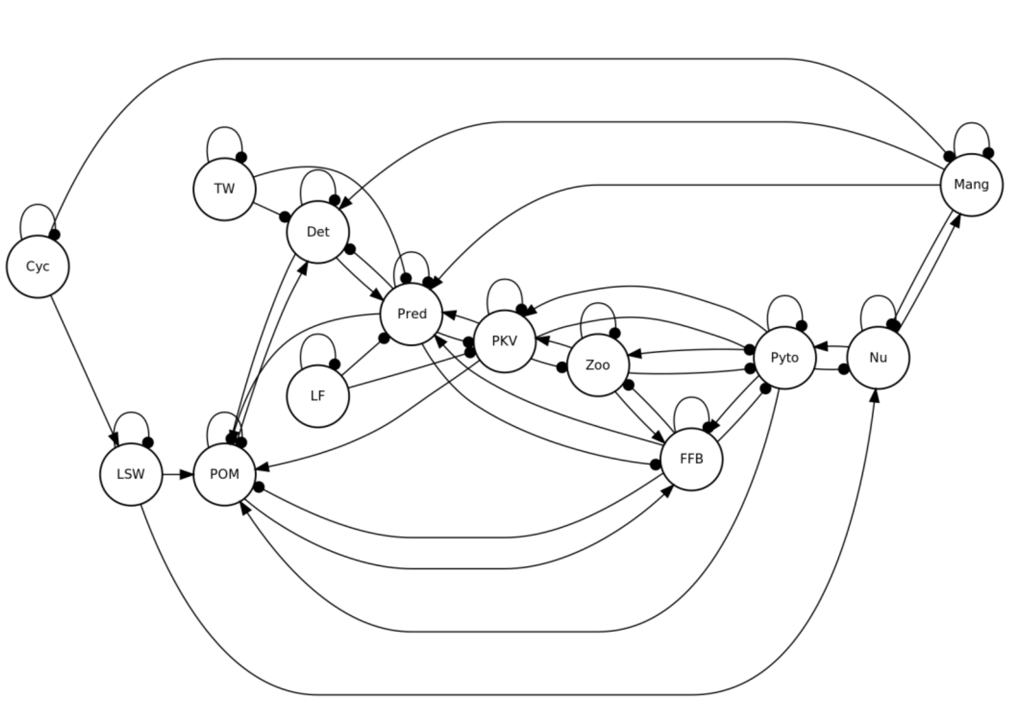


Figure 66: Ecosystem components in the qualitative model are: Particulate Organic Matter (POM), Nutrients (Nu), Phytoplankton (Pyto), Zooplankton (Zoo), Predatory Fish (Pred), Planktivores (PKV), Detritivores (Det), Filter Feeder Benthic (FFB), Mangroves (Mang) . Pressures acting on the system are: Line Fishing (LF), Low Saline Water (LSW), Trawl (TW), Cyclones (Cyc)

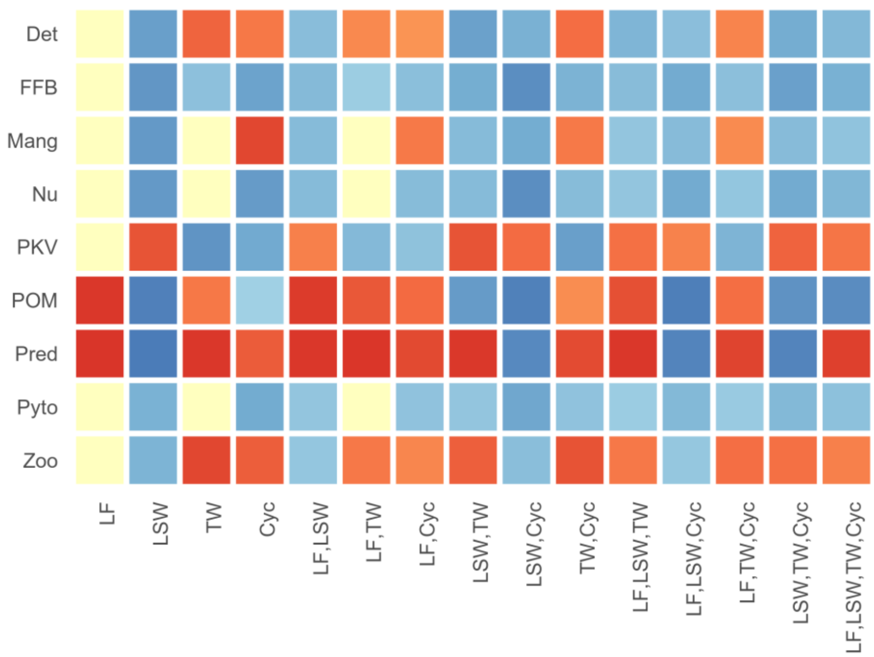
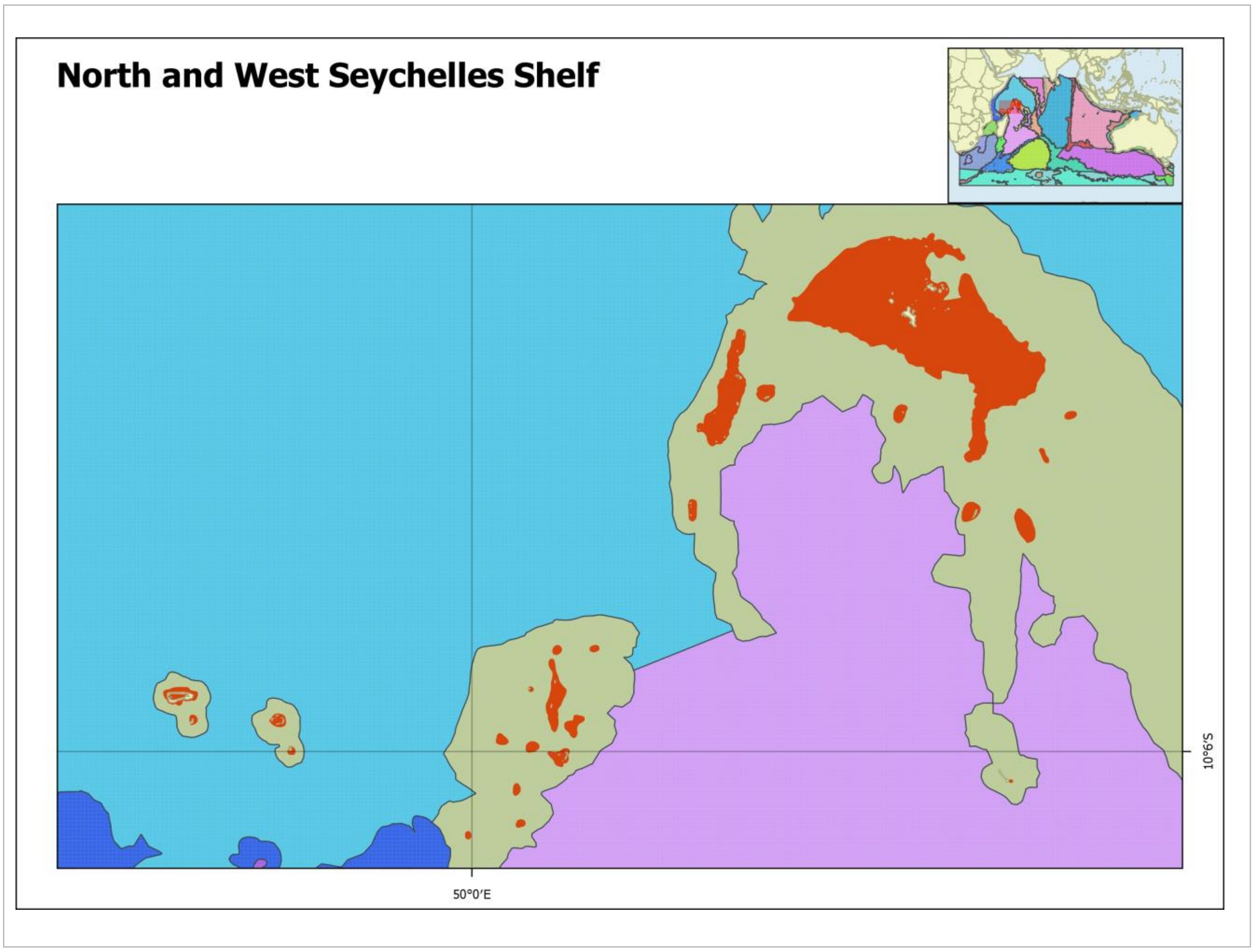


Figure 67: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.16 North and West Seychelles Shelf Province



The North and West Seychelles Province was identified in Obura (2012). Obura (2012) noted that the flow of the Southern Equatorial Current separates the northern Seychelles Islands from the Southern Mascarene Islands. There is a clear gradient between these islands and the Mozambique Channel and North Mozambique Province on the east coast of Africa. These islands typically have low coral diversity and endemism in the islands.

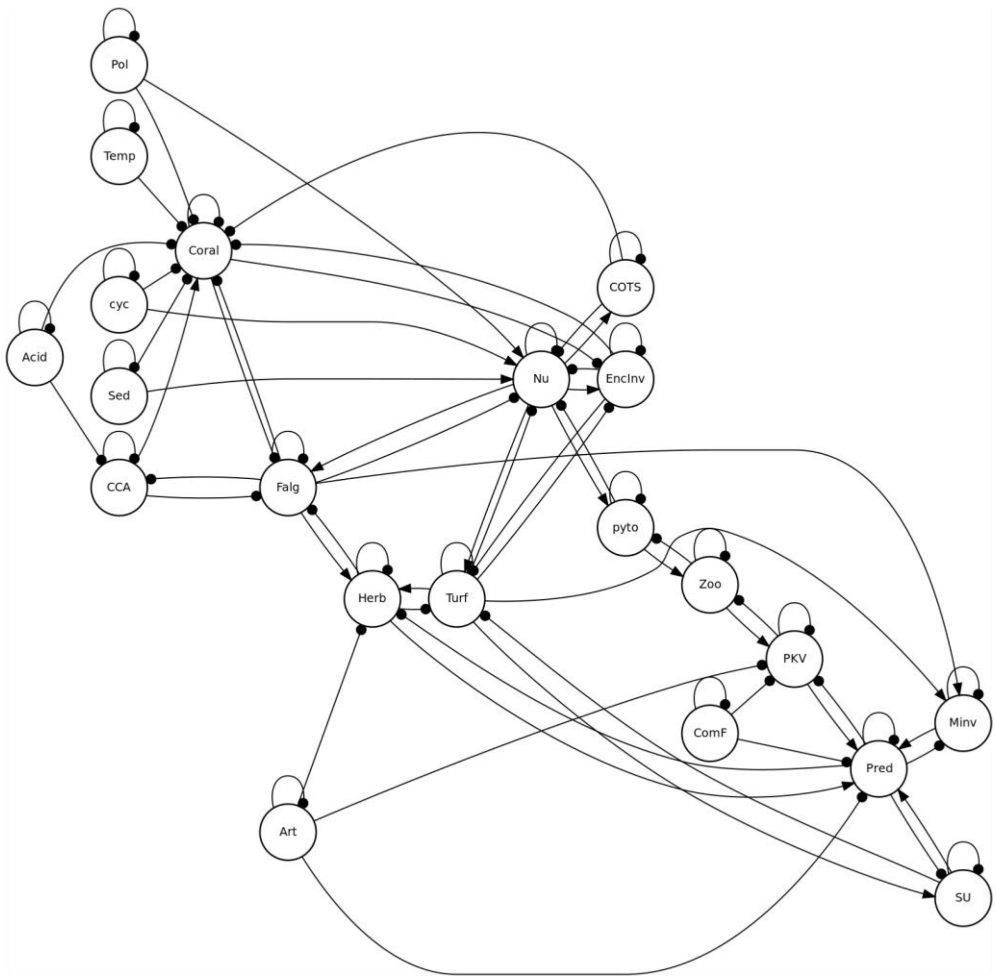


Figure 68: Ecosystem components in the qualitative model are: CCA (CCA), CoralPredators (COTS), Coral (Coral), Fleshy Algae (Falg), Mobile Invertebrates (Minv), Predatory Fish (Pred), Planktivores (PKV), Herbivorous Fish (Herb), SeaUrchins (SU), Encrusting Invertebrates (EncInv), Turf Algae (Turf), Nutrients (Nu), Zooplankton (Zoo), Phytoplankton (pyto) . Pressures acting on the system are: Sediment (Sed), Pollution (Pol), Artesinal Fisheries (Art), Temperature (Temp), Acidification (Acid), Commercial Fisheries (ComF), Cyclones (cyc)

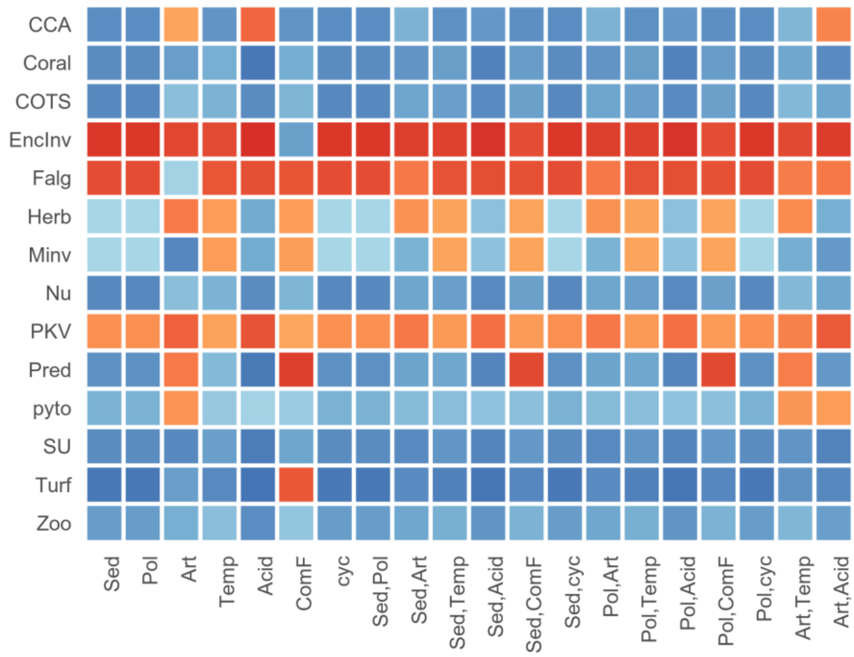
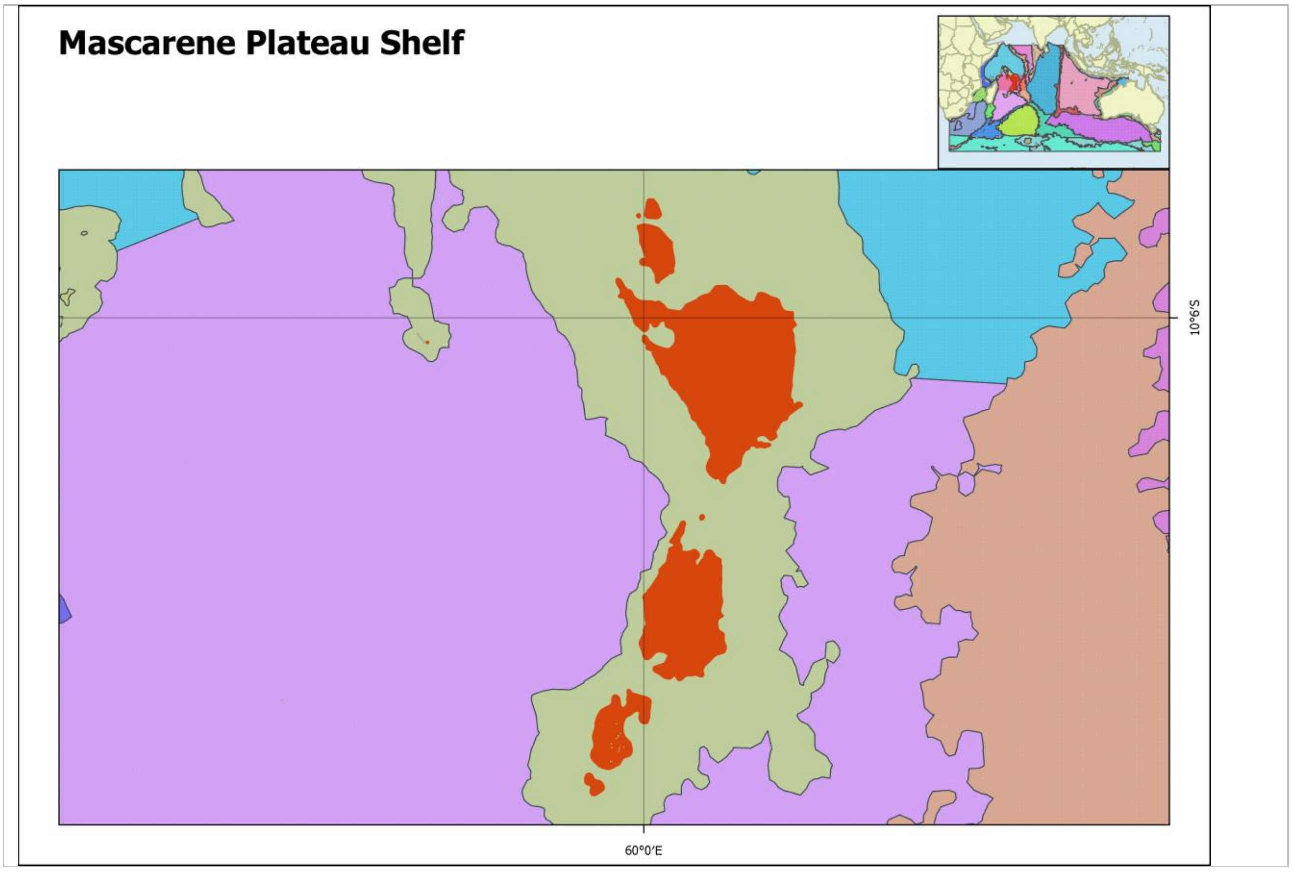


Figure 69: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.17 Mascarene Plateau Shelf



The Mascarene Plateau Shelf province is the shallow shelf areas between Seychelles and Mauritius (Obura 2012).

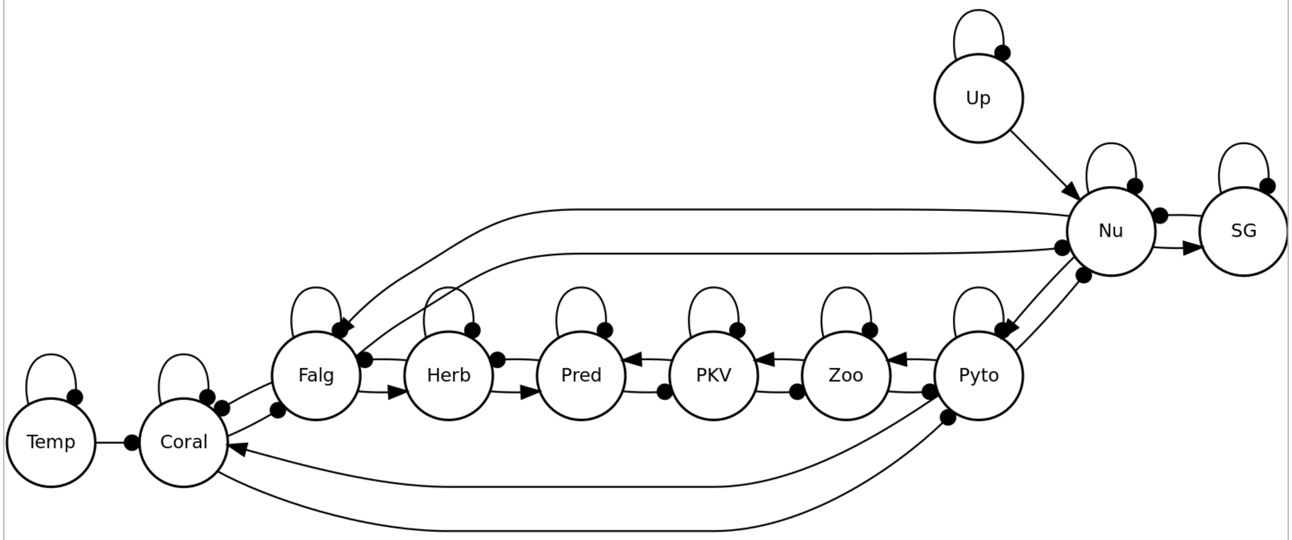


Figure 70: Ecosystem components in the qualitative model are: Coral (Coral), Seagrass (SG), Fleshy Algae (Falg), Nutrients (Nu), Planktivores (PKV), Herbivorous Fish (Herb), Predatory Fish (Pred), Zooplankton (Zoo), Phytoplankton (Pyto) . Pressures acting on the system are: Upwelling (Up), Temperature (Temp)

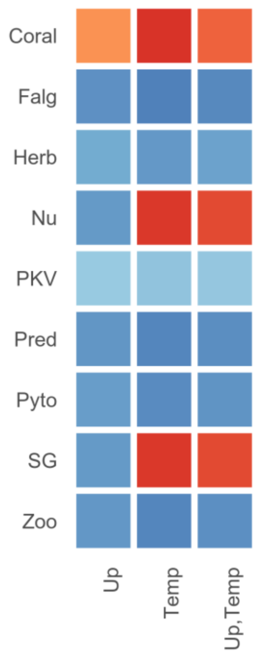
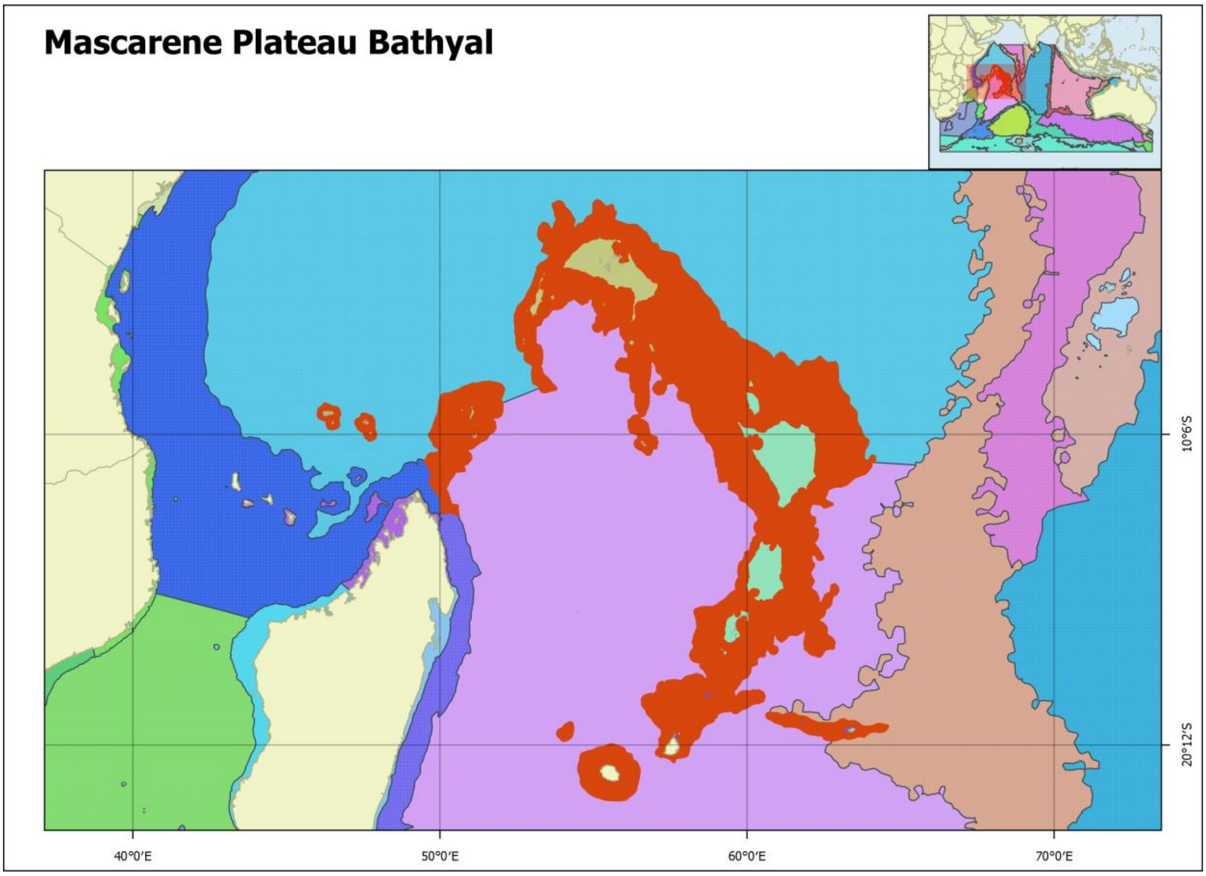


Figure 71: : Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.18 Mascarene Plateau Bathyal



The Mascarene Plateau Bathyal region is the large bathyal region between Mauritius and Seychelles. It is surrounded by abyssal areas

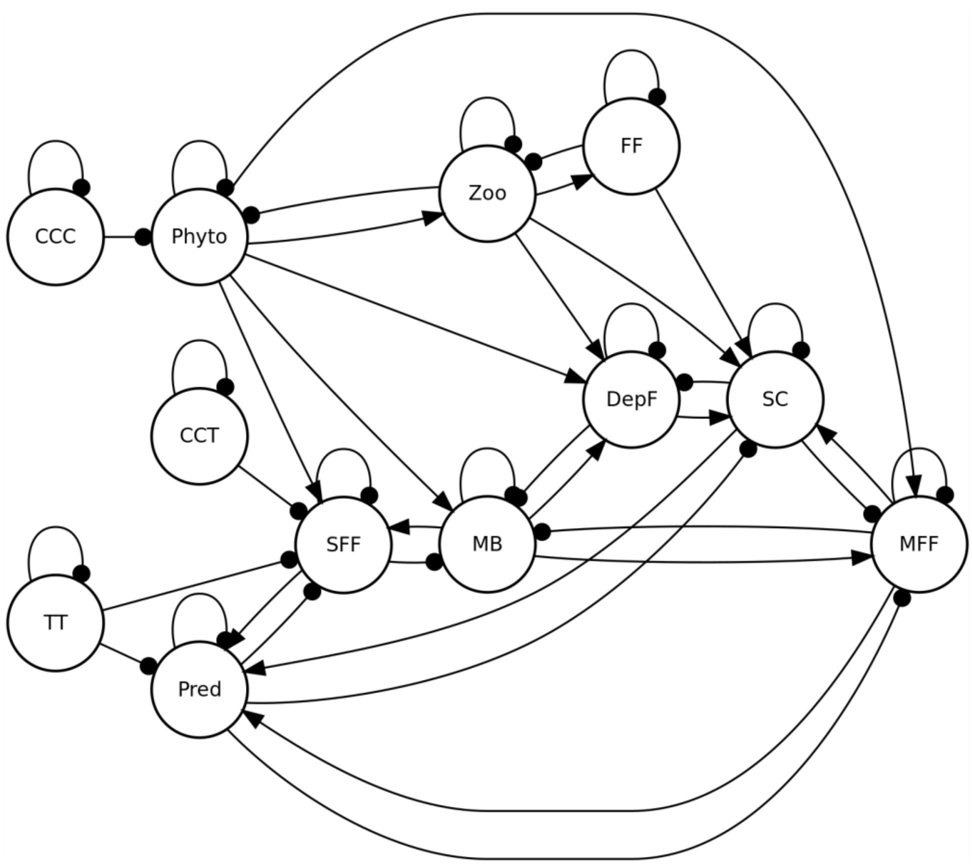


Figure 72: Ecosystem components in the qualitative model are: Predatory Fish (Pred), Sessile Filter Feeders (SFF), Mobile Filter Feeders (MFF), Scavengers (SC), Microbes (MB), Phytoplankton (Phyto), Zooplankton (Zoo), Food Falls (FF), Deposit Feeders (DepF) . Pressures acting on the system are: Climate Change Chlorophyll (CCC), Climate Change Temperature (CCT), Targeted Fishing (TT)

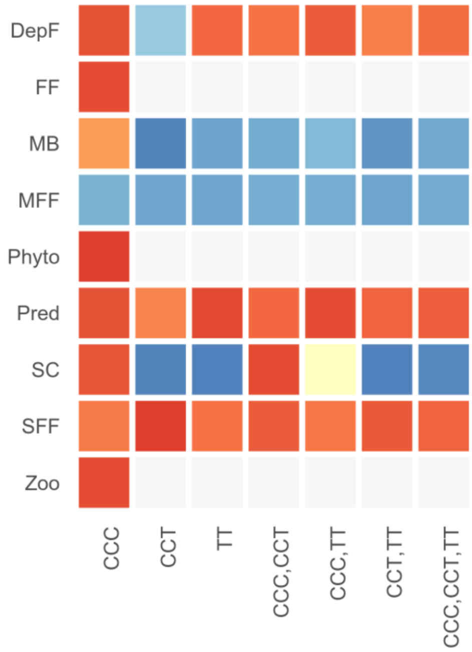
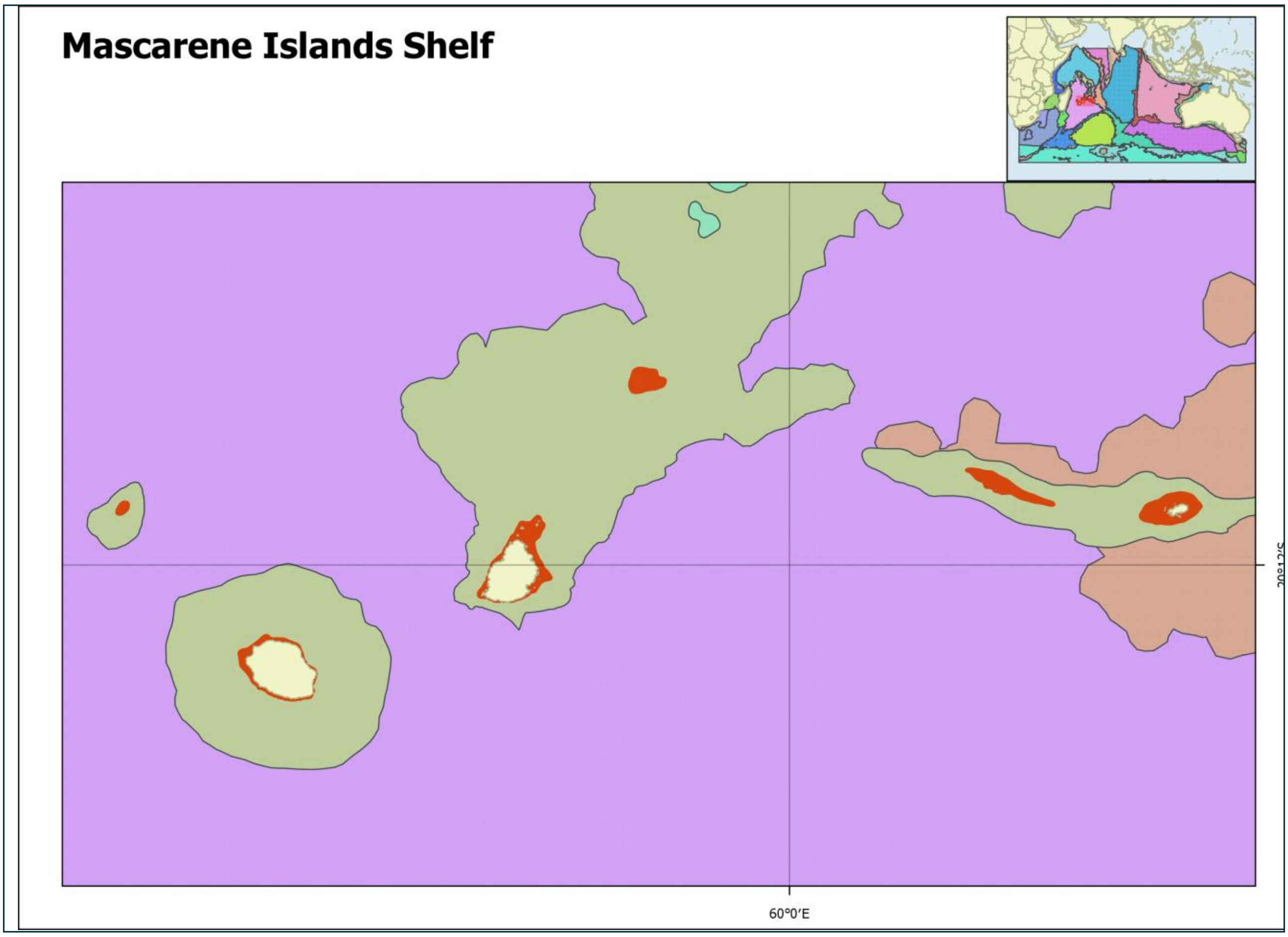


Figure 73: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.19 Mascarene Islands Shelf



The Mascarene Islands shelf is characterised by low coal diversity and endemism. This region includes the Farquhar atoll (southern Seychelles) and groups with St. Brandons Island, Mauritius, the Cargados Carajos bank and Reunion Island. These islands are outliers to other nearby regions (Obura 2012, Obura 2016)

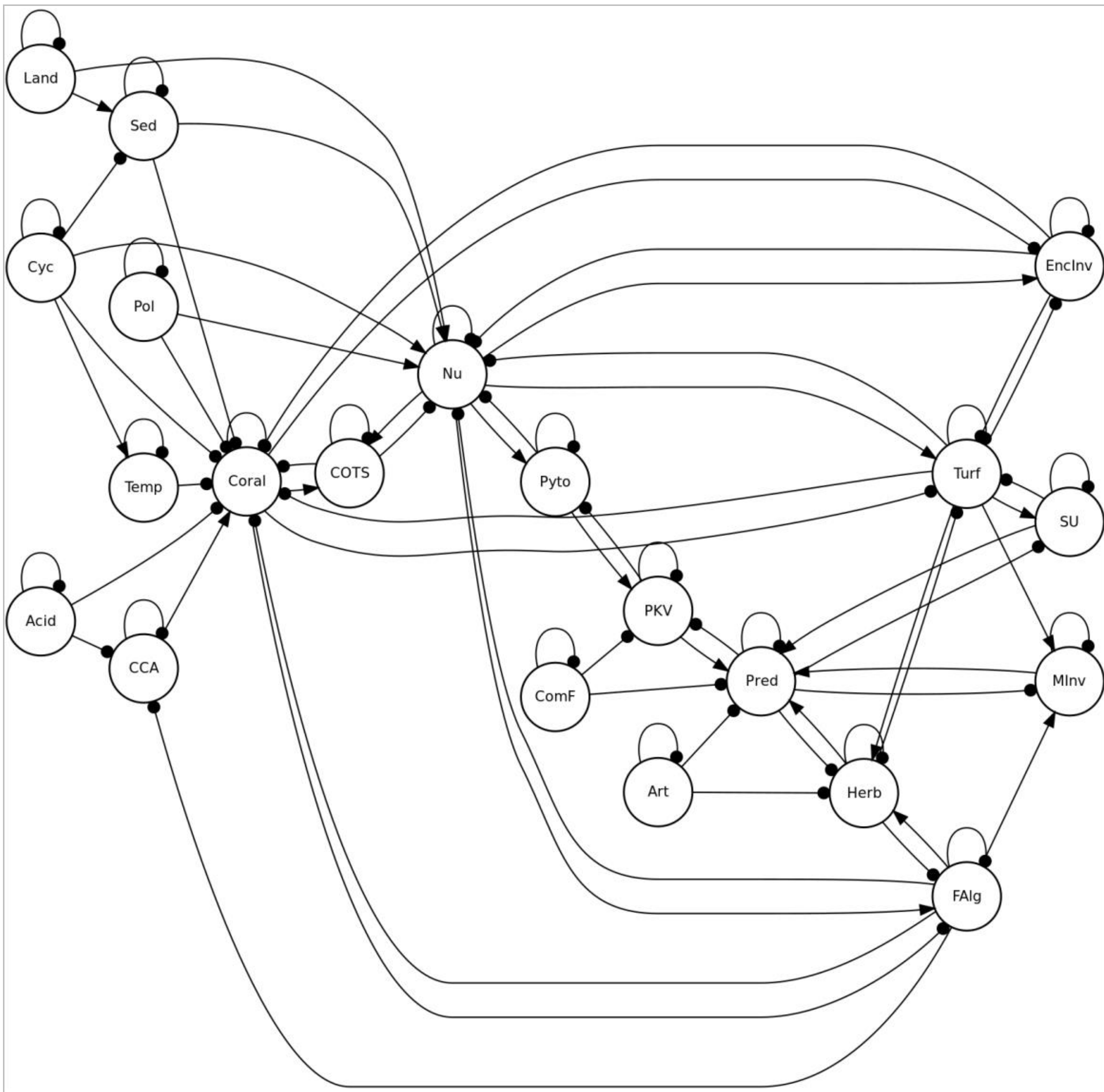


Figure 74: Ecosystem components in the qualitative model are: CCA (CCA), CoralPredators (COTS), Coral (Coral), Fleshy Algae (FAlg), Mobile Invertebrates (MInv), Predatory Fish (Pred), Planktivors (PKV), Herbivorous Fish (Herb), Sea Urchins (SU), Encrusting Invertebrates (EncInv), Turf Algae (Turf), Nutrients (Nu), Phytoplankton (Pyto) . Pressures acting on the system are: Sediment (Sed), Pollution (Pol), Temperature (Temp), Acidification (Acid), Commercial Fisheries (ComF), Cyclones (Cyc), Land Use Change (Land), Artisanal Fisheries (Art)

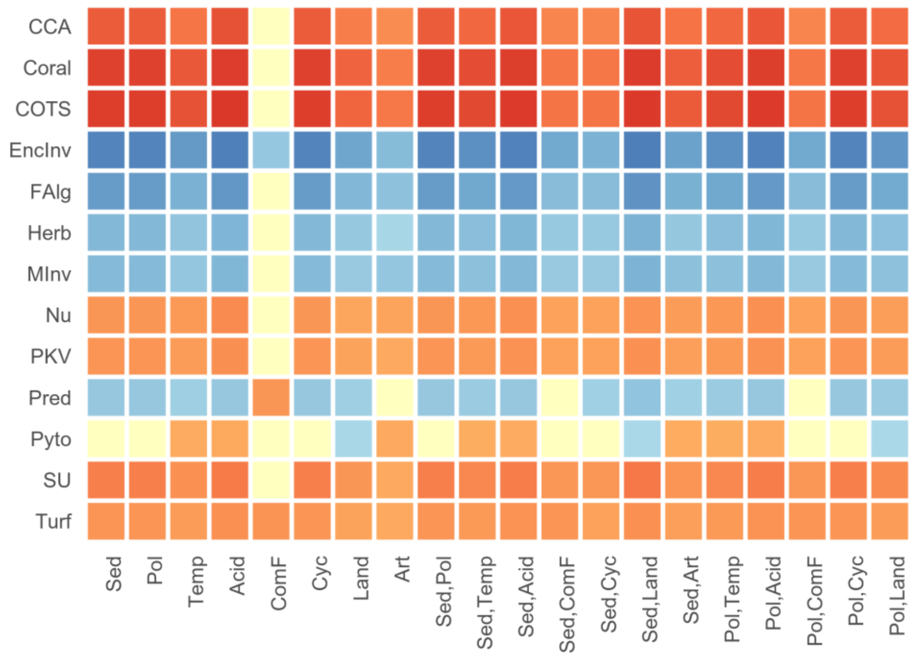
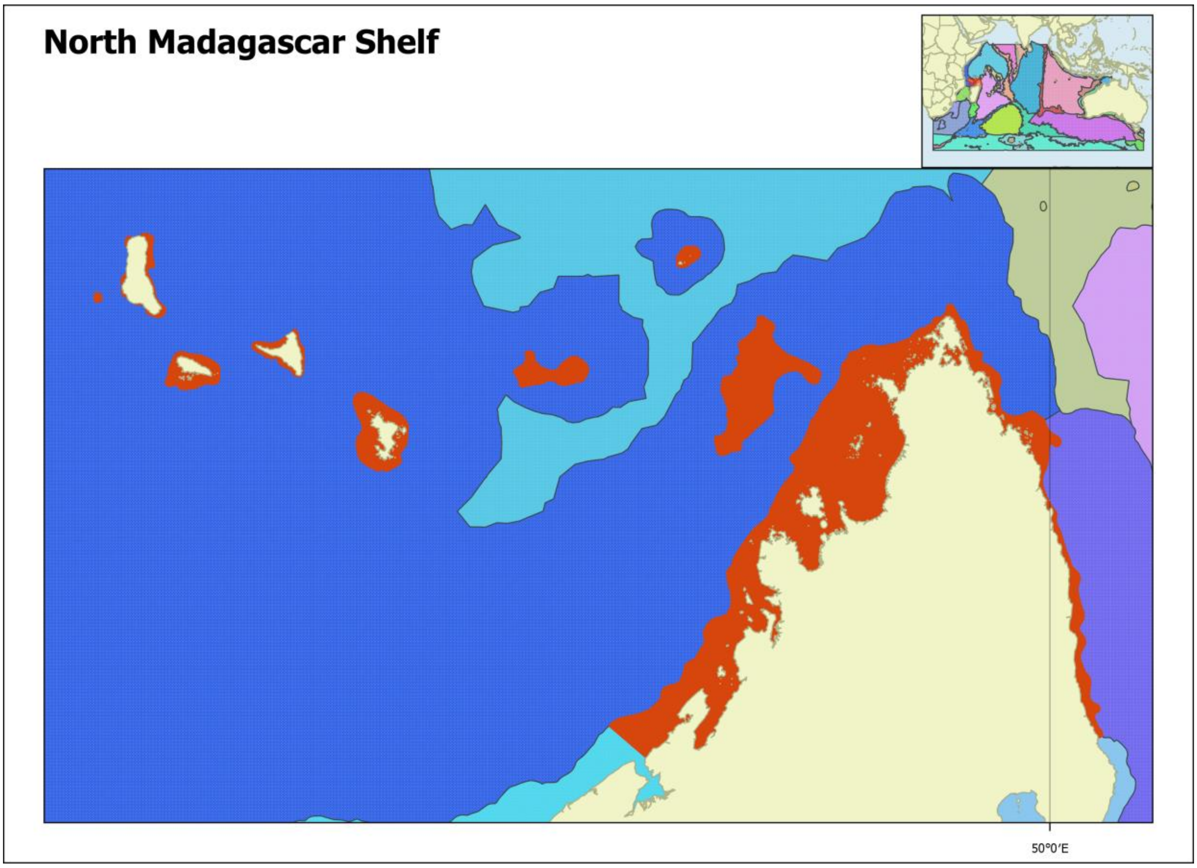


Figure 75: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.20 North Madagascar Channel Shelf Province



The area included a mix of deep and shallow bays, and an island system, separated by stretches of exposed linear coastline (RAMP-COI, 2011). Coral reefs of the far northeast are highly exposed to Indian Ocean swells, making them difficult to access. Obura et al. (2011) identified 420 species of reef fish belonging to 175 genera and 57 families and a total of 156 species of Scleractinian corals belonging to 47 genera and 13 families. This are lacks much information in the north east. Aldabra and Amirantes groups of islands in western Seychelles groups more closely with the Comoro islands (Grande Comore and Moheli) and Glorieuse Island in the northern Mozambique Province (Obura 2012).

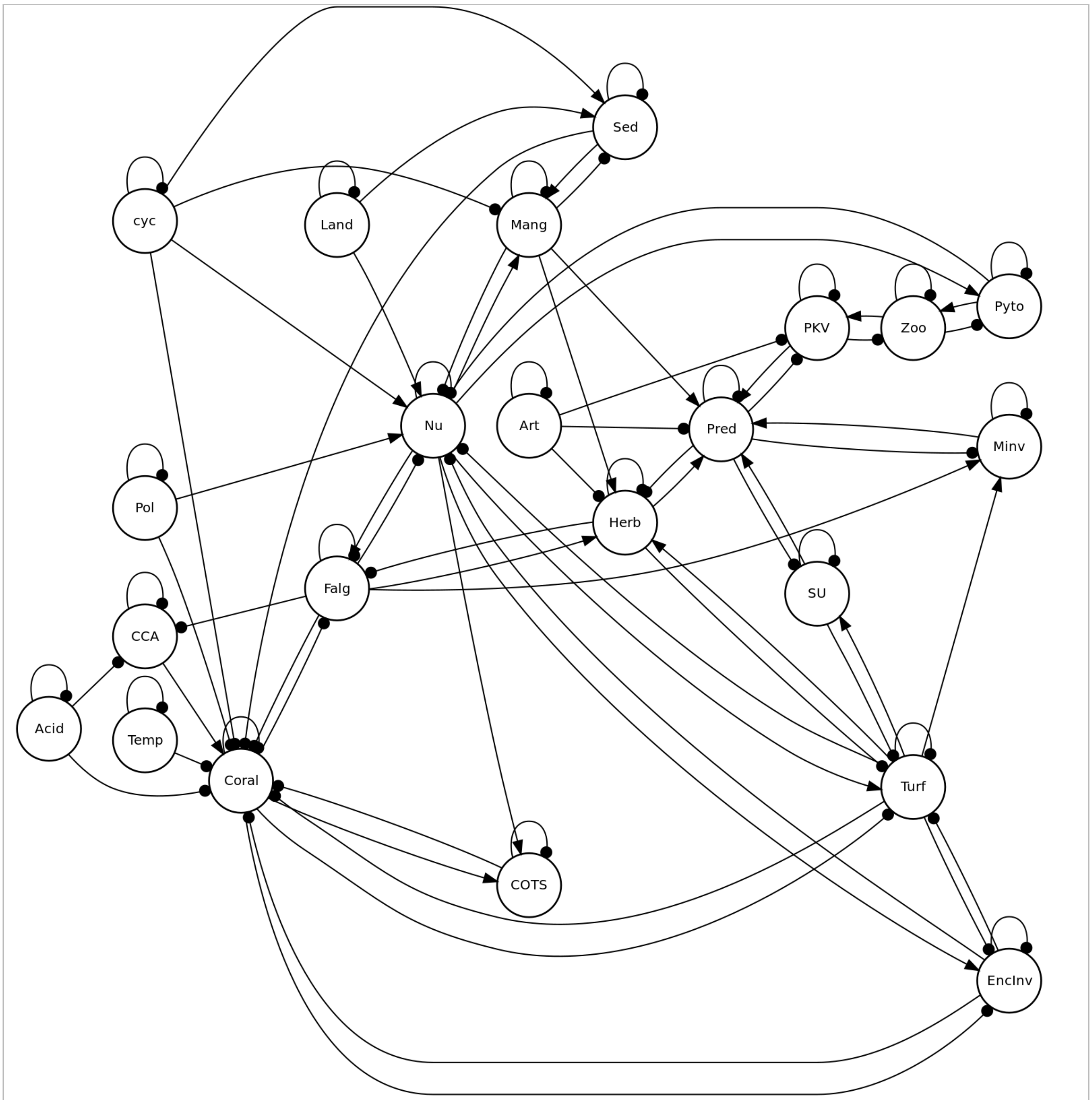


Figure 76: Ecosystem components in the qualitative model are: CCA (CCA), Coral Predators (COTS), Coral (Coral), Fleshy Algae (Falg), Mobile Invertebrates (Minv), Predatory Fish (Pred), Planktivores (PKV), Herbivorous Fish (Herb), Sea Urchin (SU), Encrusting Invertebrates (EncInv), Turf Algae (Turf), Nutrients (Nu), Phytoplankton (Pyto), Mangrove (Mang), Zooplankton (Zoo) . Pressures acting on the system are: Sediment (Sed), Pollution (Pol), Artisanal Fisheries (Art), Temperature (Temp), Acidification (Acid), Land Use Change (Land), Cyclones (cyc)

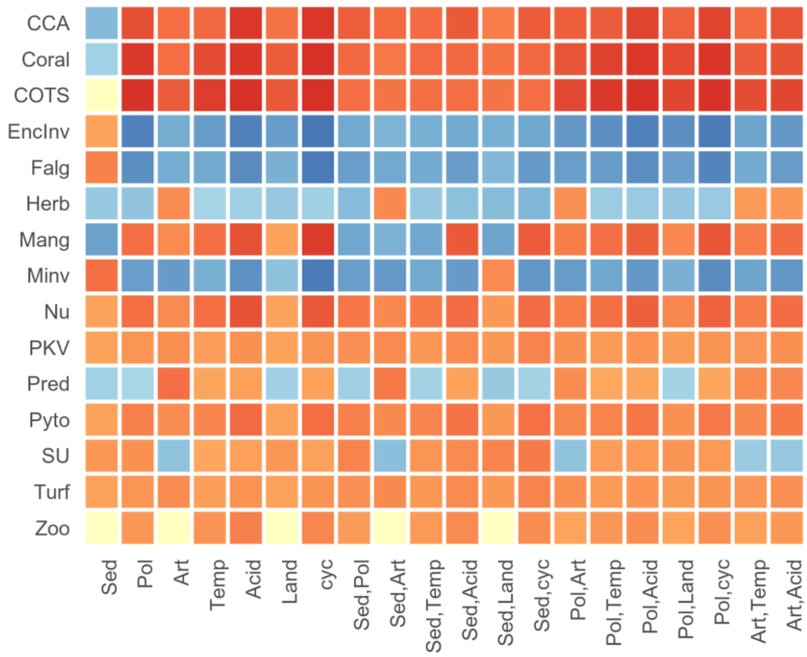
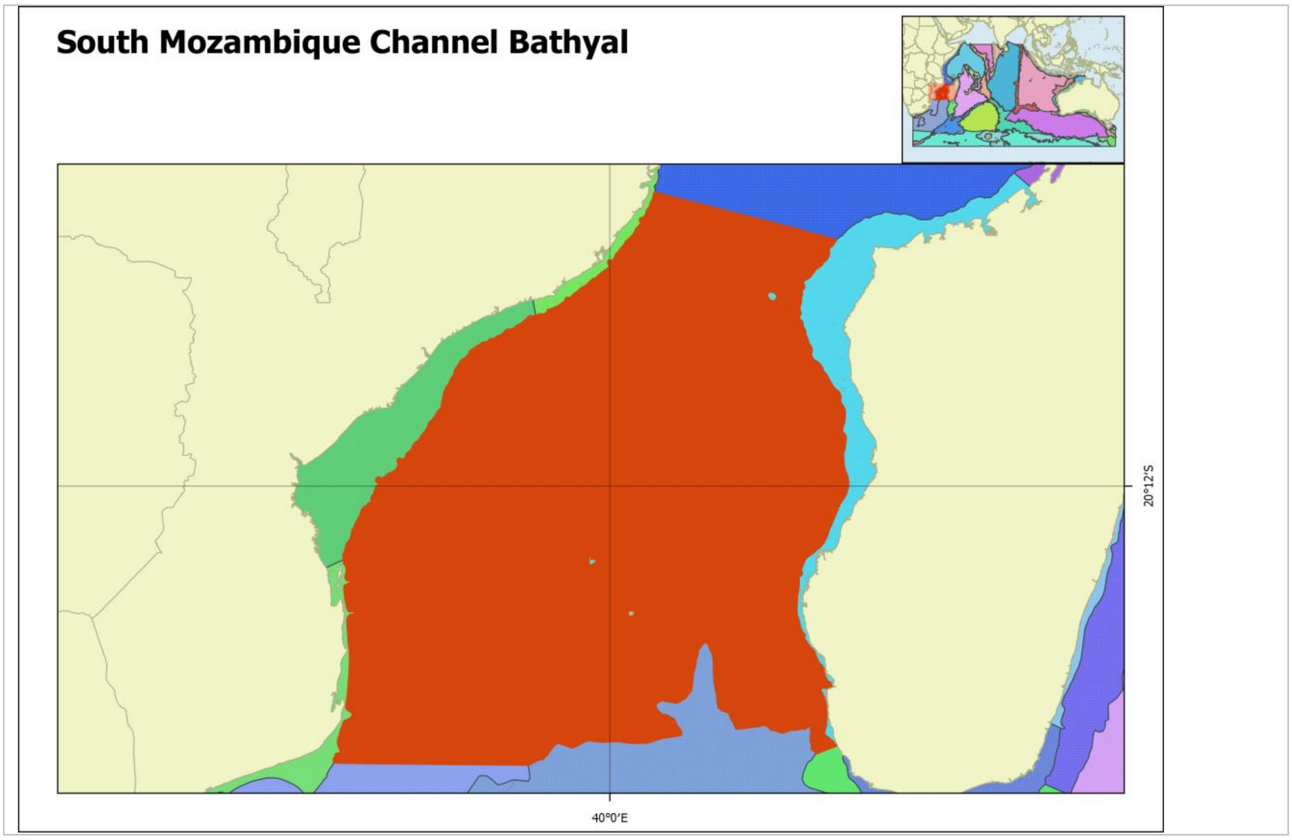


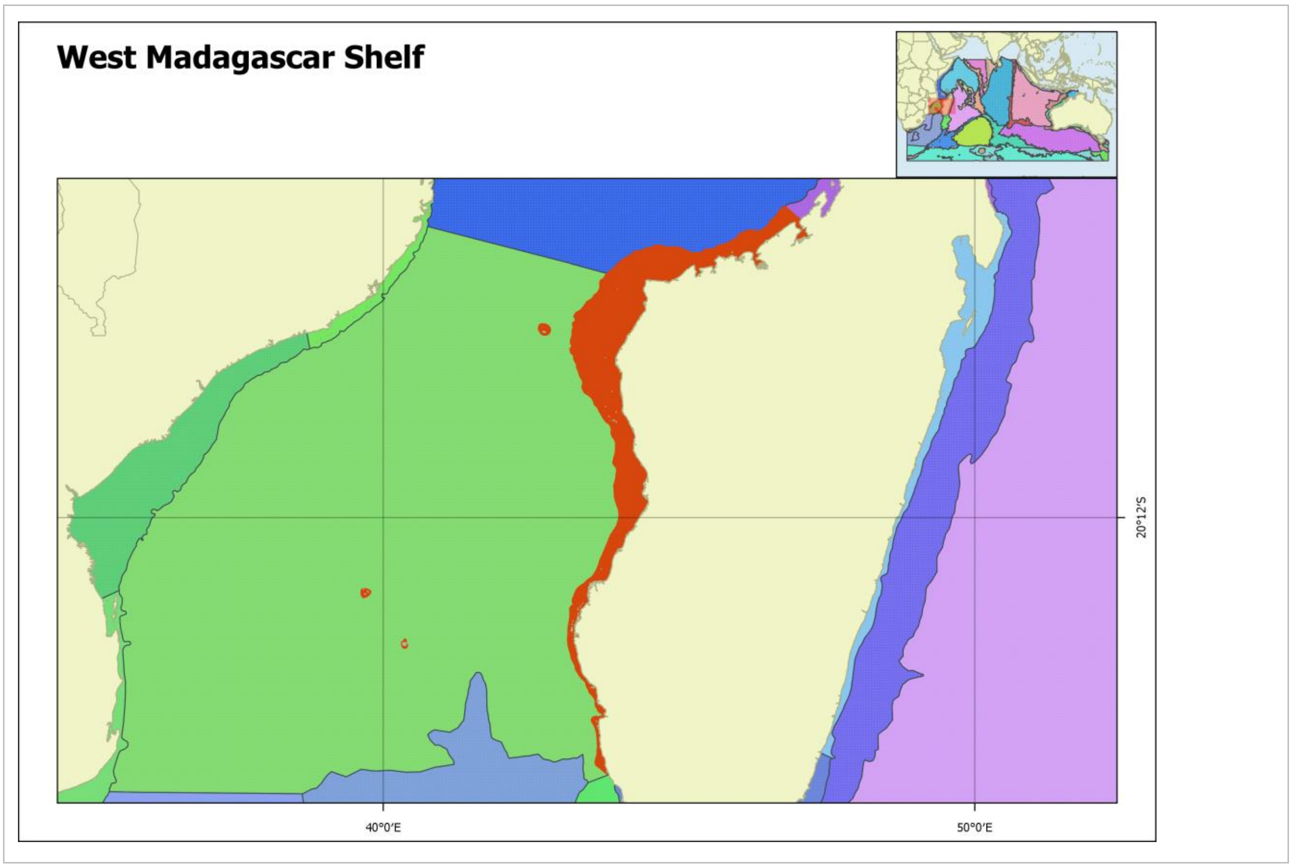
Figure 77: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.21 South Mozambique Channel Bathyal Province



The South Mozambique Channel Bathyl is the large bathyl province between the Sofala and West Madagascar shelf provinces.

2.4.22 West Madagascar Shelf Province



This province is described in detail in the RAMP-COI (2011) report as one of the distinct provinces in Madagascar. It shares a similar biota to the Sofala province on the western side of the Mozambique channel (Oboura 2012).

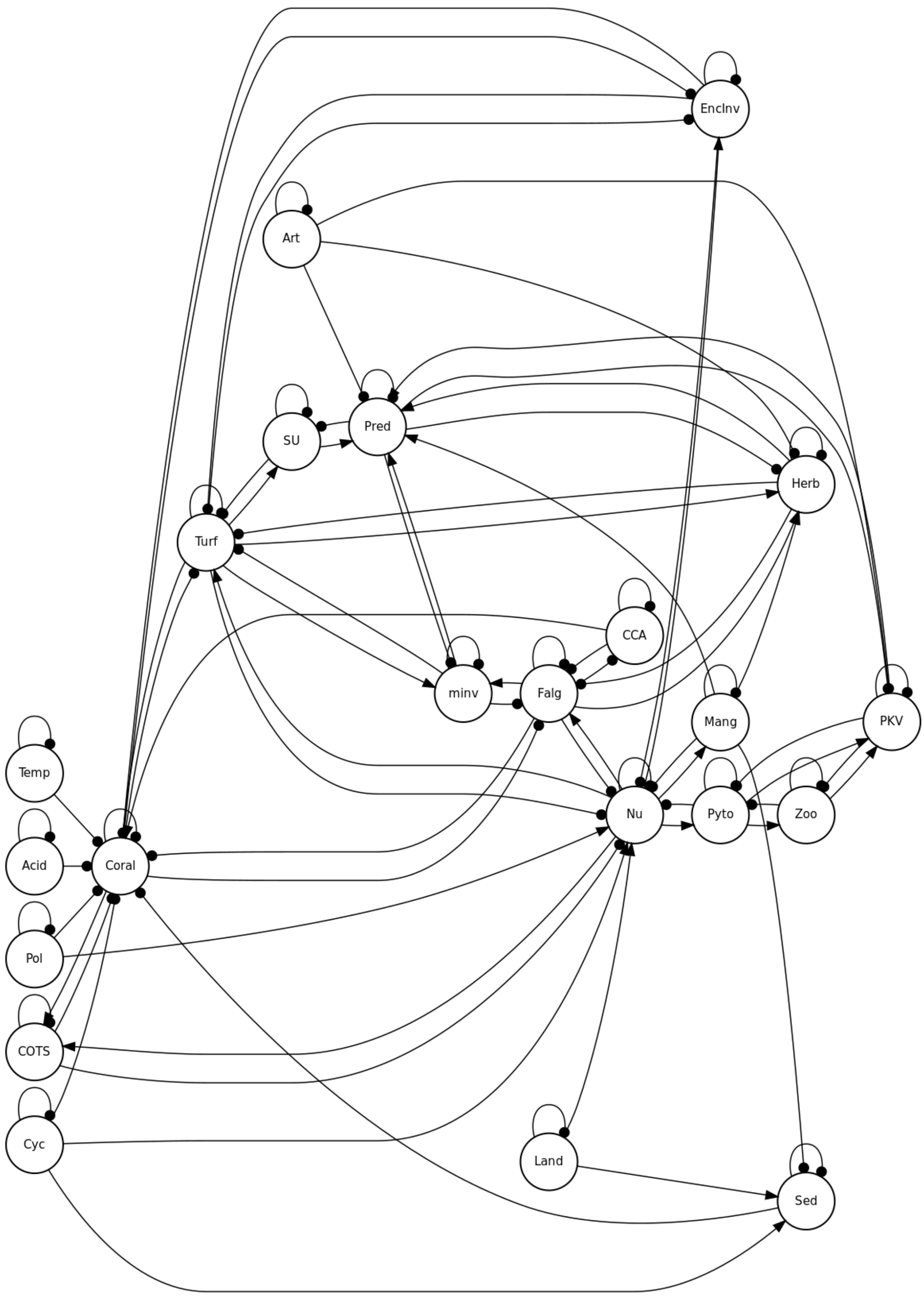


Figure 78: Ecosystem components in the qualitative model are: CoralPredators (COTS), Coral (Coral), Fleshy Algae (Falg), Mobile Invertebrates (minv), Predatory Fish (Pred), Planktivores (PKV), Herbivorous Fish (Herb), Sea Urchins (SU), Encrusting Invertebrates (EncInv), Turf Algae (Turf), Nutrients (Nu), Phytoplankton (Pyto), Mangrove (Mang), CCA (CCA), Zooplankton (Zoo) . Pressures acting on the system are: Sediment (Sed), Pollution (Pol), Artisanal Fisheries (Art), Temperature (Temp), Acidification (Acid), Land Use Change (Land), Cyclones (Cyc)

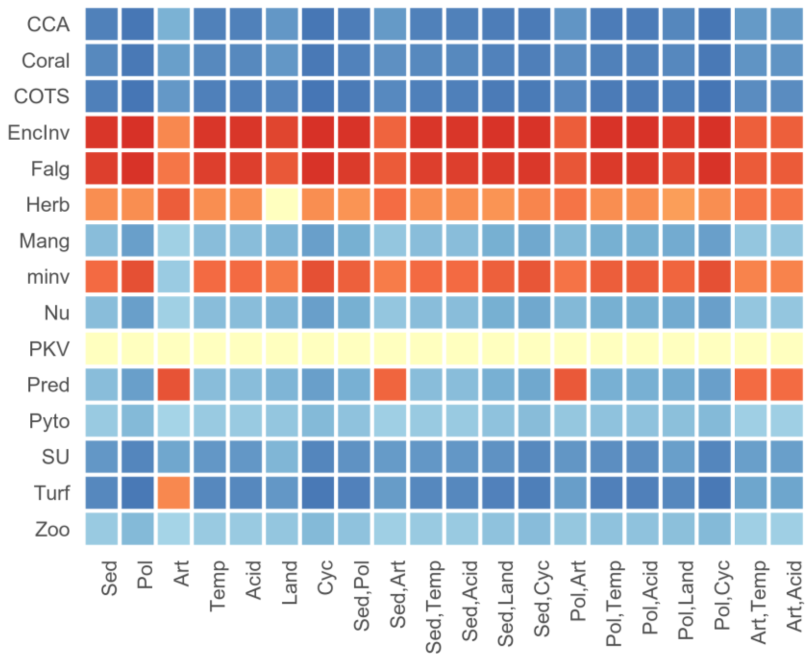
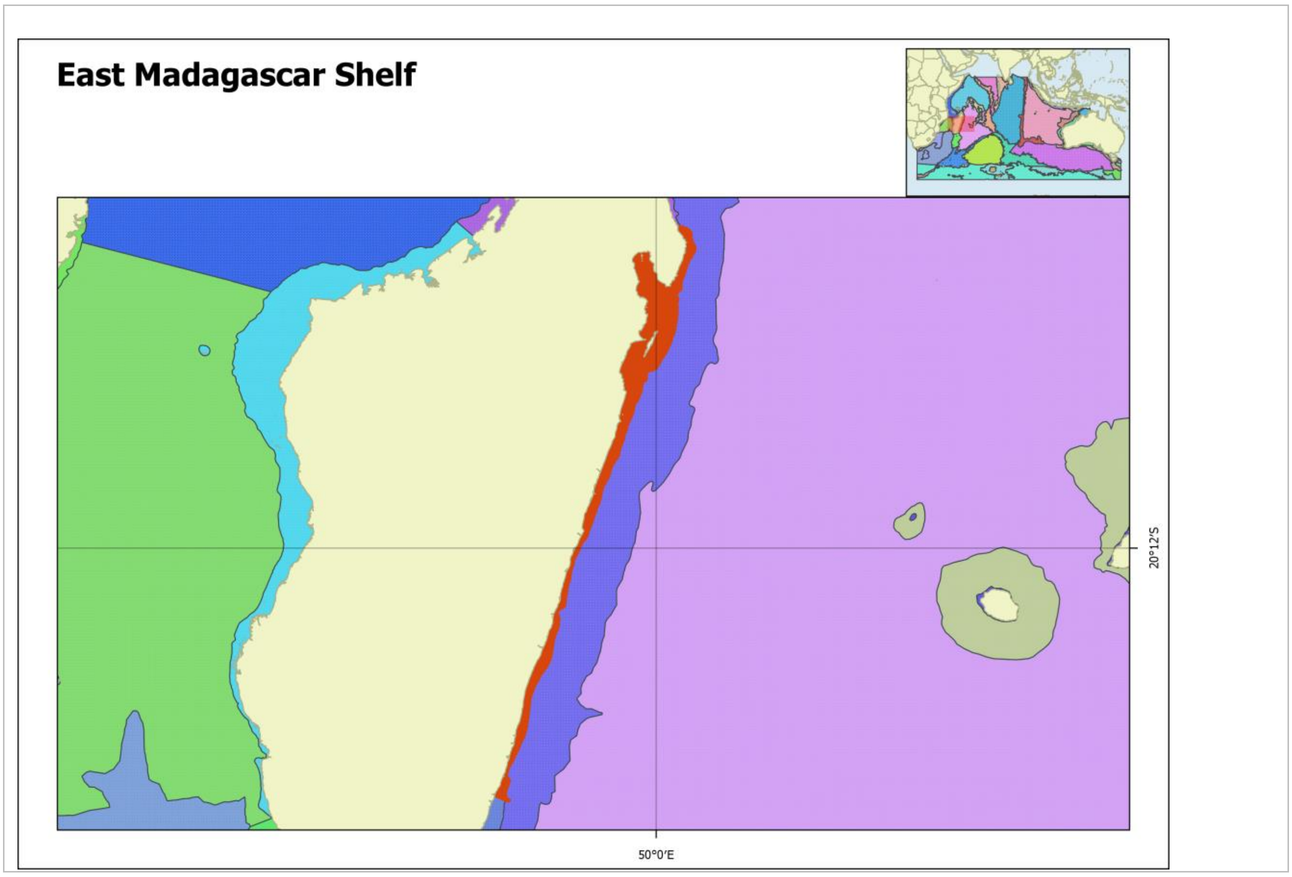


Figure 79: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.23 East Madagascar Shelf Province



There is very little information available for the East Madagascar Province (Obura 2012). However, both the RAM-COI project and Krakstad etal (2008) suggest that it is a different system to either the North or South Madagascar provinces. The East Madagascar current flows from north to south through this region carrying warn, nutrient poor water (Krakstad et al 2008). The northern boundary is where the Madagascar current bifurcates into a northern and southern component and the southern boundary aligns with the nutrient rich South Madagascar province. Due perhaps to the nutrient poor nature of the waters the abundances of demersal fish in this province are low (Krakstad et al. 2008).

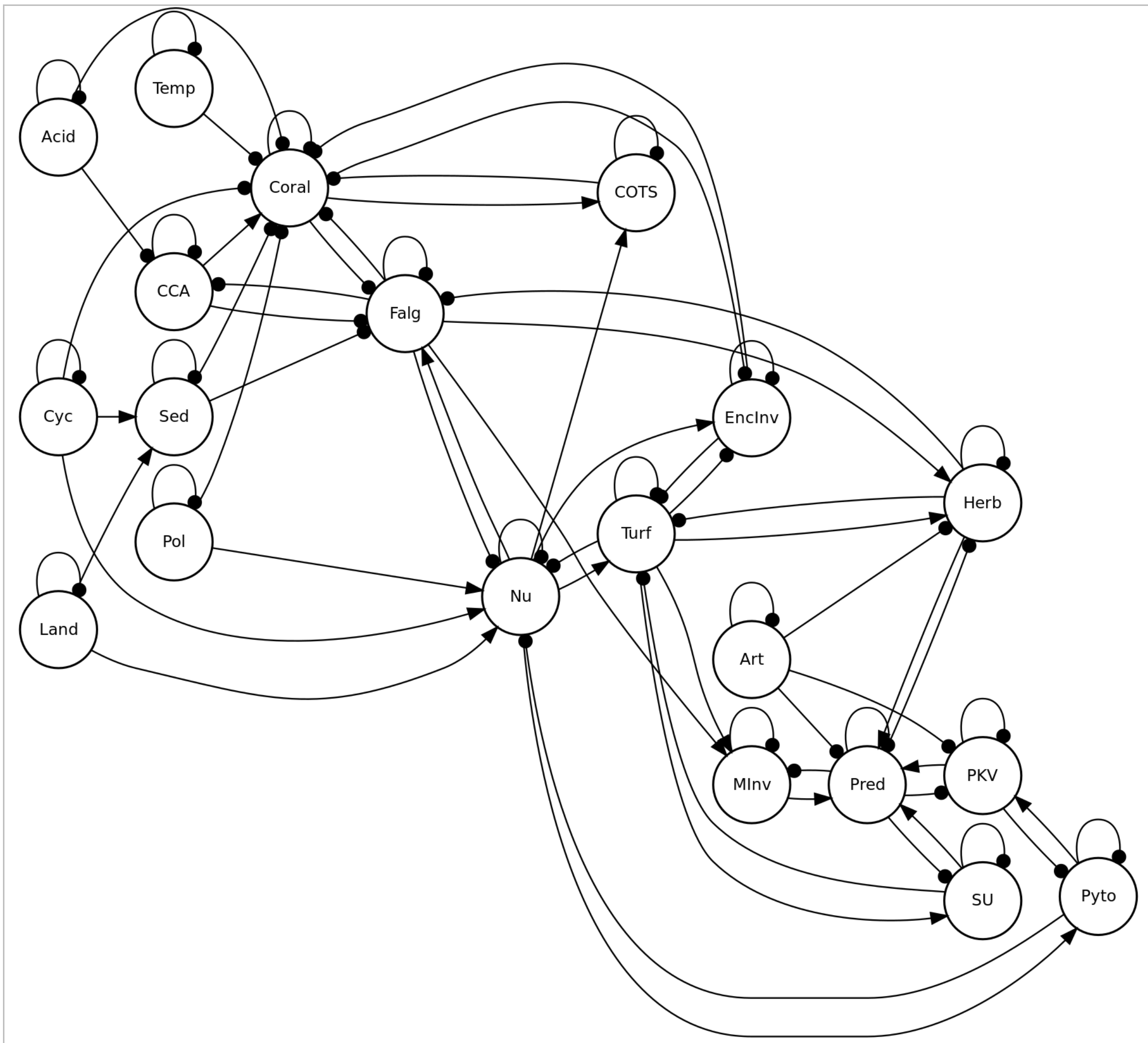


Figure 80: Ecosystem components in the qualitative model are: CCA (CCA), CoralPredators (COTS), Coral (Coral), FleshyAlgae (Falg), Mobile Invertebrates (MInv), Predatory Fish (Pred), Planktivores (PKV), Herbivorous Fish (Herb), SeaUrchins (SU), Encrusting Invertebrates (EncInv), Turf Algae (Turf), Nutrients (Nu), Phytoplankton (Pyto) . Pressures acting on the system are: Sediment (Sed), Pollution (Pol), Artisanal Fisheries (Art), Temperature (Temp), Acidification (Acid), Land Use Change (Land), Cyclones (Cyc)

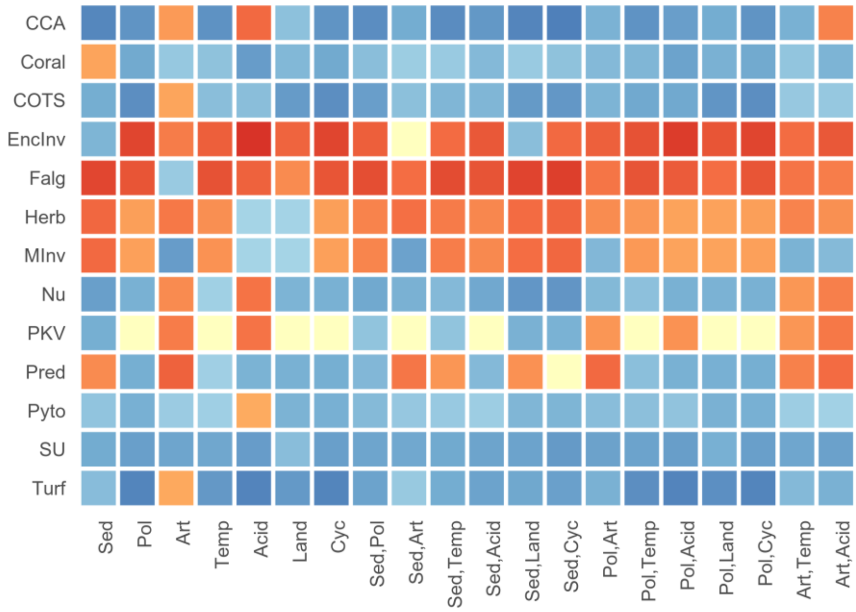
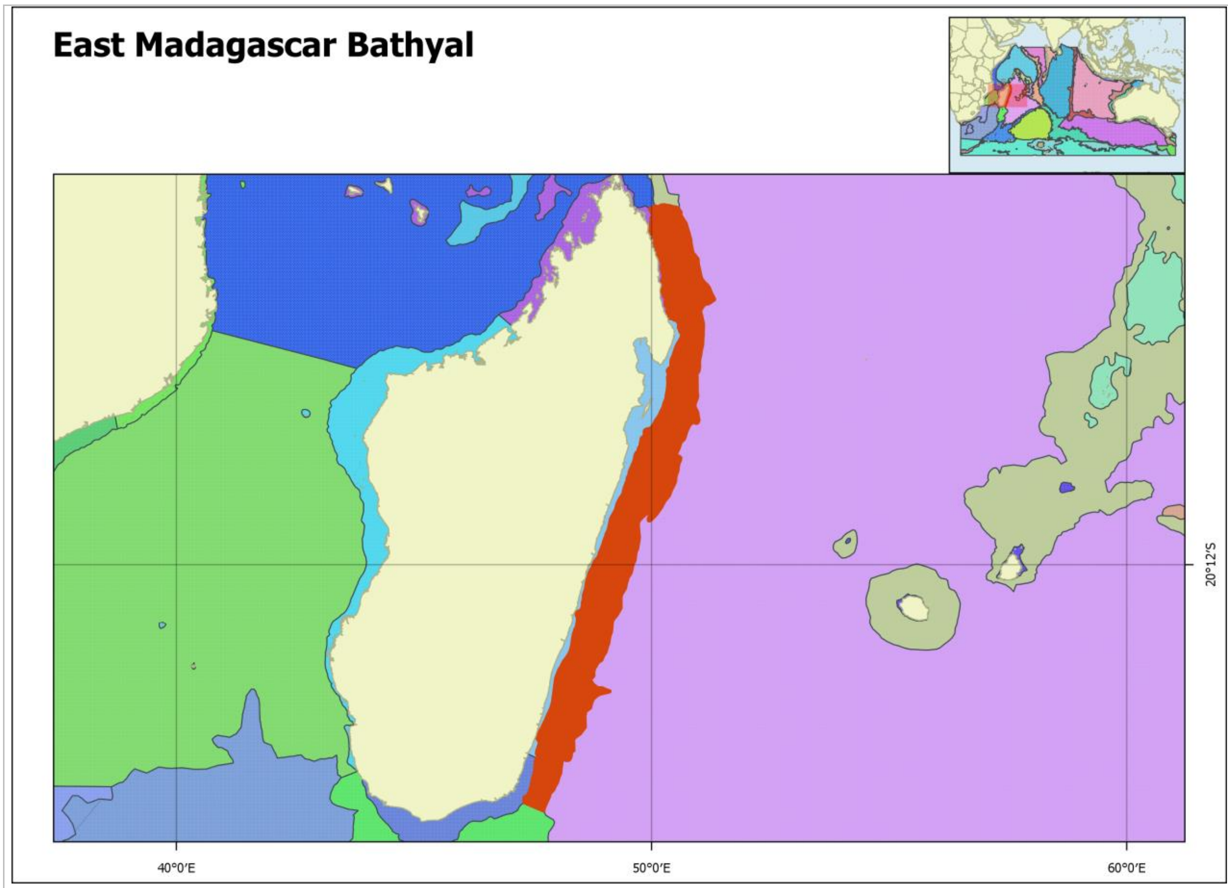
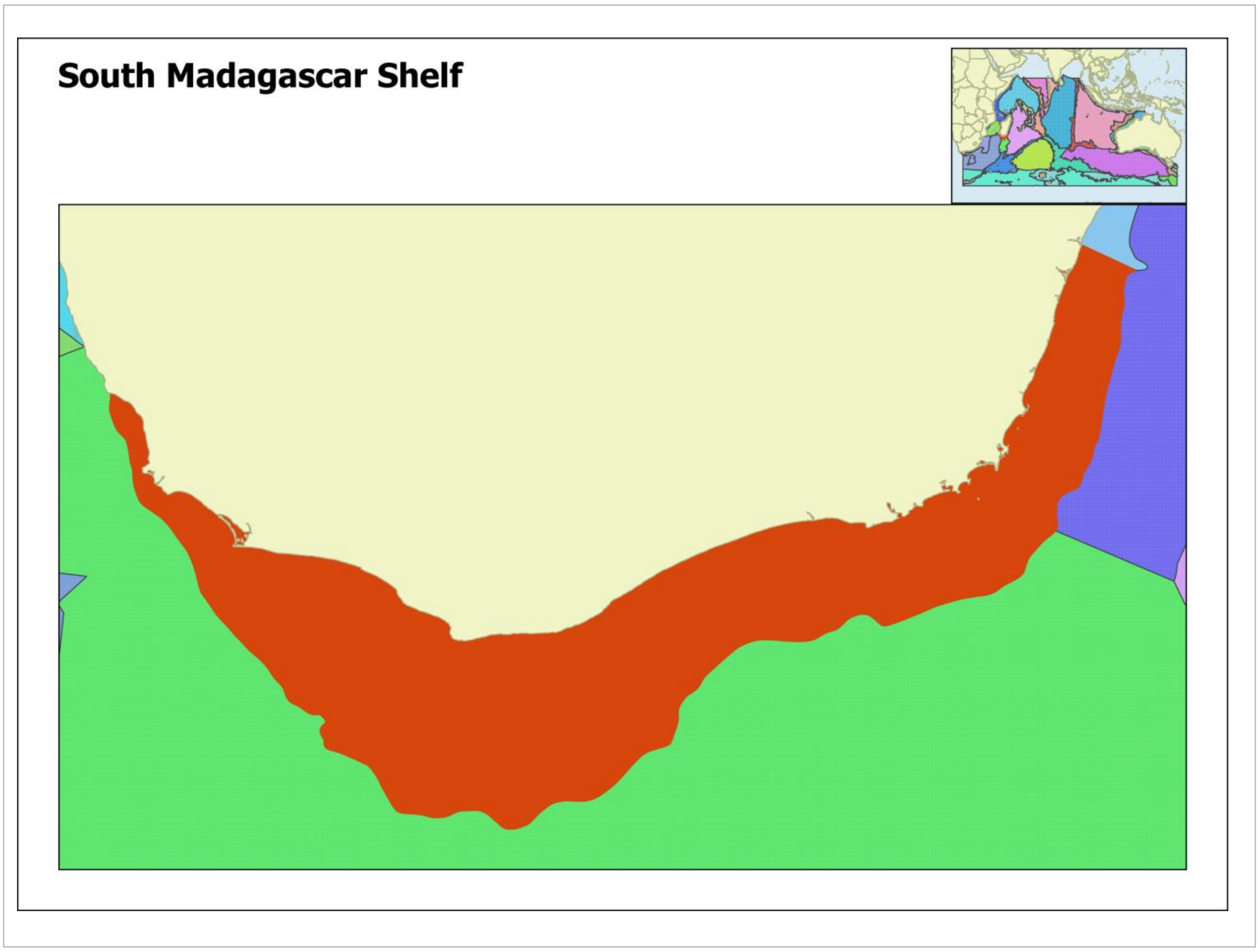


Figure 81: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.24 East Madagascar Bathyal Province



2.4.25 South Madagascar Shelf



The zone of interest is from Mananjary, Lokaro/Ste Luce in the east) to Androaka (in the west) (RAMP-COI, 2011; Obura et al., 2012; CBD EBSA Report - Southern Indian Ocean Regional Workshop, 2012). The continental shelf is very narrow between the Linta and Mangoky deltas and falls steeply down the continental slope. The shallow marine habitats of the coast are mainly rocky and experience very rough conditions exposed to the south. It is characterized by large coastal dunes, lagoons and coastal ponds, forming unique coastal habitats and wetlands; shallow benthic communities are dominated by hard substrate communities, with small isolated coral reefs at the extremities. Because of its southerly location, this is a transition zone (ecotone) in the Indian Ocean between tropical and temperate waters, at the crossroads of the fauna of South Africa and that of the Indo-Pacific, with an African affinity as one approaches the Mozambique Channel. There are very specific communities adapted to local conditions—high energy, upwellings, cooler waters. High levels of endemism have been found, i.e., 25% for molluscs, with many new species likely to be described in coming years. The shallow marine habitats of the coast are mainly rocky and experience very rough conditions due to their southerly exposure. There is minor coral reef development at the east (Lokaro, Ste Luce) and the west (Androka, banc de l'Etoile) extremities. Coastal habitats are varied, with distinctive coastal dune formations, such as at the Mangoky delta. Leatherback, loggerhead and green turtles are found in the region, one of the few locations important for leatherbacks in the WIO.

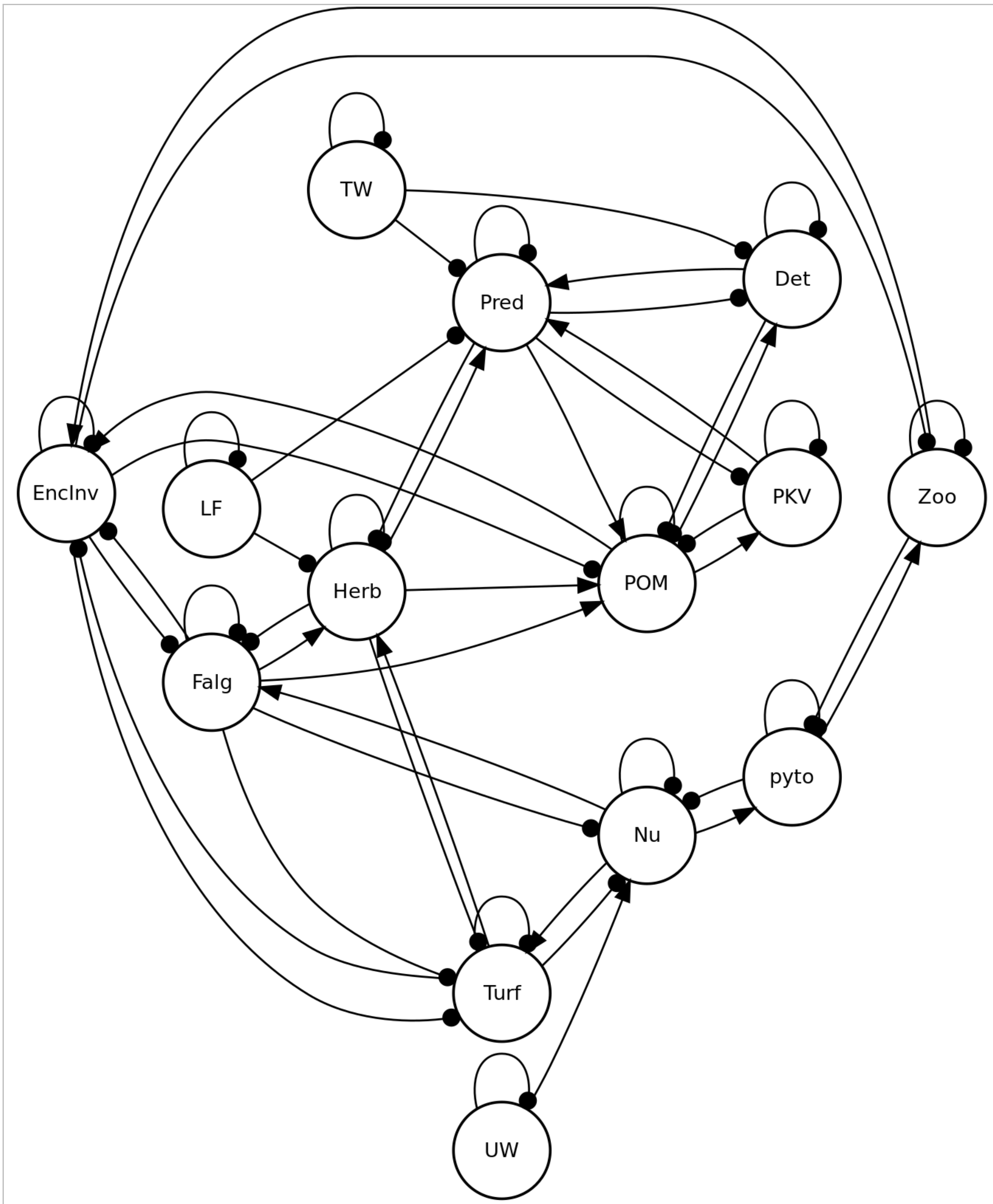


Figure 82: Ecosystem components in the qualitative model are: Encrusting Invertebrates (EncInv), Fleshy Algae (Falg), Turf Algae (Turf), Particulate Organic Matter (POM), Nutrients (Nu), Phytoplankton (pyto), Zooplankton (Zoo), Predatory Fish (Pred), Herbivorous Fish (Herb), Detritivores (Det), Planktovires (PKV) . Pressures acting on the system are: Line Fishing (LF), Trawl (TW), Upwelling (UW)

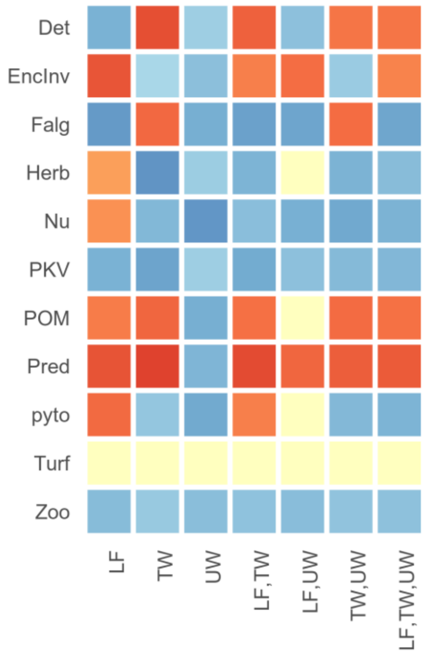
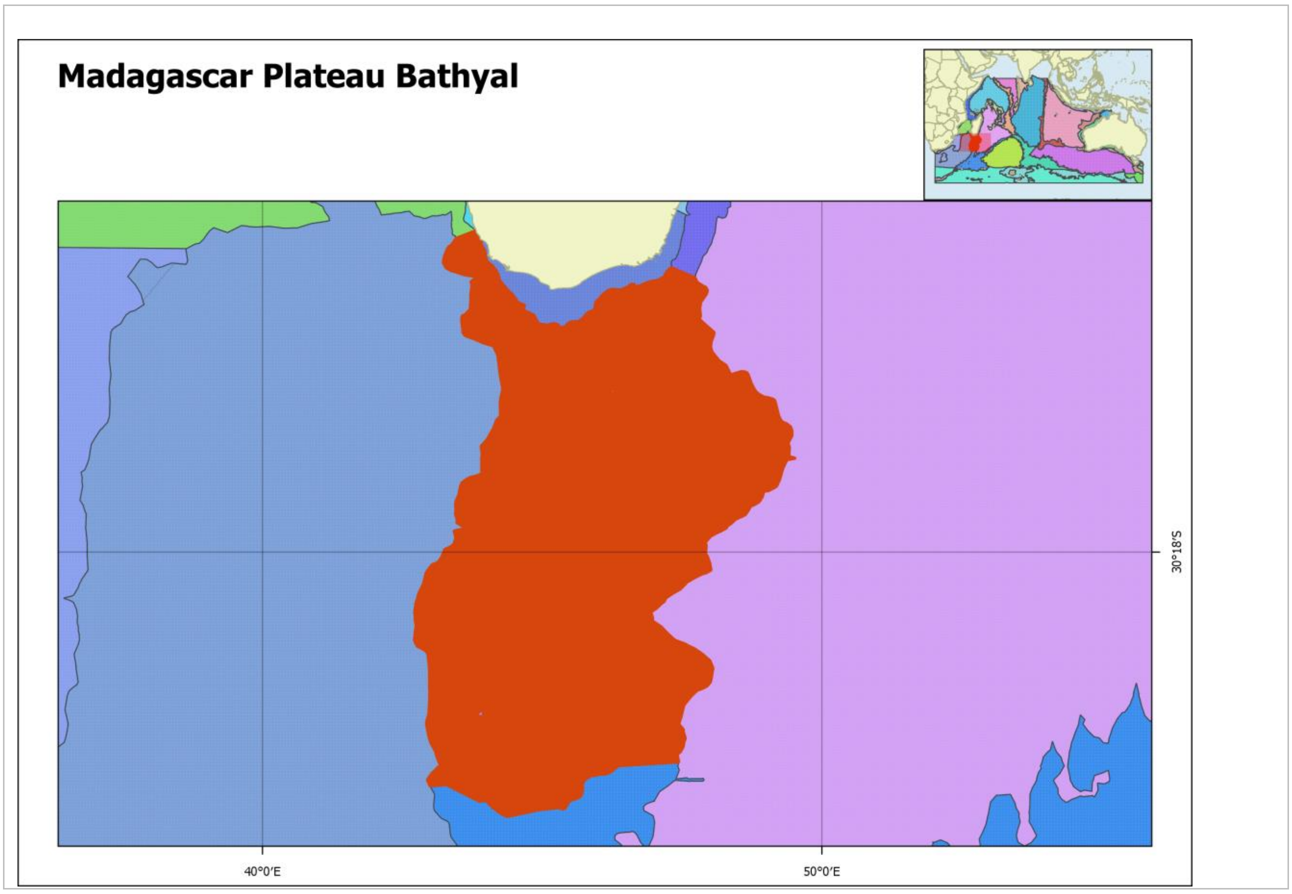


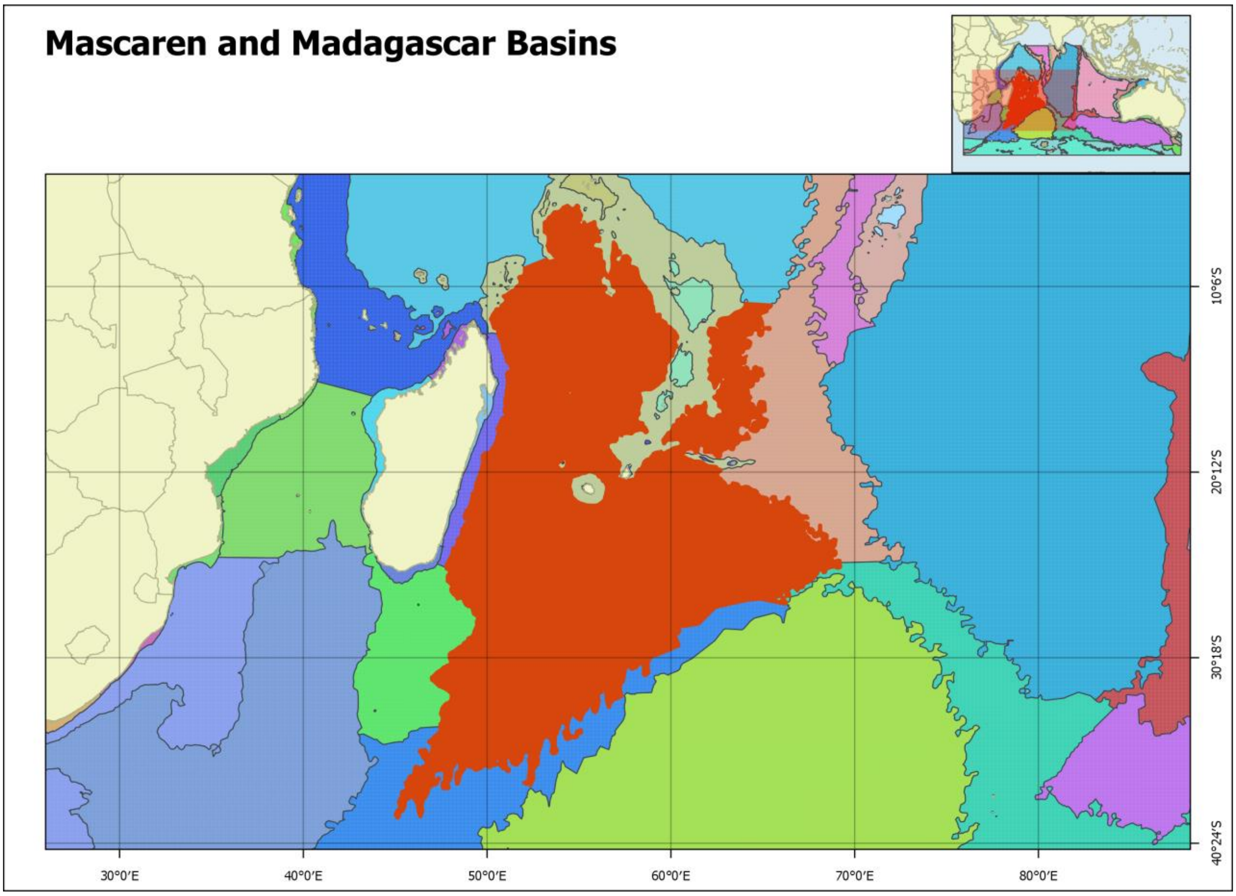
Figure 83: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.26 Madagascar Plateau



Extending south from Madagascar, an extensive underwater plateau or ridge varies from about 1000 to 2500 m deep, for a distance of nearly 1000 km. At its southern end it forms a shallow platform that extends 100 m below the surface. The platform was formed by basaltic extrusion from the Marion hotspot during the Cretaceous, as Antarctica and Madagascar moved apart. The region experiences complex oceanography caused by the strong boundary current of the East Madagascar Current impinging on the undersea Plateau, resulting in strong coastal and offshore upwelling, eddies and turbulence. The plateau extends southwards into temperature waters and ecoregions, resulting in mixed tropical and subtropical species and habitats. Even on land and in shallow waters, this region is poorly documented. A recent expedition 'Atimo Vatae', focused on the algae and invertebrates of the shallow and upper-slope marine fauna, has already shown preliminary results reporting kelp beds and over 500 species of algae, richer than the tropical algal flora of Mozambique. By contrast, diversity of animal species is lower than in tropical areas, but with extremely high levels of endemism and shared species with subtropical South Africa. Ascidians are among the first groups analysed, revealing 20% new species, 26% shared with S. Africa, and 31% shared with tropical areas. Other groups with preliminary numbers include molluscs (1200–1500 species), decapod crustaceans (766 species) and fish (253 species). Offshore, because of its upwelling and productivity, the undersea Plateau provides critical feeding grounds for multiple marine species, including seabirds, large fish and marine mammals. The red-tailed tropicbird and Barau's petrel (endemic to and nesting on Reunion Island) feed on the plateau, indicative of a high number of species that also do this. Blue, Bryde's, Right, Sperm and Humpack whales aggregate in these waters due to its raised productivity, with estimated population sizes of about 450 individuals for pygmy blue whales. Humpback whales also use the SW and SE coasts (near Toliara and Lokaro, respectively) as breeding grounds, and for nursing by mothers and calves.

2.4.27 Mascarene and Madagascar Basins



The Mascarene and Madagascar basin extends from Madagascar in the West to the Central Indian Ridge in the east. The basin is an abyssal region that completely surrounds the southern part of the Mascarene Islands, shelf and bathyal.

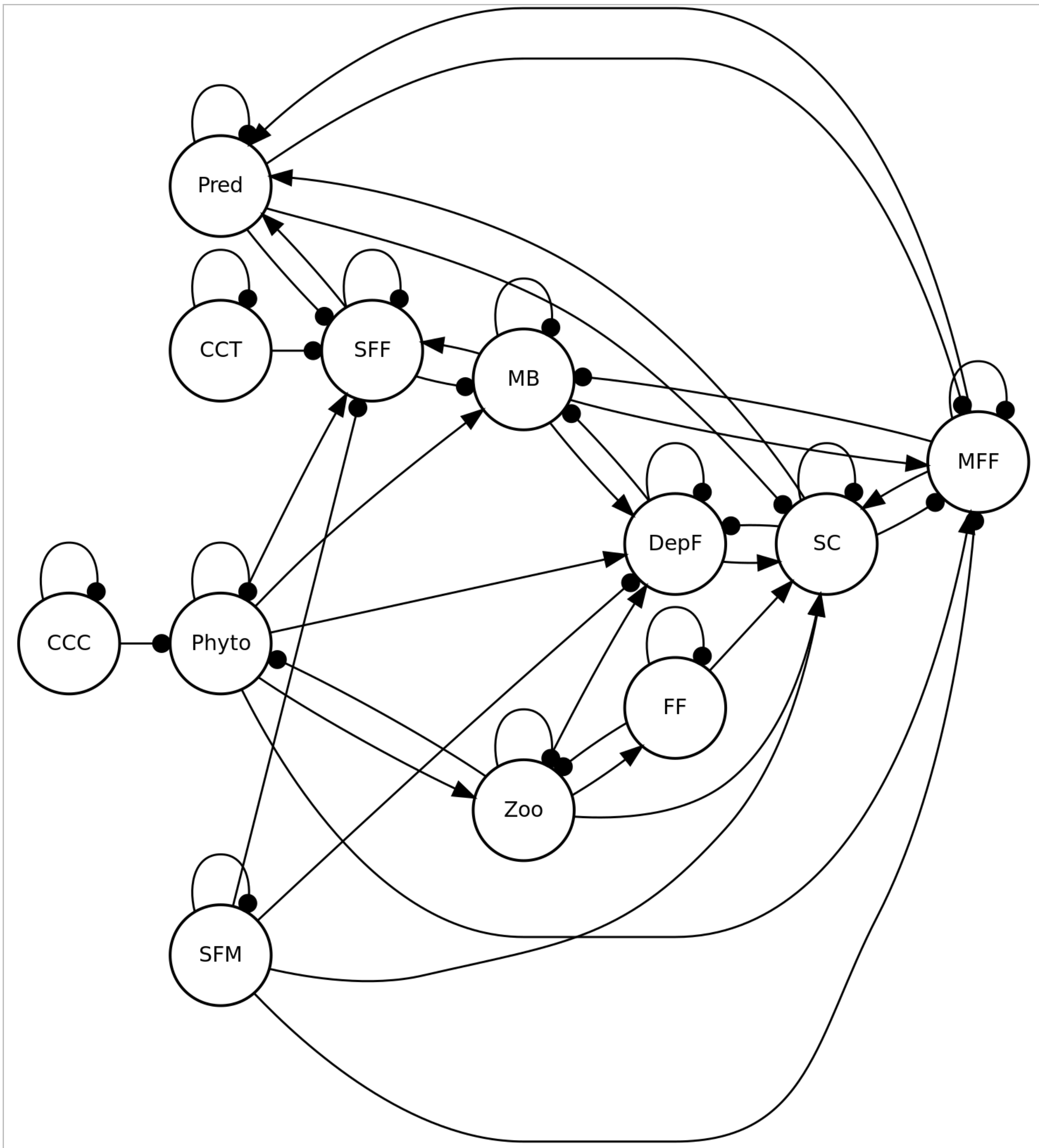


Figure 84: Ecosystem components in the qualitative model are: Predatory Fish (Pred), Sessile Filter Feeders (SFF), Mobile Filter Feeders (MFF), Scavengers (SC), Microbes (MB), Phytoplankton (Phyto), Zooplankton (Zoo), Food Falls (FF), Deposit Feeders (DepF) . Pressures acting on the system are: Seafloor Mining (SFM), Climate Change Chlorophyll (CCC), Climate Change Temperature (CCT)

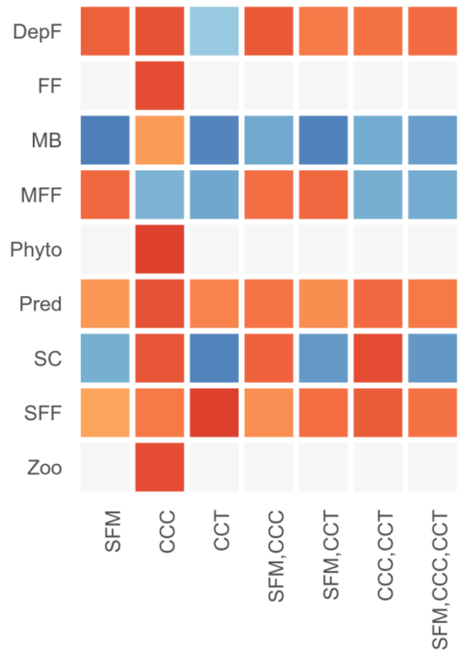
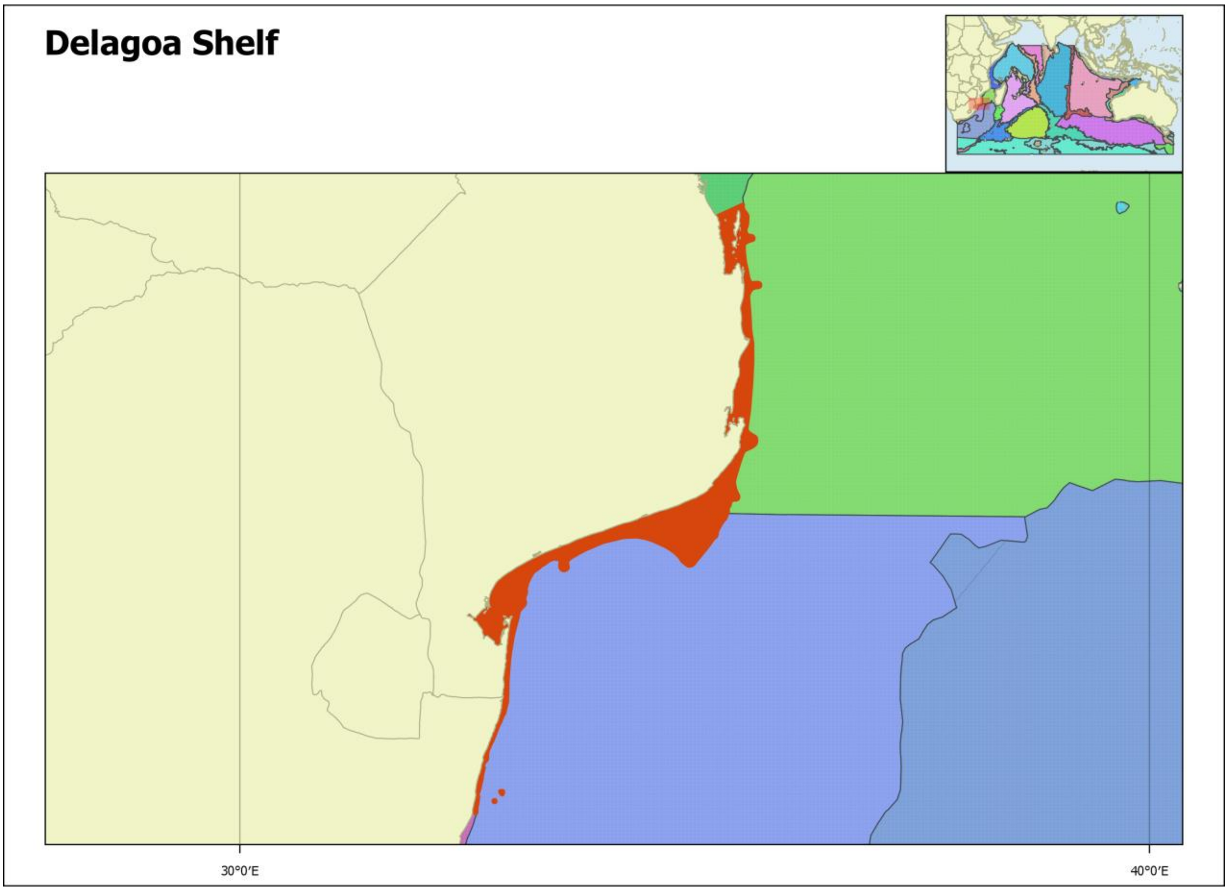


Figure 85: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.28 Delagoa Province



The Delagoa Province extends from Cape Vidal, South Africa northwards to Bazaruto Island in Mozambique (Sink et al. 2012; Porter et al. 2013; Obura 2012; Obura et al. in press; Jackson 1976; Bolton et al. 2004; Sink et al. 2005; Porter & Schleyer in prep.). It is considered to be a transitional area between subtropical and tropical coastal waters, as coral communities flourish here but rarely form true accretive coral reefs. The province displays contrasting oceanographies along its extent. The southern portion is characterised by a very narrow continental shelf, submarine canyons and an absence of riverine inputs which together result in clear oligotrophic waters (Ramsey 1994; Porter et al. 2017). Here, warm eddies from the Mozambique Current interact with the East Madagascar Current to form the fast south-flowing Agulhas Current in the southern limits of this province (Lutjeharms, 2006). Contrastingly, further north and for most of the remaining province, the shelf is considerably wider and there is an increase in riverine input resulting in increases in turbidity and nutrients (Porter et al. 2017). Intertidal rocky shores are characterised by various algae (*Cheilosporum sagittatum* & *Sargassum elegans*) and filter feeders (*Pyura stolonifera*, *Perna perna*) (Sink et al. 2005). Algae, and zooxenthellate corals, particularly soft corals, dominate shallow reefs as far down as 30m in some areas (Porter et al. 2013; Schleyer and Porter 2018). Turf algal communities as well as fleshy brown species such as *Lobophora variegata* are the dominant algae (Porter et al. 2013; Schleyer & Porter 2018). Dominant coral species include the soft corals *Sinularia* spp. (*S. brassica*, *S. abrupta*, *S. gravis*) and *Lobophytum* spp. (*L. crassum*, *L. patulum*, *L. depressum*) and hard corals *Montipora* spp., *Echinopora gemmacea*, *Acropora austera* and *Favites* spp. (Costa et al. 2005; Schleyer and Porter 2018; Porter and Schleyer 2019). Tropical coral species such as *Diploastrea heliopora*, *Halomitra pileus*, *Plerogyra sinuosa* and *Physogyra lichtensteini* are absent from the province but occur further north in east Africa (Schleyer pers. comm.). The province has small scale fishing for linefish, pelagic spp, sharks and shallow and deep water crustaceans.

Unlike typical coral reefs, where hard corals are the dominant benthic fauna, soft corals and algae tend to dominate shallow reefs in this province. The relatively cooler temperatures in this province favour soft corals over hard corals, which dominate reef communities further north in more tropical conditions (Obura et al. 2012; Porter et al. 2013, 2017a). Soft corals exist in competition with other benthic encrusting types, including algae (turfs and fleshy algae) and other invertebrates (including hard corals). Soft and hard corals are autotrophic due to symbiotic algae, thus do best in clear-water and low-nutrient conditions, while their competitors are promoted when turbidity and nutrients are higher (Porter et al. 2014). Herbivores (both fish and mobile invertebrates) play an important role in controlling competitive interacts on the benthos, with high herbivory promoting coral dominance. Coral predators may also be locally important, and may be driven by different drivers, although Crown of Thorns seastars are generally not an issue in this province.

External factors important on coral reefs include: river and surface runoff (including sediments and nutrients), cyclones and storms that damage benthic organisms and shift competitive advantage to fast-growing algal taxa and filter feeders, and climate change, through warming (that causes coral bleaching and mortality) and acidification (which undermines the integrity of the reef and imposes a metabolic cost on corals) (Porter et al. 2017a, b; Schleyer et al. 2018). Interacting influences include cyclones that reduce water temperatures, thus reduce the effect of warming, and increase rainfall and flooding on land, thus increase the influence of river and surface runoff (Pereira & Gonçalves, 2004). In the south of this province, upwelling of cooler water facilitated by submarine canyons are also thought to moderate temperatures (Porter and Schleyer 2019). Coral predators (and diseases) may be enhanced by increased runoff, and higher temperatures.

Anthropogenic factors affecting the reef system include fishing, through targeted extraction of some fish, excessive offtake and destructive methods, in localised areas particularly in southern Mozambique that cause benthic damage; coastal development, which may be through agriculture, urban development or tourism, each with somewhat different ramifications on river/surface runoff, sedimentation and nutrients, as well as chemical pollution (Porter et al. 2018); and anthropogenically driven climate change (Sola 2017). Alien invasive species are not yet an important factor on coral reefs in this province, except potentially for the role of introduced microbes in coral diseases.

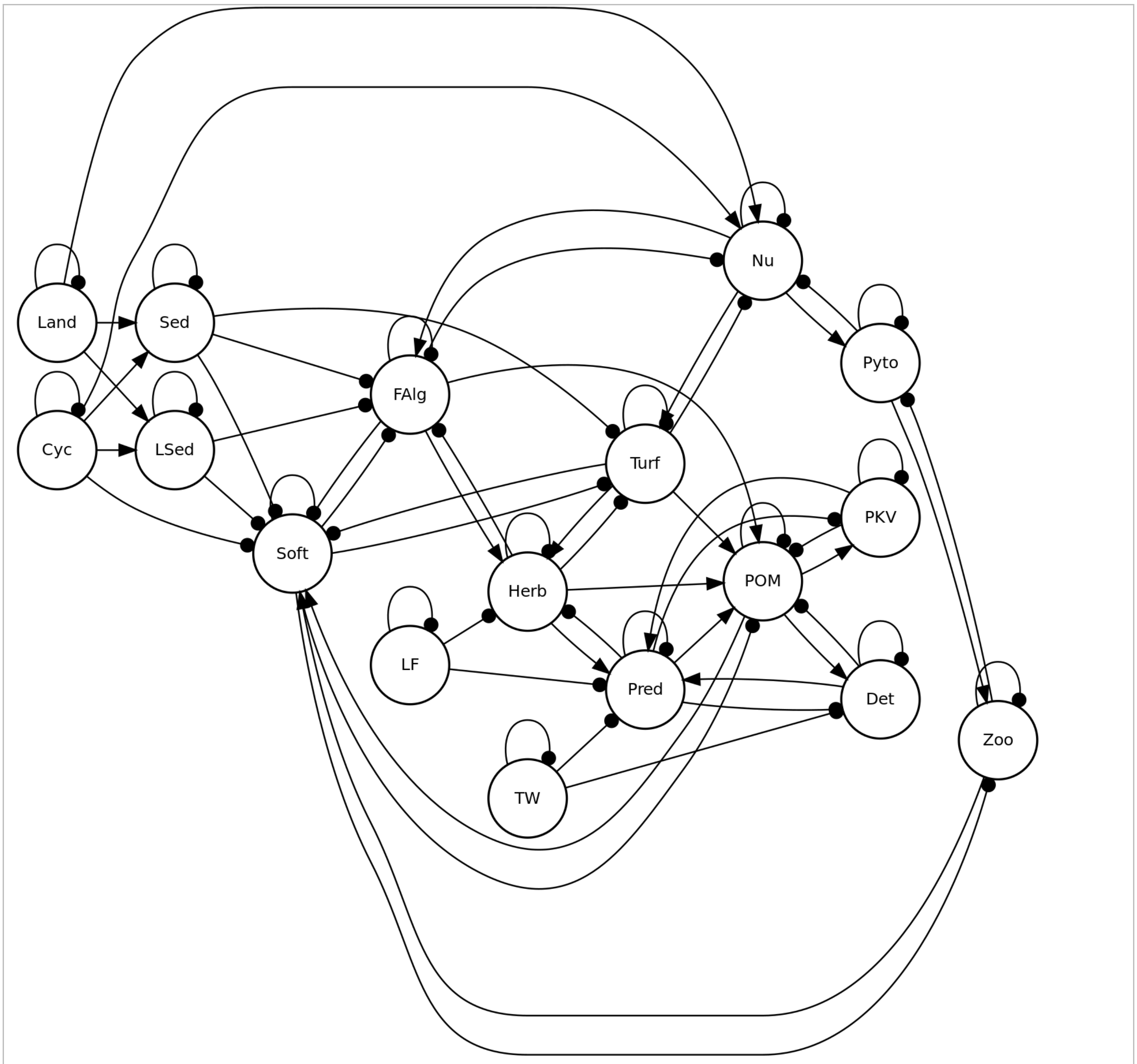


Figure 86: Ecosystem components in the qualitative model are: Soft Corals (Soft), Fleshy Algae (FAlg), Turf Algae (Turf), Particulate Organic Matter (POM), Nutrients (Nu), Phytoplankton (Pyto), Zooplankton (Zoo), Predatory Fish (Pred), Herbivorous Fish (Herb), Detritivores (Det), Planktivores (PKV) . Pressures acting on the system are: Sediment (Sed), Large Sediment (LSed), Line Fishing (LF), Land Use Change (Land), Trawl (TW), Cyclones (Cyc)

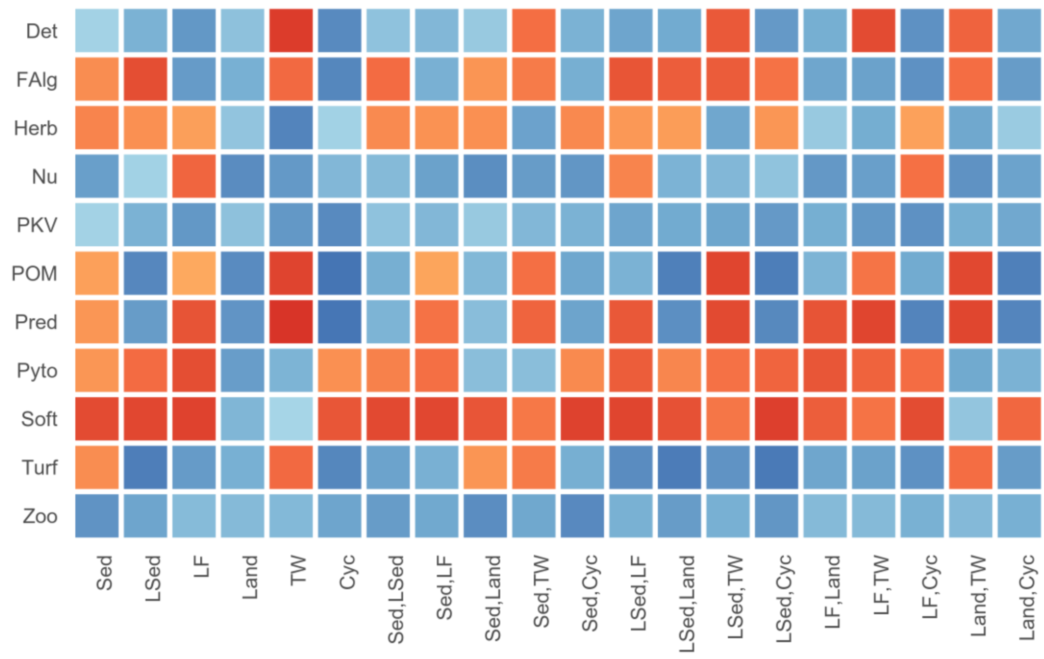
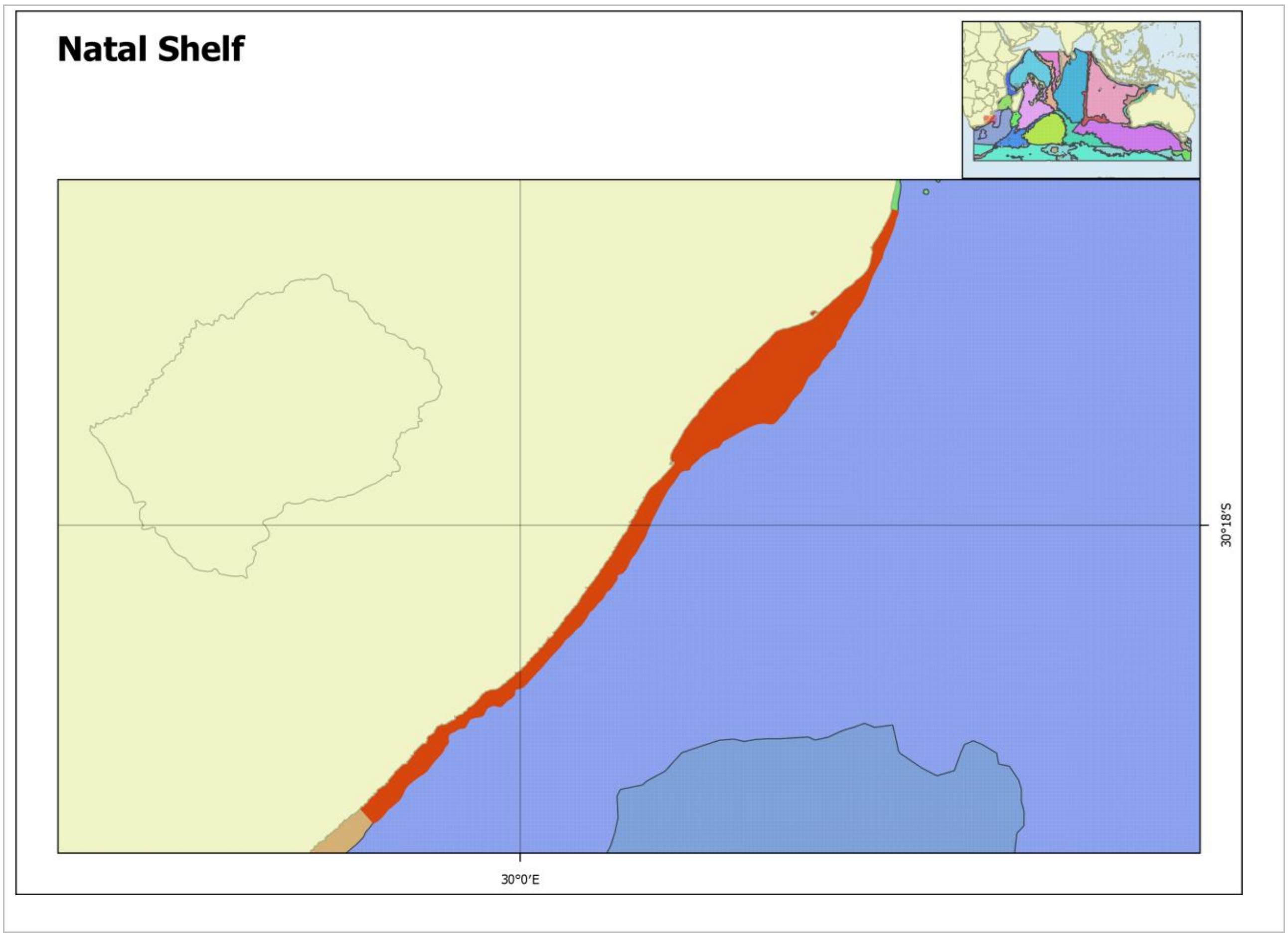


Figure 87: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

2.4.29 Natal Shelf Province



Natal Shelf Province is a subtropical province at the southern end of the Mozambique Channel (Porter et al. 2013; Stephenson 1939; Brown and Jarman 1978; Jackson 1976; Bolton et al. 2004; Sink et al. 2005; Turpie et al. 2000). It extends from the Mbashe River in the Eastern Cape northwards to Cape Vidal in KwaZulu-Natal, South Africa. The shelf edge and therefore the eastern boundary of the province ranges from 10-50km offshore (Lutjeharms et al. 2000). The Agulhas Current flows southwards through the province and interacts with the shelf resulting in a dynamic upwelling cell in the Natal Bight (Lutjeharms et al. 2000; Meyer et al. 2002). The province is characterised by higher turbidity and riverine influence relative to the southern part of the adjacent Delagoa Province to the north (De Lecea et al. 2013; Porter et al. 2014; Scharler et al. 2016; Porter et al. 2017). The rocky intertidal shores are characterised by the algae *Hypnea spicifera* and *Cheilosporum sagittatum*, and the filter feeders *Perna perna* and *Octomeris angulosa* (Sink et al. 2005). The dominance of *P. perna* distinguishes this province from most of the Delagoa Province to the north. The shallow rocky reefs are dominated by algal, sponge and ascidian communities with small components of mainly azooxenthellate coral species (Porter et al. 2013; Olbers et al. 2009; Celliers et al. 2007). Characteristic taxa include turf algae, several articulated coralline (*Amphiroa ephedraea*, *A. bowerbankii*, *Halimeda cunneata*) and fleshy algae (*Sonderophycus capensis*, *Ptilopohora pinnatifida*, Zonaria spp.) sponges (*Suberites kelleri*, *Speciospongia vagabunda* & *S. globularis*), ascidians (Pyura stolonifera) and various azooxenthellate octocorals (*Homophyton verrucosum* & gorgonians). Soft sediment macrofauna are dominated by Annelida, Arthropoda, Mollusca, and Echinoderms with their distribution chiefly related to the distribution and variance of different sediment sizes and muds (MacKay et al. 2016). The province is distinguished by the annual sardine run.

Oceanographic conditions together with the strong terrestrial-marine linkage play the dominant roles in underpinning ecosystem interactions in the Natal Shelf Province. The trophic structure of reefs in this province is characterised by a high biomass of filter-feeders and algae, especially articulated coralline species (Sink et al. 2005; Porter et al. 2013). The subtropical water temperatures and the high riverine influence favour filter-feeders and algae communities over coral communities (Porter et al. 2017a). In fact, a significant amount of riverine particulate organic matter is assimilated by reef and demersal communities (De Lecea et al. 2013; Porter et al. 2014; De Lecea 2016). The relatively high nutrient levels due to a topographic upwelling cell in the north of the province and riverine input throughout the province also enhance productivity in phytoplankton and algal communities (Lutjeharms et al. 2000; Roberts & Nieuwenhuys 2016; Scharler et al. 2016; Porter et al. 2017a). The riverine input of suspended sediments and the enhanced productivity of the region result in relatively high levels of turbidity. Rivers also provide large amounts of sand to the nearshore region which is periodically remobilised by large storms, and this process is thought to play an important disturbance role and enhance diversity (Porter et al. 2017b). Increased sedimentation of fine sediments due to poor farming practices, a reduction in large sediment due to sand mining and increased impoundments on rivers, as well as trawl and line fishing are key pressures and factors governing ecological interactions in bottom-up and top-down processes respectively (Dunlop and Mann 2013; Mann, Fennessy 2016; 2013; Porter et al. 2017b).

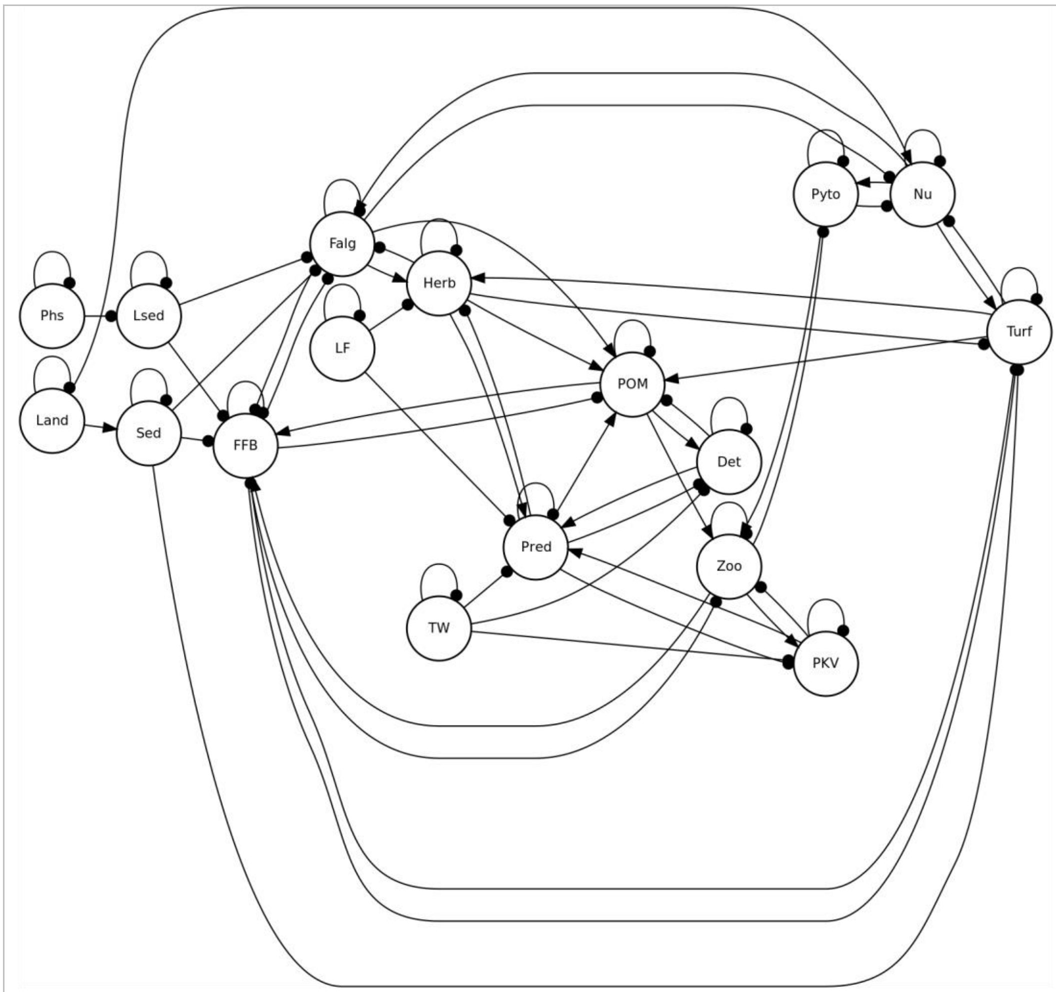


Figure 88: Ecosystem components in the qualitative model are: Filter Feeding Benthic (FFB), Fleshy Algae (Falg), Turf Algae (Turf), Particulate Organic Matter (POM), Nutrients (Nu), Phytoplankton (Pyto), Zooplankton (Zoo), Predatory Fish (Pred), Herbivorous Fish (Herb), Physical Disturbance (Phs), Detritivores (Det), Planktivores (PKV) . Pressures acting on the system are: Sediment (Sed), Large Sediment (Lsed), Line Fishing (LF), Land Use Change (Land), Trawl (TW)

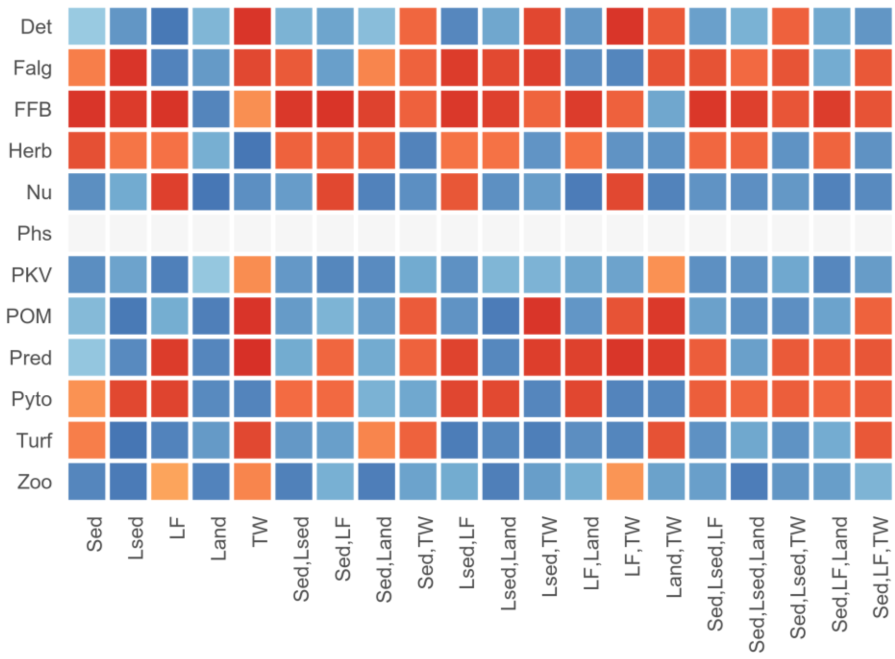


Figure 89: Ecosystem scenario responses to combinations of pressures. Red indicates a negative change and blue indicates a positive change. Labels are described above.

Appendix 1: Statistical Bioregions

We developed and implemented a series of models which extended on a Regions of Common Profile (RCP) models (Foster et al., 2013) to generate biologically data driven bioregions for the Indian and the Southwestern Pacific Ocean regions. The RCP approach is a 'Mixture-of-Experts' finite mixture model. This model characterizes a bioregion as a spatial region, where the probability of observing a species, at a randomly chosen location falling within that bioregion, should be approximately constant. Additionally, the chances of observing that species at random sites in different bioregions should be unequal. This model based notion was formally introduced by Foster et al., (2013).

However, at regional scales the availability of broad scale biological datasets tends to decrease, instead, ad-hoc datasets which are an amalgamation of smaller scientific surveys and ad-hoc collections. These records are often kept in natural history collections and in online repositories. These ad-hoc data often come with the unfortunate problem of missing information on where species were not observed (absences). As a consequence we can never truly estimate the probability of occupancy form these data as we are missing key information (absences). This also means that the models (built for presence-absence and abundance data) are ill equipped to deal with these data, without some modifications.

We do this by extending the RCP model to be a spatial point process (Cressie 1993). Based on the current implementation of the RCP models, we can do this simply by generating a spatial Poisson model, which is often done for single species models (Fithian & Hastie, 2014). The inhomogeneous Poisson point process RCP (IPPM-RCP) was fitted as a Poisson model. This was achieved by fitting the model to a grid of environmental predictors, where individual species occurrences are summed to reflect a count (Poisson), the exception being that cells will no species records in them are not excluded from model fitting, but rather are given a value of zero (akin to a background point). This model then produces a bioregions similar to the definition above, but rather than a probability of occurrence of a species within a bioregion, we generate a probability of sighting a species within a bioregion (a density based on the presence points).

We used the IPPM-RCP method to generate bioregions from benthic regions of the Indian Ocean we developed two seafloor taxonomic groups, brittle stars (Ophiuroidea) and squat lobsters (Galatheoidea and Chirostyloidea). Two biological datasets were used that included 152 brittle star and 41 squat lobster species with greater than 10 observations across the Indian Ocean region. These biological data were fitted to a set of environmental and spatial data, including latitude, longitude, depth, nitrate, oxygen, silicate and temperature as linear and quadratic terms. The environmental covariates were derived from the World Ocean Atlas datasets, and were tri-linearly interpolated to the seafloor using the GEBCO bathymetry layer.

Based on model fitting, taking a parsimonious approach, we found three broad regions for the ophiuroid species, and four for the squat lobster dataset. The number of groups was derived based on Bayesian Information Criteria. Spatial predictions where made across the Indian Ocean seafloor for each taxa, which contained mean (point) and standard errors in the prediction of each archetype (group).

These model predictions where then taken to the first Indian Ocean expert elicitation workshop for generating bioregions across the Indian Ocean. After consultation among experts with reference to these models and local knowledge of the region three broad scale bioregional provinces were agreed upon which represented broad scale biological and physical classifications which strongly reflected predicted distribution form the IPPM-RCP models. The large regions where then used at the top of hierarchical scheme which then classified finer scale region within each of the broad provinces.

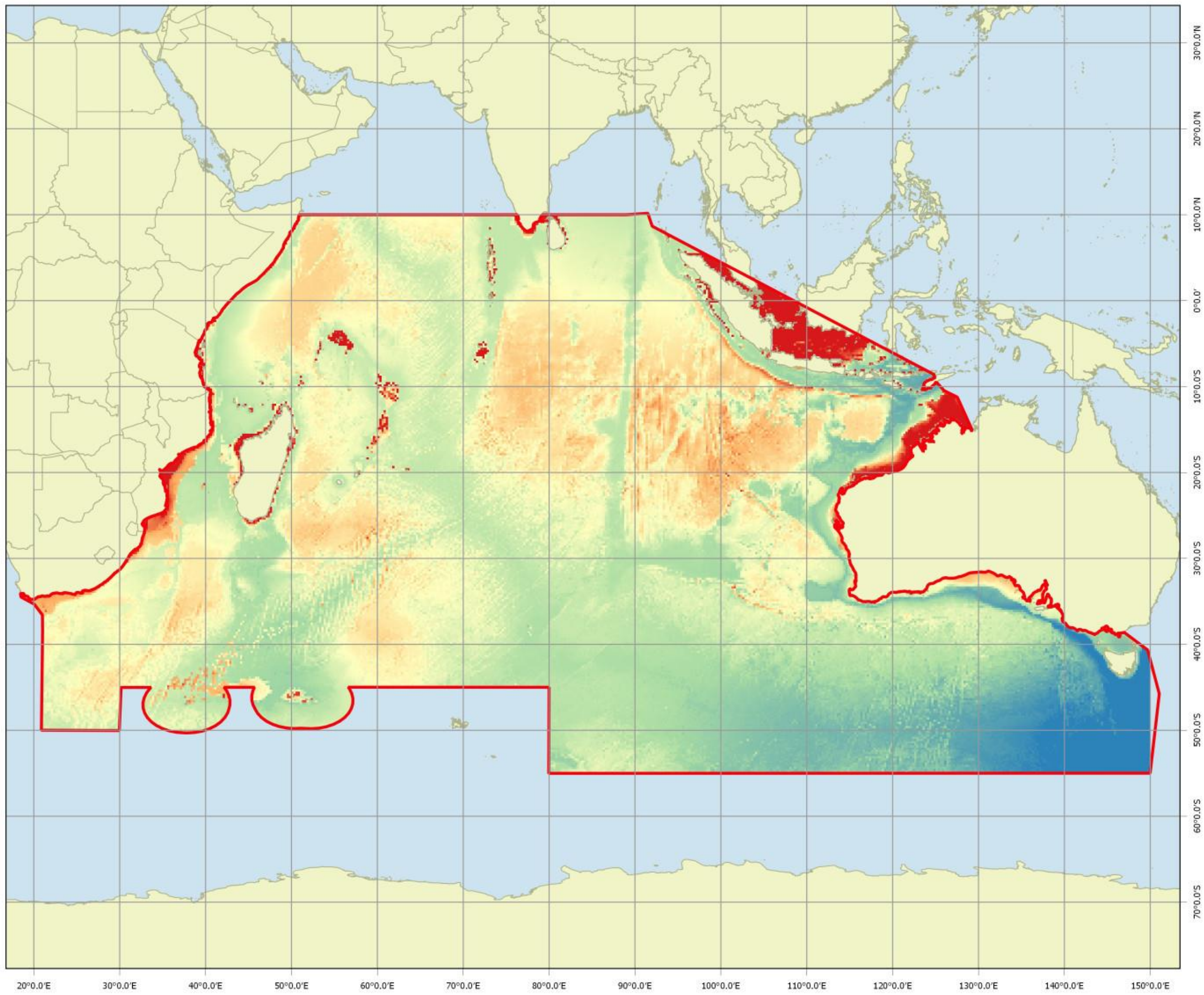


Figure 90 Ophiuroid Group 1

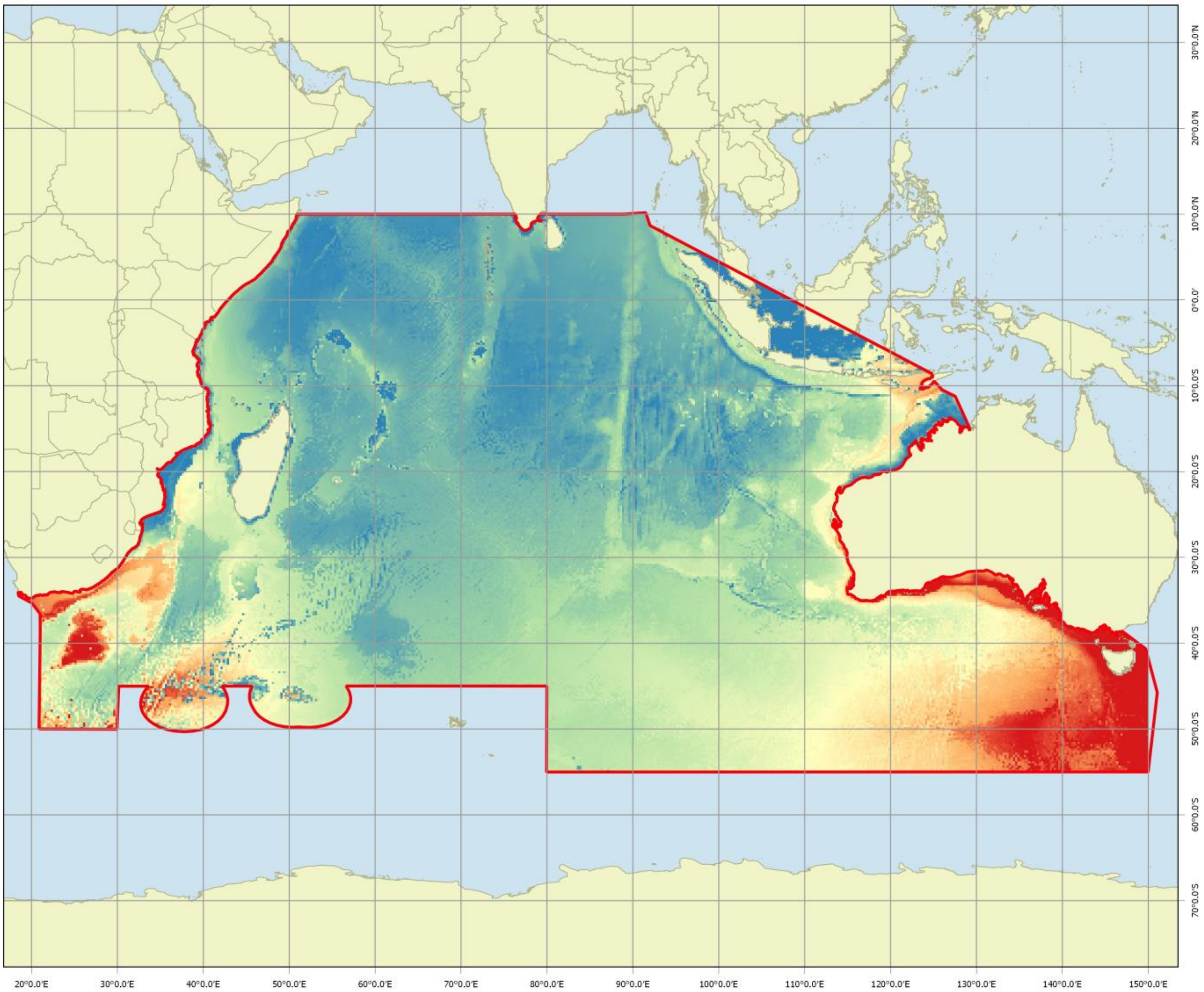


Figure 91 Ophiuroid Group 2

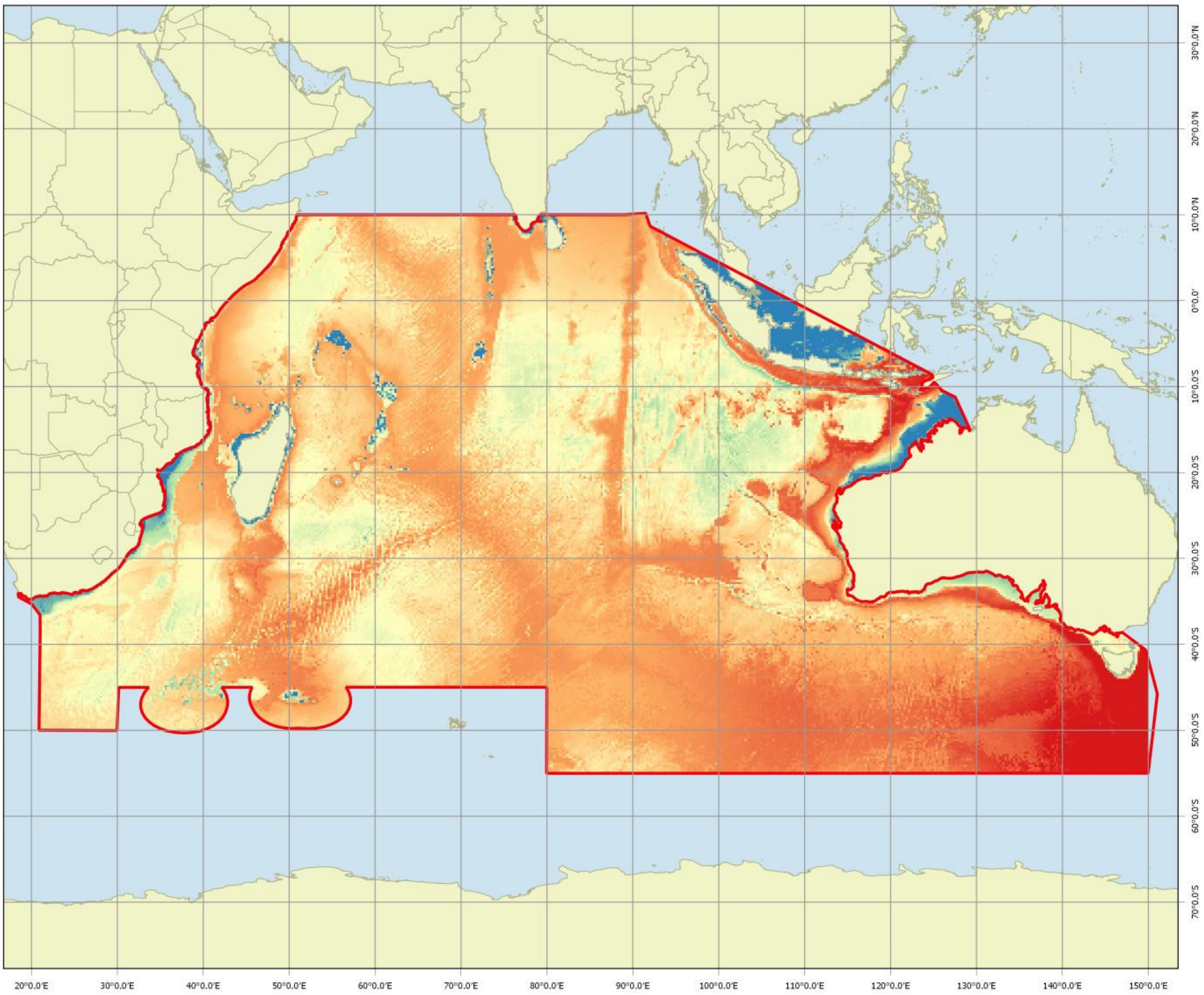


Figure 92 Ophiuroid Group 3

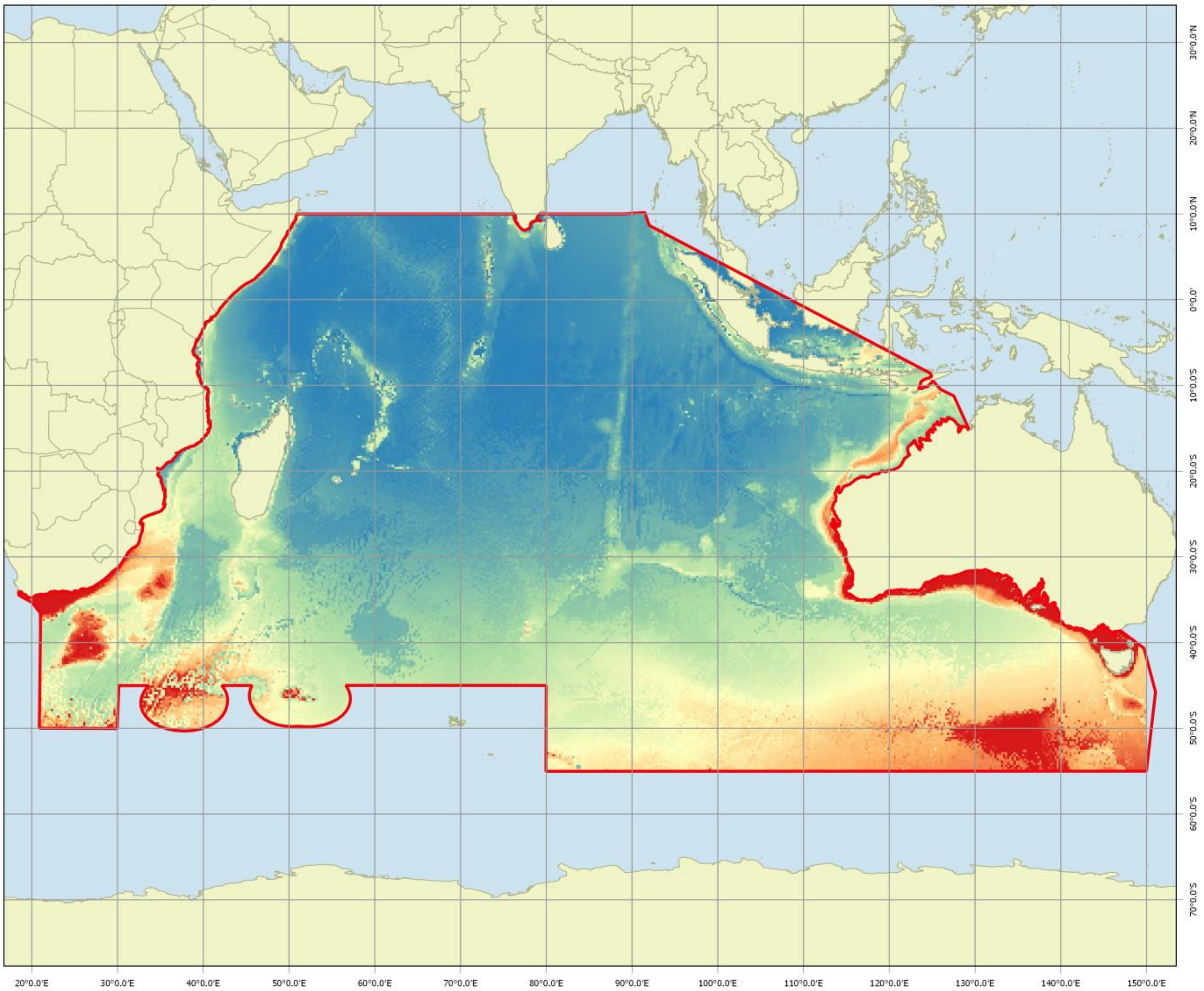


Figure 93 Ophiuroid Group 4

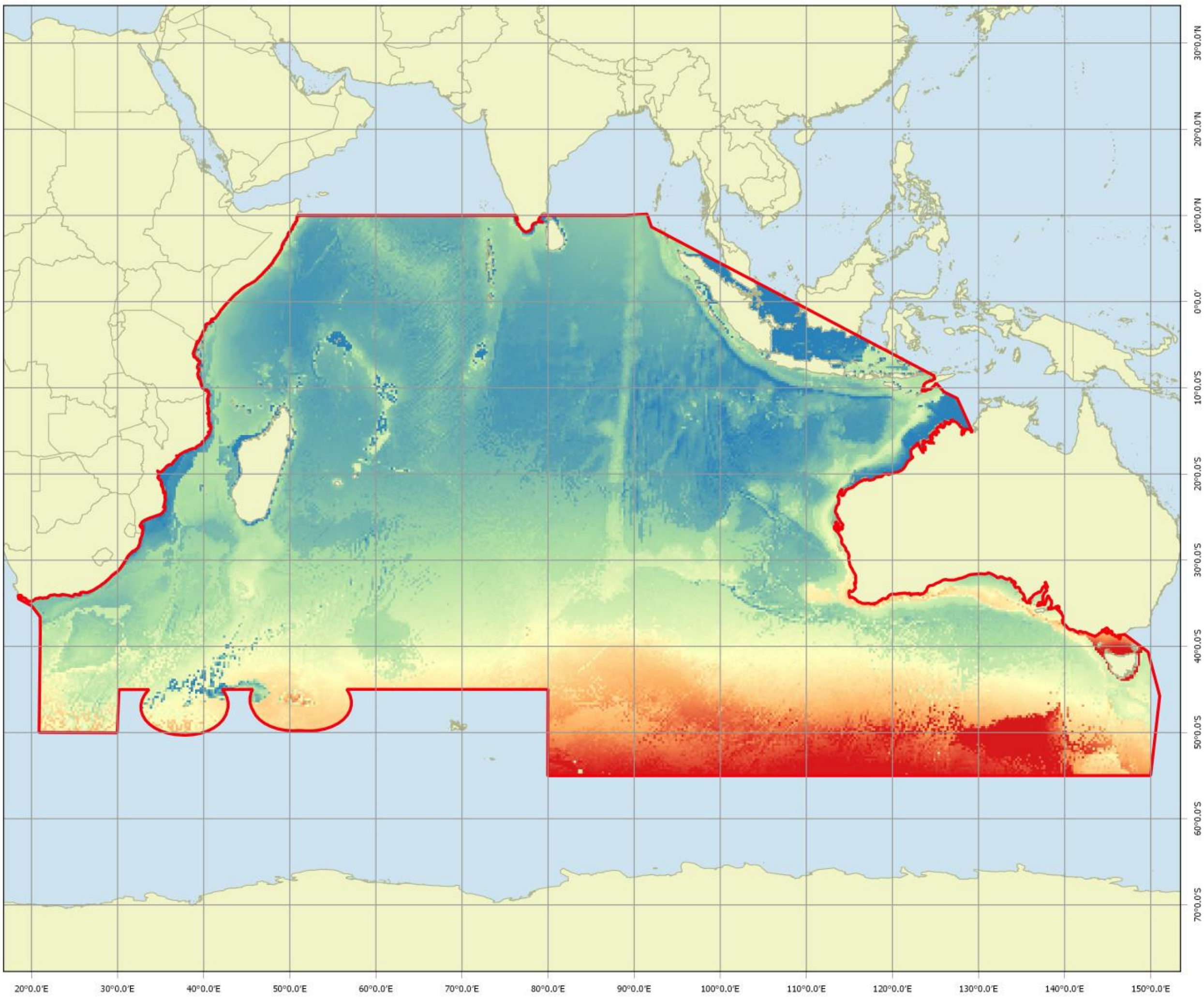


Figure 94 Ophiuroid Group 5

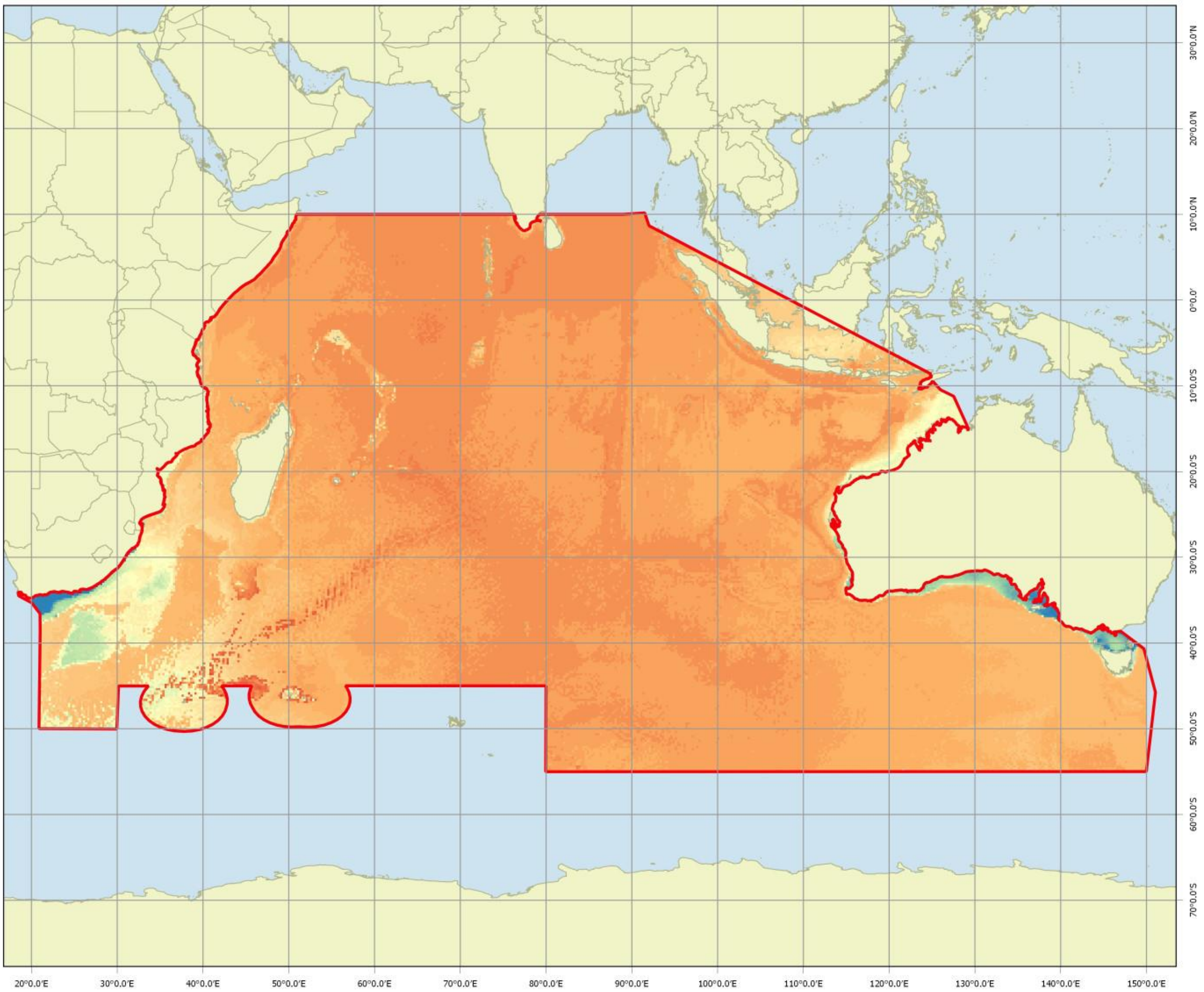


Figure 95 Ophiuroid Group 6

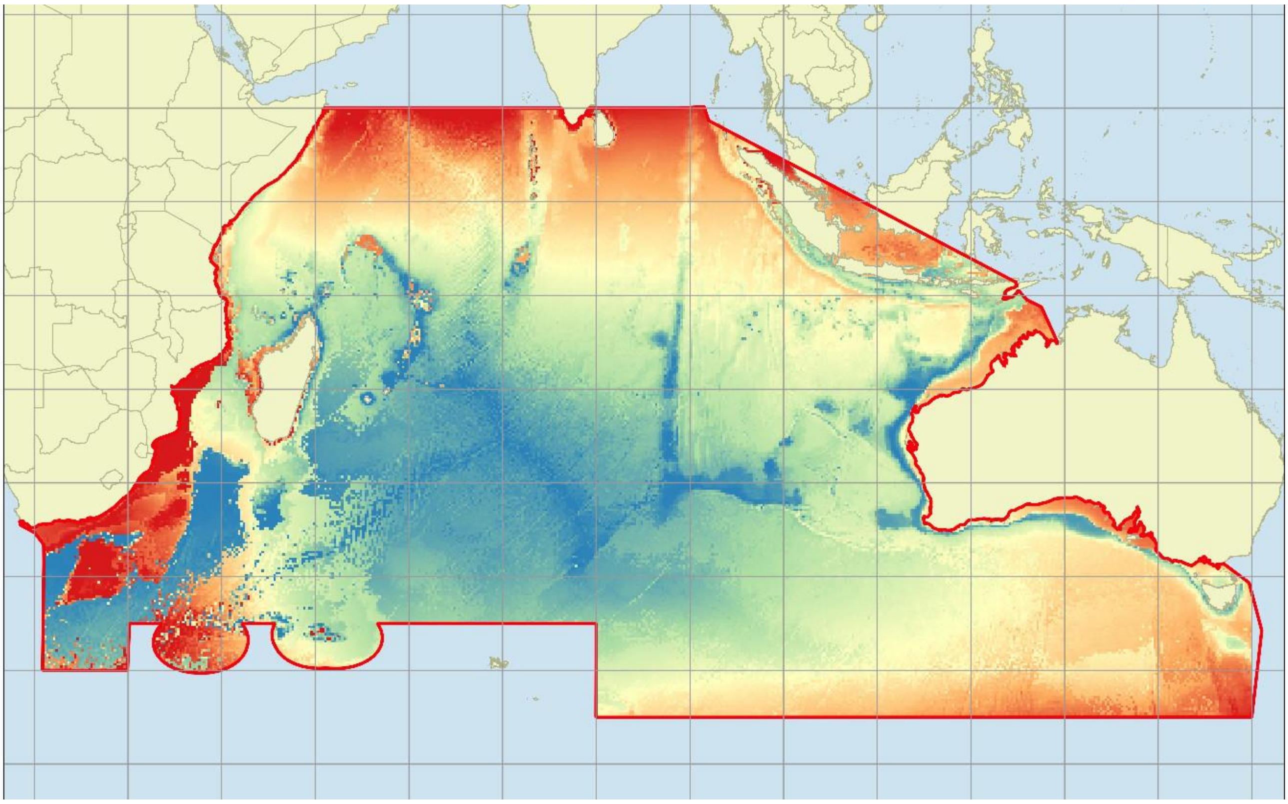


Figure 96 Squat Lobster Group 1

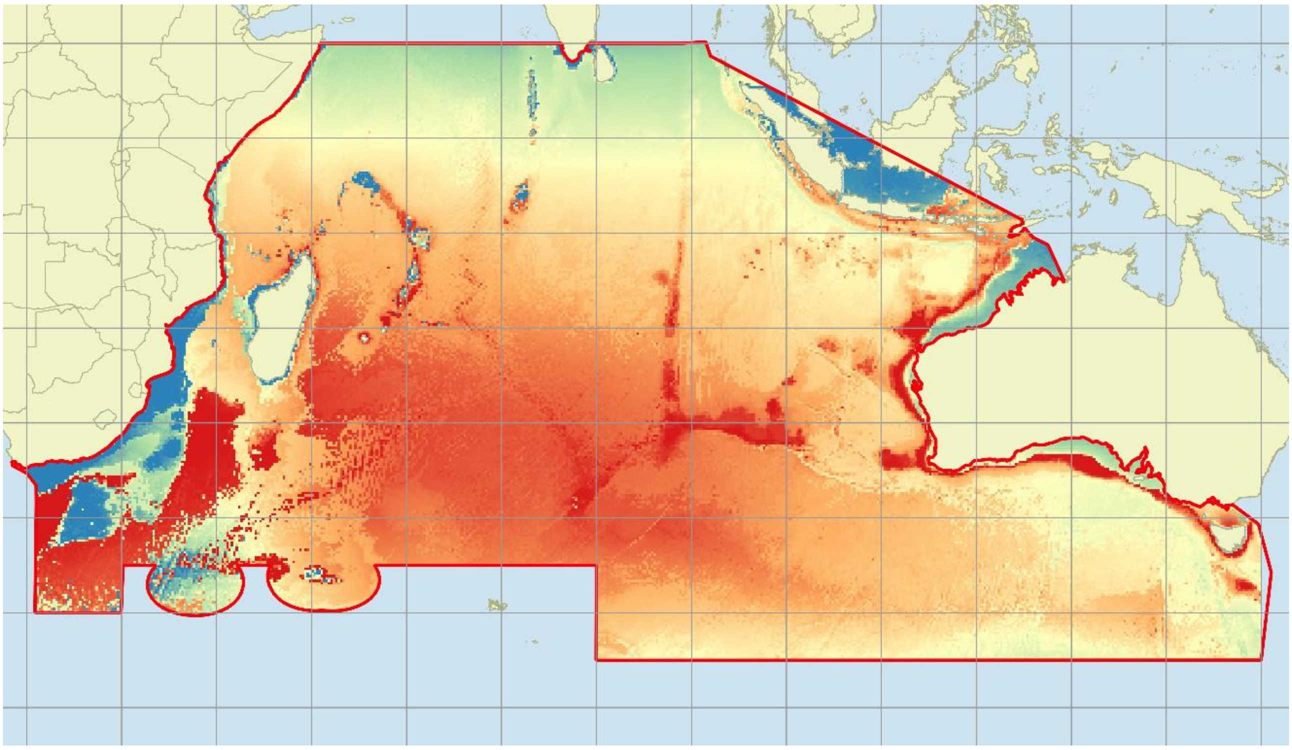


Figure 97 Squat Lobster Group 2

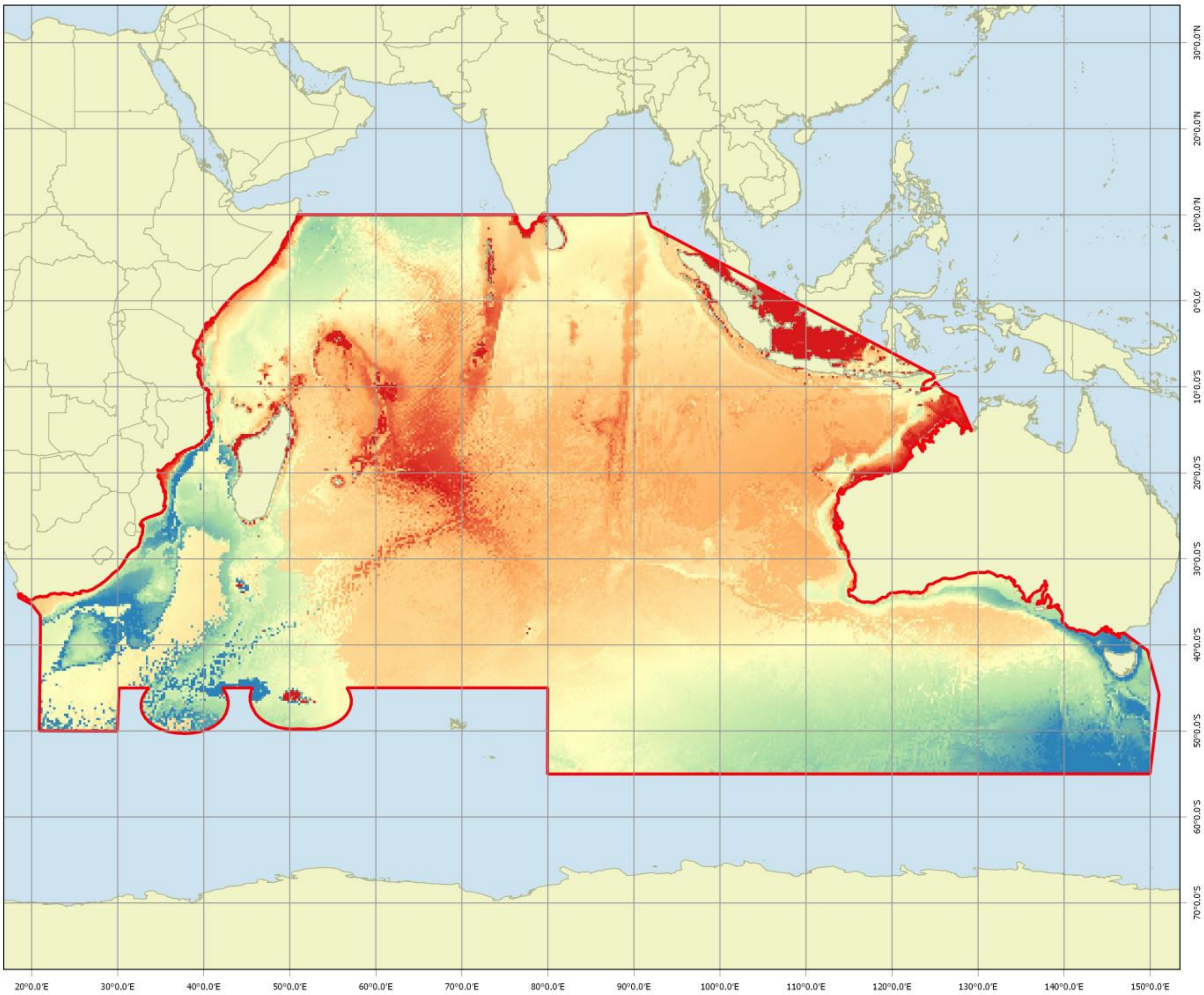


Figure 98 Squat Lobster Group 3

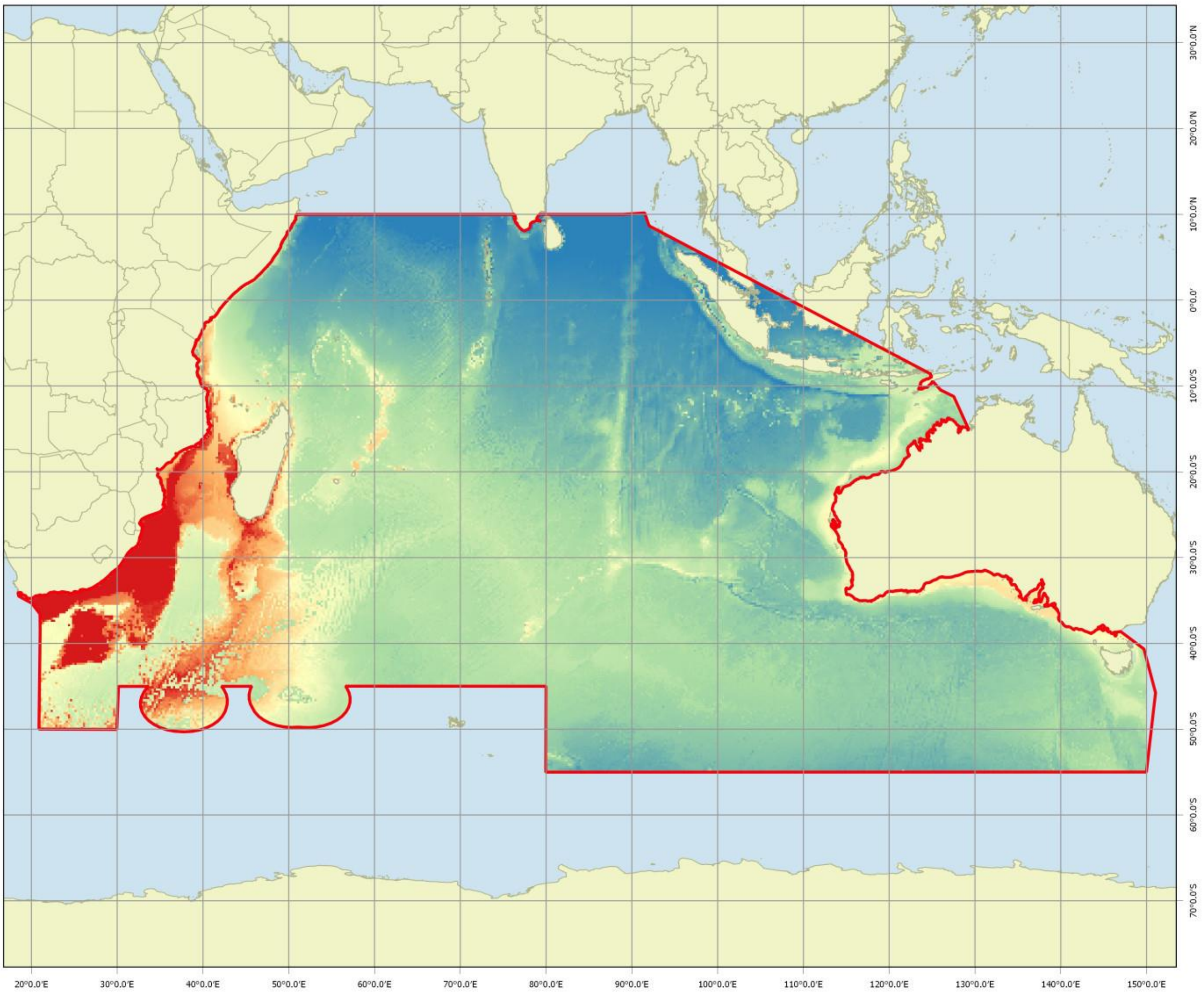


Figure 99 Squat Lobster Group 4

Appendix 1: Qualitative Models

Table 1 Functional Groups used in the qualitative modelling.

Name	Acronym	Pressure
Acidification	Acid	p
Artesinal Fisheries	Art	p
Bacteria Graizers	Bgraz	
Biofilm	Bfil	
BioTurbators	BT	
Birds	Bird	
Bivalues	BiV	
CCA	CCA	
Chemosynthetic Bacteria	ChemB	
Chemosynthetic Symbionts	ChSym	
Climate Change Acidification	CCA	p
Climate Change Chlorophyll	CCC	p
Climate Change Temperature	CCT	p
Climate Change	CC	p
Commercial Fisheries	ComF	p
Coral	Coral	
Coral Predators	COTS	
Crabs	Crab	
Crocodile	Croc	
Crustacean Fishery	CrF	
Cyclones	cyc	p
Detritivores	Det	
Distance to Deep water	Dist	
Deposit Feeders	DepF	
Demersal Fishes	DemF	
Demersal Trawling	DT	p
Dugong	DG	
Encrusting Invertebrates	EncInv	
Epiphytes	EP	
Filter Feeding Benthic	FFB	
Fleshy Algae	Falg	
Food Falls	FF	
Grounding Ships	GS	
Hake Fishery	HF	
Herbivorous Fish	Herb	
Land Use Change	Land	p
Large Sediment	Lsed	p
Leaf Litter	LL	
Line Fishing	LF	p
Lobster	Lob	
Longline Fishing	LLF	p

Low Saline Water	LSW	p
Mangrove	Mang	
Marine Debris	MD	p
Medium Sized Predators	MSP	
Mining Prospecting	MinP	p
Mining Tailings	MinT	p
Microbes	MB	
Mobile Filter Feeders	MFF	
Mobile Invertebrates	Minv	
Net Fishing	Net	p
Non-Vent Predators	NVP	
Nutrification	Nuf	p
Nutrients	Nu	
OilSpills	Oil	p
Particulate Organic Matter	POM	
Pelagic Fishing	PF	p
Physical Disturbance	Phs	p
Phytoplankton	Phyto	
Planktivores	PKV	
Pollution	Pol	p
Prawns	PW	
Predatory Fish	Pred	
Reef Complexity	RC	
Seafloor Mining	SFM	p
Sea Urchins	SU	
Seagrass	SG	
Scavengers	SC	
Sediment	Sed	p
Sessile Filter Feeders	SFF	
Soft Corals	Soft	
Soil Nutrients	Snu	
Squid	SQ	
Targeted Fishing	TT	p
Temperature	Temp	p
Trawl	TW	p
Turf Algae	Turf	
Turbitiy Increase	Tur	p
Turtle	Tu	
Upwelling	UW	p
Vent Mining	VM	p
Zooplankton	Zoo	
RootStructureNursury	Nus	

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