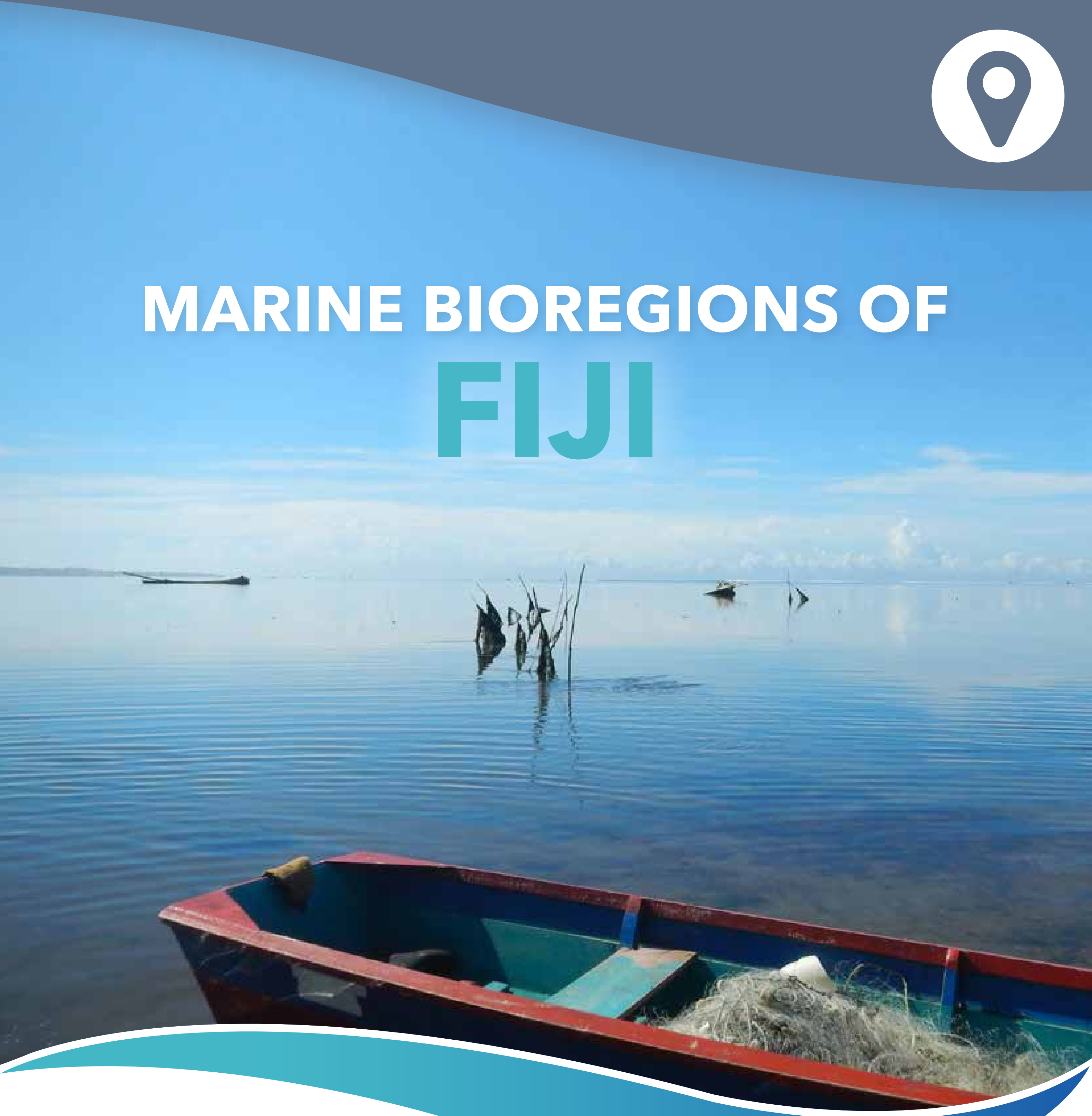
MARINE BIOREGIONS OF
FIJI



Rerevaka na Kalou ka doka na Tui

MACBIO

Marine and Coastal Biodiversity Management
in Pacific Island Countries

MARINE SPATIAL PLANNING

Marine Spatial Planning is an integrated and participatory planning process and tool that seeks to balance ecological, economic, and social objectives, aiming for sustainable marine resource use and prosperous blue economies.

The MACBIO project supports partner countries in collecting and analyzing spatial data on different forms of current and future marine resource use, establishing a baseline for national sustainable development planning.

Aiming for integrated ocean management, marine spatial planning facilitates the sustainable use and conservation of marine and coastal ecosystems and habitats.

The report outlines the technical process undertaken to develop draft marine bioregions across the SW Pacific and the national, expert-drive process to refine the bioregions for use in Fiji. These marine bioregions provide a basis for identifying ecologically representative areas to include in national networks of marine protected areas.

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MARINE BIOREGIONS OF FIJI

AUTHORS: Wendt H[1], Beger M[2], Sullivan J[3], LeGrand J[4], Davey K[1], Yakub N[1], Kirmani SN[5], Grice H[6], Mason C[7], Raubani J[8], Lewis A[9], Jupiter S[10], Hughes A[11], Ceccarelli D[12], Fernandes L[1]

2018

Marine and Coastal Biodiversity Management in Pacific Island Countries

Rerevaka na Kalou ka doka na Tui

SPREP Secretariat of the Pacific Regional Environment Programme

IUCN

giz

On behalf of
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
of the Federal Republic of Germany

AUTHOR AFFILIATIONS

1 International Union for the Conservation of Nature – Oceania Regional Office (IUCN-ORO)
2 University of Leeds (previously University of Queensland)
3 Geoscience Australia (previously IUCN-ORO)
4 Legacy Property and Investment Group (previously IUCN-ORO)
5 Wildlife Conservation Society (previously IUCN-ORO)
6 University of Leeds
7 University of Queensland
8 Secretariat of the Pacific Community
9 Geoscience Australia
10 Wildlife Conservation Society
11 Coastal Marine Management Ltd and Wildlife Conservation Society
12 ARC Centre of Excellence for Coral Reef Studies, James Cook University and Marine Ecology Consultant

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MACBIO

Marine and Coastal Biodiversity Management in Pacific Island Countries

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EXECUTIVE SUMMARY

Marine spatial planning is underway now, or starting, in many Pacific Island countries, including Fiji. This planning aims, amongst other things, to achieve the Convention on Biological Diversity's (CBD) Aichi Target 11 which states, in part, that at least 10 per cent of coastal and marine areas are conserved through ecologically representative and well-connected systems of protected areas.

However, means for Fiji, who has signed on to the CBD, to achieve an ecologically representative system of marine protected areas is missing. There are not perfect data which describe the distribution and abundance of every marine habitat and species anywhere, including Fiji. And certainly not at a scale that is useful for national planning in the ocean.

Bioregionalisation, or the classification of the marine environment into spatial units that host similar biota, can serve to provide spatially explicit surrogates of biodiversity for marine conservation and management.

Existing marine bioregionalisations however, are at a scale that is too broad for national governments in the Pacific to use. Often whole countries are encompassed in just one or two bioregions (or ecoregions).

Recognising this, the Marine Working Group of Fiji's Protected Area Committee of the Ministry of Environment and the Marine Protected Areas Technical Committee of the Ministry of Fisheries asked the MACBIO project to assist them to describe the entire marine environment of the country.

This report presents, for the first time, marine bioregions across the Southwest Pacific in general, and Fiji in particular, at a scale that can be used nationally, as a basis for the systematic identification of an ecologically representative system of marine protected areas.

Bioregions, of course, are just one of the important data layers in indentifying an ecologically representative system of marine protected areas. To be truly ecologically representative and comprehensive, one must also consider all available information about habitats, species and ecological processes. In addition, socio-economic and cultural considerations are vital in the spatial planning process. This report is focussed upon one important, but only one, input to marine spatial planning: the development of marine bioregions.

To take account of differing types and resolution of data, two separate bioregionalisations were developed; firstly, for the deepwater environments and secondly for reef-associated environments. For the deepwater, thirty, mainly physical, environmental variables were assessed to be adequately comprehensive and reliable to be included in the analysis. These data were allocated to over 140 000 grid cells of 20x20 km across the Southwest Pacific. K-means and then hierarchical cluster analyses were then conducted to identify groups of analytical units that contained similar environmental conditions. The number of clusters was determined by examining the dendrogram and setating a similarity value that aligned with a natural break in similarity.

For the second bioregionalisation, reef-associated datasets of more than 200 fish, coral and other invertebrate species were collated from multiple data providers who sampled over 6500 sites. We combined these datasets, which were quality-checked for taxonomic consistency and normalised, resulting in more than 800 species that could be used in further analysis. All these species data and seven independent environmental datasets were then allocated to over 45 000 grid cells of 9x9 km across the SW Pacific. Next, the probability of observing these species was predicted, using the environmental variables, for grid cells within the unsurveyed reef-associated habitats. Hierarchical cluster analysis was then applied to the reef-associated datasets to deliver clusters of grid cells with high similarity.

The final analytical steps, applied to all the outputs, were to refine the resulting clusters using manual spatial processing and to describe each cluster to deliver the draft bioregions. This work resulted in 262 draft deepwater marine bioregions and 102 draft reef-associated bioregions across the SW Pacific, and 18 deepwater bioregions and seven reef-associated bioregions of Fiji.

People's expertise in the Pacific marine environment extends beyond the available datasets. An important, subsequent, non-analytical step, was to review and refine the resultant draft bioregions with marine experts in Fiji prior to their use in planning. The process of review, and the resulting changes to the bioregions, are also presented in this report. The review process led to 23 deepwater and four reef-associated marine bioregions being finalised for use in national planning in Fiji. By ensuring that each bioregion is represented adequately within Fiji's network of marine protected areas, Fiji will ensure that the network is *ecologically representative* as per their commitments.

1 INTRODUCTION

Pacific Island countries, including Fiji, are moving towards more sustainable management of their marine and coastal resources (e.g. see Pratt and Govan 2011, Pacific Island Country Voluntary Commitments at the United Nations Ocean Conference), and many are also party to the Convention on Biological Diversity (CBD)[1]. Although the land area of these countries is small, they have authority over large ocean spaces within their Exclusive Economic Zones (EEZs), with 98% of most countries being ocean.

Pacific Island countries who are signatory to the CBD have committed to an ecologically representative system of Marine Protected Areas (MPAs) (see box below[2]). In addition, several leaders from the region have made commitments to better protect large parts or all of their EEZs. Many of these commitments were declared internationally and are being implemented nationally. For example, Fiji has committed to protect 30% of its marine environment in ecologically representative MPAs in its Green Growth Framework, at the Small Island Developing States meetings in 2014 and 2005, in its new National Biodiversity and Action Plan (2017) and at the United Nations Ocean Conference in 2017 (#OceanAction 19904).

CBD Aichi Target 11: By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.

Kiribati and the Cook Islands have already put in place significant measures to protect their marine environment, creating the Phoenix Islands Protected Area and the Marae Moana Marine Park, respectively[3]. Many are also committed to integrating their national networks of MPAs into wider seascapes through national Marine Spatial Plans (e.g. Vanuatu, Tonga and the Solomon Islands[4]).

There are a number of initiatives from international, regional, national and local organisations that are assisting Pacific Island countries in achieving their national goals in marine and coastal resource management (e.g. see projects being run by the Secretariat of the Pacific Regional Environment Programme, the Pacific Community, the Forum Fisheries Agency, the Office of the Pacific Ocean Commissioner, the International Union for the Conservation of Nature – Oceania Regional Office, the CBD Secretariat[5]). Many Civil Society Organisations and Non-Government Organisations are also well established in the region and have, over the years, supported Pacific Island Countries in the management and protection of their environment both at the local community scale and at national and regional levels (e.g. see projects by the Wildlife Conservation Society, the Locally-Managed Marine Area Network, WWF-Pacific, the Coral Triangle Initiative, Conservation International[6]).

However, in Fiji there is a lack of an effective way to systematically represent biodiversity. None of the previous work has provided an ocean-wide description of the marine environment at a scale needed for national marine spatial planning, and decisions about locations of ecologically representative MPAs within and across the nation.

Recognising this, the Marine Working Group of Fiji's Protected Area Committee of the Ministry of Environment and the Marine Protected Areas Technical Committee of the Ministry of Fisheries asked the MACBIO project to assist them to describe the entire marine environment of the country.

1 https://oceanconference.un.org/commitments/, www.cbd.int/information/parties.shtml, www.cbd.int/sp/targets/ accessed 28/9/17

2 www.cbd.int/sp/targets/ accessed 28/9/17

3 www.phoenixislands.org, www.maraemoana.gov.ck) accessed 28/9/17

4 oceanconference.un.org/ commitments, accessed 28/9/17

5 www.sprep.org, www.spc.int, www.ffa.int, www.forumsec.org/pages.cfm/strategic-partnerships- coordination/pacific-oceanscape/pacific-ocean-commissioner, www.iucn.org/regions/oceania/our-work/conserving-biodiversity/marine-programme, www.cbd.int/secretariat accessed 28/9/17

6 fiji.wcs.org, lmmanetwork.org, www.wwfpacific.org, thecoraltriangle.com, www.conservation.org/where/Pages/Fiji.aspx accessed 28/9/17

The Marine and Coastal Biodiversity Management in Pacific Island Countries (MACBIO) is a project funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) through its International Climate Initiative (IKI). The Project is helping the countries to improve management of marine and coastal biodiversity at the national level including to meet their commitments under the CBD Strategic Plan for Biodiversity 2011–2020 such as relevant Aichi Biodiversity Targets. MACBIO is implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) with the countries of Fiji, Kiribati, Solomon Islands, Tonga and Vanuatu. It has technical support from the Oceania Regional Office of the International Union for the Conservation of Nature (IUCN-ORO) and is working closely with the Secretariat of the Pacific Regional Environment Programme (SPREP), see www.macbio-pacific.info.

MACBIO's objectives are to help ensure that:

1. The economic value of marine and coastal ecosystem services is considered in national development planning;
2. Exclusive economic zone-wide spatial planning frameworks are used to align national marine and coastal protected area systems with the requirements of ecosystem conservation; and
3. Best practices for managing MPAs, including payments for environmental services, are demonstrated at selected sites.

Under the second objective, the project is assisting governments with their Marine Spatial Planning (MSP) processes to better manage the different uses of marine resources. For the countries that MACBIO is working with, the MSP process is also aiming to include a national ecologically-representative network of marine protected areas (MPAs). In principle, this requires complete and accurate spatial biodiversity data, which are rarely available. Bioregionalisation, or the classification of the marine environment into spatial units that host similar biota, can serve to provide spatially explicit surrogates of biodiversity for marine conservation and management (Fernandes et al. 2005, Last et al. 2010, Fernandes et al. 2012, Terauds et al. 2012, Foster et al. 2013, Rickbeil et al. 2014). Bioregions define areas with relatively similar assemblages of biological and physical characteristics without requiring complete data on all species, habitats and processes (Spalding et al. 2007). This means, for example, that seamounts within a bioregion will be more similar to each other than seamounts in another bioregion. Similarly, for example, seagrasses beds within one bioregion will be more similar to each other than seagrass beds in another bioregion. An ecologically representative system of MPAs can then be built by including examples of every bioregion (and, every habitat, where known) within the system. Defining bioregions across a country mitigates against ignoring those areas about which no or little data are available.

The MACBIO project has built draft marine bioregions across the Southwest Pacific (SW Pacific) for use by Pacific Island countries, including Fiji, in their national marine spatial and marine protected area planning processes. By ensuring that each bioregion is represented adequately within Fiji's network of marine protected areas, Fiji will ensure that the network is ecologically representative as per their commitments.

1.1 AIMS OF THE BIOREGIONALISATION

Our marine bioregionalisation aims to support national planning efforts in the Pacific. This report describes the technical methods used by the MACBIO project to classify the entire marine environment within the MACBIO participating countries to inform, in particular, their national marine spatial and marine protected area planning efforts. The draft outputs are marine bioregions that include reef-associated and deepwater biodiversity assemblages with complete spatial coverage at a scale useful for national planning. Results for Fiji have been presented to the marine experts and government of Fiji for review. The resulting Fijian marine bioregions will provide a biological and environmental basis for the nation's MSP process. Specifically, it allows for the identification of candidate sites for an ecologically-representative system of MPAs in the country.

Spatial planning for MPAs, including ecologically representative MPAs, requires much more than just holistic description of the marine environment in which one is working. Whilst marine bioregions can form an important biophysical data layer in planning, to be truly ecologically representative and comprehensive, one must also consider all available information about habitats, species and ecological processes (Lewis et al. 2017, Ceccarelli et al. 2018). Marine bioregions are useful because they offer insurance against ignoring parts of the ocean were data are incomplete or, even, absent. In the planning process overall, however, socio-economic and cultural considerations and data are also vital (Lewis et al. 2017). This report is focussed upon one important, but only one, input to MSP: the development of marine bioregions. By ensuring that each bioregion is represented adequately within Fiji's network of marine protected areas, Fiji will ensure that the network is *ecologically representative* as per their commitments.

2 RATIONALE

The decline of marine biodiversity and ecosystem services is a worldwide problem and requires better management (Jackson et al. 2001, Worm et al. 2006, Mora 2008, Beger et al. 2015, Klein et al. 2015). This has been recognised at the global level and countries are trying to address the problem through national efforts, multi- and bi-lateral initiatives and other agreements and commitments. For example, over 1400 Voluntary Commitments to improve ocean management were made at the United Nations Ocean Conference in June 2017[8]. This includes at least 130 Pacific-specific targets. In order to achieve these targets, many nations are currently in the process of zoning their marine and coastal areas for better management and greater protection. The placement and effective designation of sites as MPAs within each country requires the full representation of marine biodiversity in conservation and management areas, whilst considering socio-economic and cultural needs.

In data-poor regions, such as the Pacific, representing marine biodiversity based on comprehensive habitat and species information is impossible. Such cases require the use of biological proxies (Sutcliffe et al. 2014, Sutcliffe et al. 2015), such as environmental conditions (Grantham et al. 2010), non-comprehensive data collected at different spatial scales (Mellin et al. 2009), surrogate species (Olds et al. 2014, Beger et al. 2015), marine classifications (Green et al. 2009), expert decision-making (Brewer et al. 2009) or some combination of these (Kerrigan et al. 2011).

Since assemblages of marine species with similar life histories, often respond similarly to environmental conditions (Elith and Leathwick 2009), these species can be grouped for biogeographical predictions or ecological modelling (Treml and Halpin 2012). The probability of occurrence of such species groupings is often determined by the unique combinations of environmental parameters that are likely to drive the distribution of these groups. The classes resulting from unique combinations of environmental parameters can thus serve as surrogates for marine biodiversity that is otherwise unrecorded (Sutcliffe et al. 2015). In the marine realm, marine classification schemes also range from global (Spalding et al. 2007, Vilhena and Antonelli 2015), regional (Keith et al. 2013, Kulbicki et al. 2013) to “local” scales (Fernandes et al. 2005, Green et al. 2009, Terauds et al. 2012), with many studies including multi-scale hierarchical classes (Spalding et al. 2007).

However, the existing bioregionalisations of marine environments (both coastal and offshore) are too coarse to inform most national planning processes (Figure 1). Often entire countries in the Pacific are classified into just three, two or even one marine region. This is despite known variability within and across the marine environment within Pacific Island countries, often identified by local experts. Reef-associated marine habitats are known to vary within the scale of Pacific Island countries with changing environment and coastal morphology (Chin et al. 2011). Offshore pelagic environments are also highly variable, and are shaped by dynamic oceanographic and biophysical factors (Game et al. 2009, Sutcliffe et al. 2015) that drive pelagic population dynamics.

In offshore environments, large scale environmental dynamics drive the distributions of primary producers such as phytoplankton and consumers such as zooplankton, as well as secondary consumers such as fishes, sea-birds, turtles, jellyfish, tuna, and cetaceans. For example, sea surface temperature (SST) can be the best predictor of species richness for most taxonomic groups (Tittensor et al. 2010). By contrast, species such as pinnipeds, non-oceanic sharks, and coastal fish that are associated with coastal habitats, are predicted by the length of coastline (Tittensor et al. 2010). Furthermore, changes in thermocline characteristics affect the productivity, distribution and abundance of marine fishes (Kitagawa et al. 2007, Schaefer et al. 2007, Devney et al. 2009). For instance, the depth of the 20 degree Celsius thermocline predicts bigeye tuna catches (Howell and Kobayashi 2006). Similarly, the patterns of zooplankton distributions depend on thermoclines; however these patterns are not necessarily associated with changes in productivity (Devney et al. 2009).

Zooplankton further can respond strongly to El Niño–Southern Oscillation (ENSO) patterns (Mackas et al. 2001), whereas phytoplankton abundance is predicted by the photosynthetically available radiation (PAR, i.e. a measure of light) and nitrate concentrations, depending on their functional traits (i.e. light tolerance, temperature tolerance, growth rate) (Edwards et al. 2013). It follows that differing PAR and nitrate within a region are likely to support different phytoplankton assemblages. Temperature also predicts phytoplankton size, structure and taxonomic composition (Heather et al. 2003),

8 oceanconference.un.org/ commitments accessed 28/9/17

and in some cases, models might be improved by considering SST and chlorophyll alpha (Chl a) together and to include nitrate. Changes in diversity of plankton assemblage drives changes in the carbon, nitrogen and phosphorus (C/N/P) ratio (Martiny et al. 2013), and this corresponds to using the N/P ratio (or C/N/P ratio) as a surrogate for plankton diversity. Similarly, harmful algal bloom (HAB) species of plankton are sensitive to (and can be predicted by) temperature, phosphate, and micronutrients from land-runoff (Hallegraeff 2010).

Mega-fauna and shore-birds using the offshore habitats also follow environmental cues in search of food, which is often associated with algal blooms or indicated by changes in sea temperatures. For example, the distribution of cetaceans is predicted by primary productivity (Tittensor et al. 2010), and studies of Dall's porpoise (*Phoecoenoides dalli*) and common dolphins (*Delphinus delphis*) show that they respond to changes in SSTs (Forney 2000). A metric of SST, the annual SST range, predicts tunas and billfishes, Euphausids, and to a lesser degree corals and mangroves and oceanic sharks (Tittensor et al. 2010). Bluefin tuna (*Thunnus maccoyii*) feeding success is predicted by SST mean, SST variability, and the sea surface colour anomaly (Bestley et al. 2010). Similarly, the abundance and breeding success of seabirds in the tropics is influenced by environmental conditions (Devney et al. 2009), particularly the variability in productivity with season (expressed as mean annual variation in Chl a), but also any with upwelling changes. This shows that Chl a is a good surrogate, or a direct measure, of productivity.

Aside from patterns that may be detected in the surface waters of ocean habitats, deepwater ocean habitats can also be characterized in various ways. Firstly, there are topographic features on the sea floor such as seamounts, rises, shelf breaks, canyons, ridges and trenches, as well as oceanographic features such as currents, fronts, eddies and upwelling, which can be mapped (Harris et al. 2014). Secondly, the deep open ocean varies dramatically with depth, in physical (especially light, temperature and pressure), biological and ecological characteristics, across at least five major layers or vertical zones, known as the epipelagic or photic, mesopelagic or mesophotic, bathypelagic, abyssopelagic and hadal zones (Herring 2002).

Thirdly, within each zone there are horizontal patterns that differ in physical and biological characteristics with latitude and longitude, at various spatial scales, which may or may not overlap vertically (Craig et al. 2010, Benoit-Bird et al. 2016).

Fourth, the coupling between surface and deeper waters seems to be increasingly understood to be significant and important. So, primary productivity at the surface can influence the habitat and species that occur at much deeper oceanic layers (Graf 1989, Rex et al. 2006, Ban et al. 2014, Woolley et al. 2016).

Also, offshore species, at least partly because of the above-described features of the open ocean, do not move randomly through either surface or deep oceanic waters. Instead they tend to follow certain pathways and/or aggregate at certain sites (Ban et al. 2014).

2.1 EXISTING CLASSIFICATIONS IN THE PACIFIC REGION

There are many existing marine biogeographical regions and even smaller marine regions or provinces described for the oceans of the world (or parts of the oceans of the world) (Lourie and Vincent 2004, Brewer et al. 2009, Kerrigan et al. 2011, Green et al. 2014, Sayre et al. 2017). The countries within the MACBIO region and within the Pacific more generally, are part of some of these existing classifications (Figure 1). We review these with regard to their scale as it pertains to use by Pacific Island countries for national planning purposes and use these works as overarching guides to our current effort.

2.1.1 Coastal classifications

Classifications typically assess spatial patterns in generalised environmental characteristics of the benthic and pelagic environments such as structural features of habitat, ecological function and processes, and physical features such as water characteristics and seabed topography to select relatively homogeneous regions with respect to habitat and associated biological community characteristics. These are refined with direct knowledge or inferred understanding of the patterns of species and communities, driven by processes of dispersal, isolation and evolution. Using such data and, often, literature reviews, experts aim to ensure, also, that biologically unique features, found in distinct basins and water bodies, are also captured in the classification. Spalding et al. (2007) applied this approach to inshore and nearshore marine environments, and delineated 232 marine ecoregions globally (Figure 1b). Of these, fifteen applied to the SW Pacific with most Pacific Island archipelagic clusters falling into their own ecoregion.

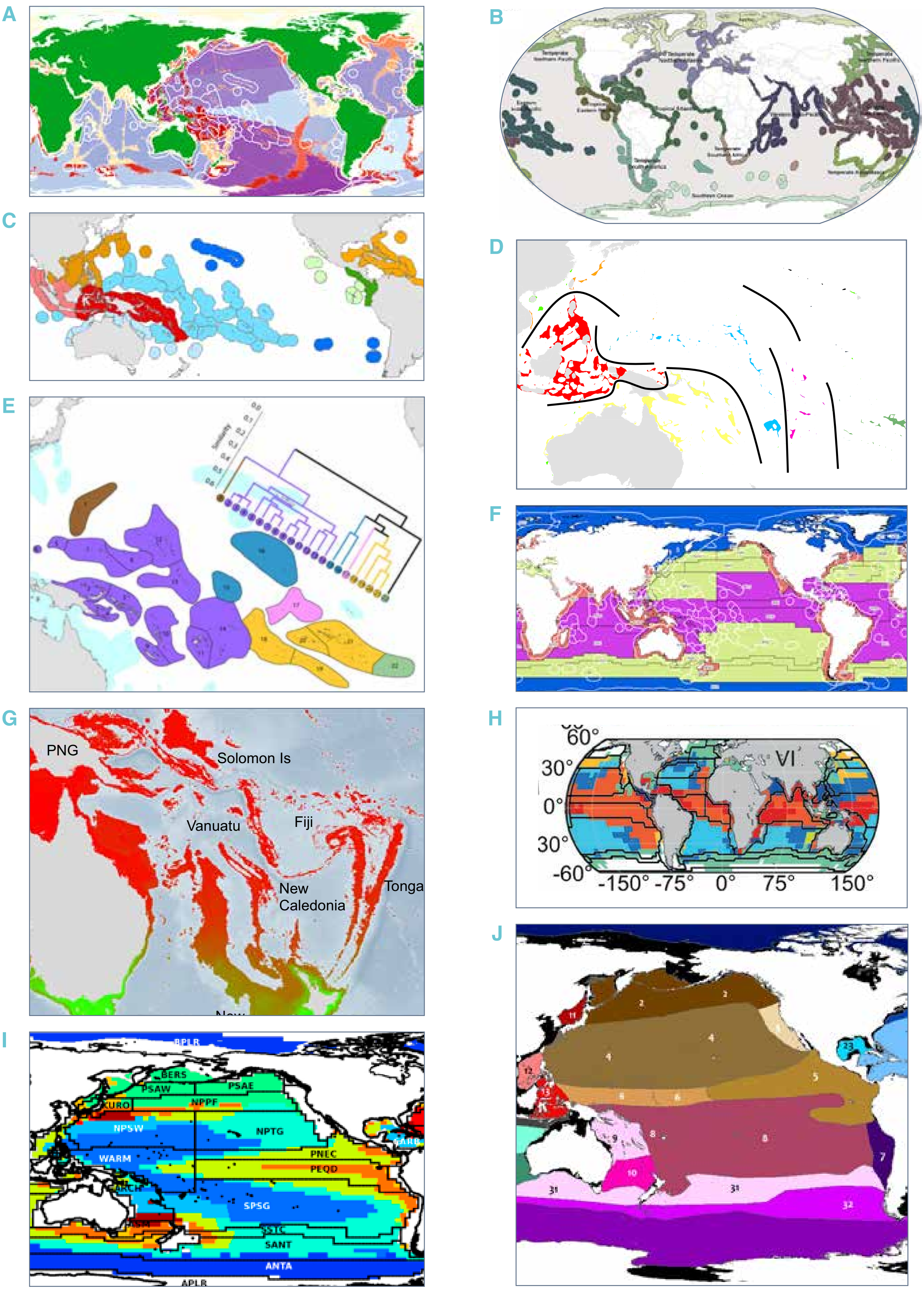

FIGURE 1: Maps of selected existing classification schemes. a) GOODS (UNESCO 2009); b) MEOW (Spalding et al. 2007); c) coral reef fishes (Kulbicki et al. 2013); d) Scleractinian corals (Keith et al. 2013); e) Veron et al. 2015; f) Biogeochemical provinces (Longhurst 2006); g) Deepwater ophiurods (O'Hara et al. 2011); h) Tuna and billfish (Reygondeau et al. 2012); i) Mesopelagic bioregions (Proud et al. 2017); j) Mesopelagic classification (Sutton et al. 2017).

Kulbicki et al. (2013) used 169 checklists of tropical reef fish to conduct four different types of classifications; the various methods were applied to ensure robust findings despite potential limitations in the data (Figure 1c). They found that the four different classification outputs converged into a hierarchy of 14 provinces, within six regions, within three realms (Kulbicki et al. 2013). The SW Pacific countries were included in four provinces (Kulbicki et al. 2013). Keith et al. (2013) explored the ranges of coral species against a variety of factors to reveal that Indo-Pacific corals are assembled within 11 distinct faunal provinces, four in the SW Pacific (Figure 1d). Veron et al. (2015) also used coral data to describe the SW Pacific into 22 ecoregions within six provinces (Figure 1e).

2.1.2 Oceanic classifications

In 1998, Longhurst divided the ocean into pelagic provinces using oceanographic factors and tested and modified them based on a large global database of chlorophyll profiles (Figure 1f). Thus he defined four global provinces (three in Oceania) and 52 sub-provinces (9 in Oceania) (Longhurst 2006).

UNESCO (2009) and Watling et al. (2013) used their expertise, guided by the best available data, to divide the ocean beyond the continental shelf into biogeographical provinces based on both environmental variables and, to the extent data are available, their species composition (Figure 1a). The ocean was first stratified into 37 benthic and 30 pelagic zones. In addition, 10 hydrothermal vent provinces were delineated, for a total of 77 large-scale biogeographic provinces of which 4 were in the tropical SW Pacific (UNESCO 2009). Watling et al. (2013) then refined the deepwater provinces using higher resolution data into 14 Upper Bathyl (about four in the SW Pacific) and 14 Abyssal provinces (one in the SW Pacific) across the globe.

The biogeography of benthic bathyal fauna can be characterised into latitudinal bands of which three are in the tropical SW Pacific (O'Hara et al. 2011) (Figure 1g). The bathyal ophiuroid fauna recorded by a number of separate expeditions was found to be distributed in three broad latitudinal bands, with adjacent faunas forming transitional ecoclines rather than biogeographical breaks. The spatial patterns were similar to those observed in shallow water, despite the order-of-magnitude reduction in the variability of environmental parameters at bathyal depths.

A bioregionalisation of the ocean's mesopelagic zone (200–1,000m) was also recently developed, using information from the deep scattering layers (a biomass-rich layer of marine animals, found between 300 and 460m deep, thick enough to reflect sound waves), resulting in ten biogeographic provinces (about six in the tropical SW Pacific) (Proud et al. 2017) (Figure 1i). Ecoregions defined with a modified Delphic Method describe the mesophotic zone of the world into 33 ecoregions, of which ten are in the Pacific (Sutton et al. 2017) (Figure 1j).

Horizontal structure within the photic surface layer has been expressed biogeographically using the distribution of tuna and billfish communities (Reygondeau et al. 2012) (Figure 1h). It was found that tuna and billfish species form nine well-defined communities across the global ocean, each inhabiting a region (about four in the SW Pacific) with specific environmental, including biogeochemical, conditions. More recently, environmental data has been used to create three-dimensional maps of the ocean, resulting in a comprehensive set of 37 distinct volumetric region units, called ecological marine units (EMUs), eleven in the tropical SW Pacific (Sayre et al. 2017).

The largely biogeographic and provincial-scale descriptions of the marine environment provided above should be considered in any national-scale marine planning exercise in the nations of the tropical SW Pacific. They also provide a higher-level regionalisation within which more detailed descriptions can be developed. However, it is clear that the level of biophysical differentiation provided by these analyses is too coarse; it is too coarse to inform country decision-makers about where to locate different marine management zones or marine protected areas if aiming for ecological representativeness within their country. Our analysis provides the finer scale description needed to support these decisions.

3 TECHNICAL METHODS

Scale-appropriate, comprehensive descriptions of the marine environment of Pacific Island countries and territories remain missing. Existing higher-level marine bioregionalisations, as described above, are not sufficiently refined to effectively inform within-country planning. This impedes the implementation of ecologically representative networks of MPAs nationally, including in Fiji. Existing information on habitats and species distributions is also incomplete and not spatially continuous. To fill this gap of classifications at an appropriate spatial scale to support national planning for oceans, the methods here were designed to provide a detailed description of marine biodiversity for Pacific Island countries and territories in the SW Pacific (Wendt et al. 2018).

The methods section comprises two parts: an introduction to the overarching approach of the analysis (including why the analysis was conducted across the SW Pacific), and the slightly different but complementary analyses that were applied to develop the deepwater and reef-associated bioregions. To take account of differing types and resolution of data, two separate bioregionalisations were developed; firstly, for the deepwater environments and secondly for reef-associated environments (Figure 2). These bioregions do not overlap in space, rather they are complementary to make use of different data resolutions available and represent different physical and biological features in these two environments.

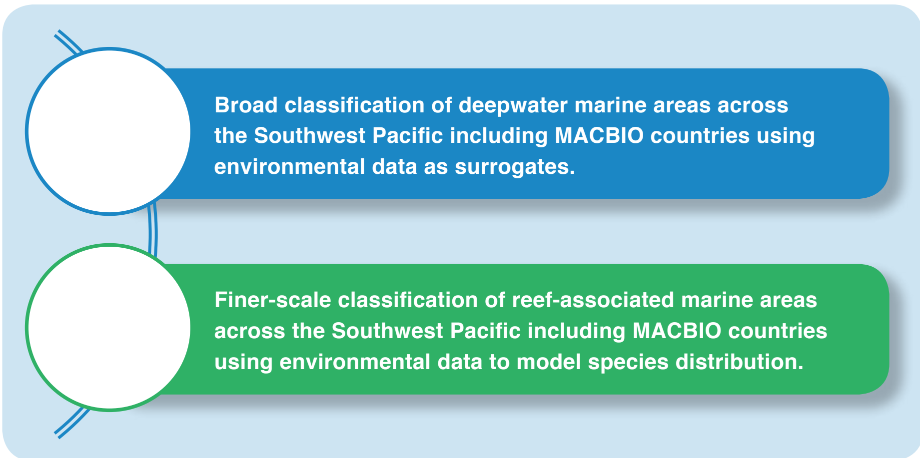

FIGURE 2: MACBIO's two-pronged integrated marine classification approach.

3.1 OVERARCHING APPROACH

As a preliminary step, we firstly defined the Area of Interest (AOI) for the analysis (Figure 3). Recognising, of course, that ecological and biological processes have no regard for jurisdictional boundaries and are operating beyond national boundaries. Therefore, any description of the marine environment within one country would be likely to "flow over" into and be relevant to neighbouring countries. So, whilst the MACBIO project focussed upon Fiji, Kiribati, the Solomon Islands, Tonga and Vanuatu, the marine systems that the project is working upon are not only contained within these country boundaries. Therefore, the AOI for the bioregion analysis was defined to include all the countries that the MACBIO project works within and all adjacent countries in the SW Pacific with the exception of Australia, New Zealand and Papua New Guinea, for which other, existing, marine regionalisations already exist or were in development (Department of the Environment and Heritage 2006, Department of Conservation and Ministry of Fisheries 2011, Green et al. 2014).

The AOI for the bioregion analyses was defined by creating a bounding box outside the EEZs of the MACBIO countries region. It extends across the SW Pacific Ocean, from Palau and Federated States of Micronesia to French Polynesia (130°W to 127°E, 34°S to 20°N). Except for Australia, New Zealand and Papua New Guinea (as mentioned above), all other marine areas that were not part of the EEZs of countries participating in the MACBIO project but fall within the AOI were also included in the bioregions analyses.

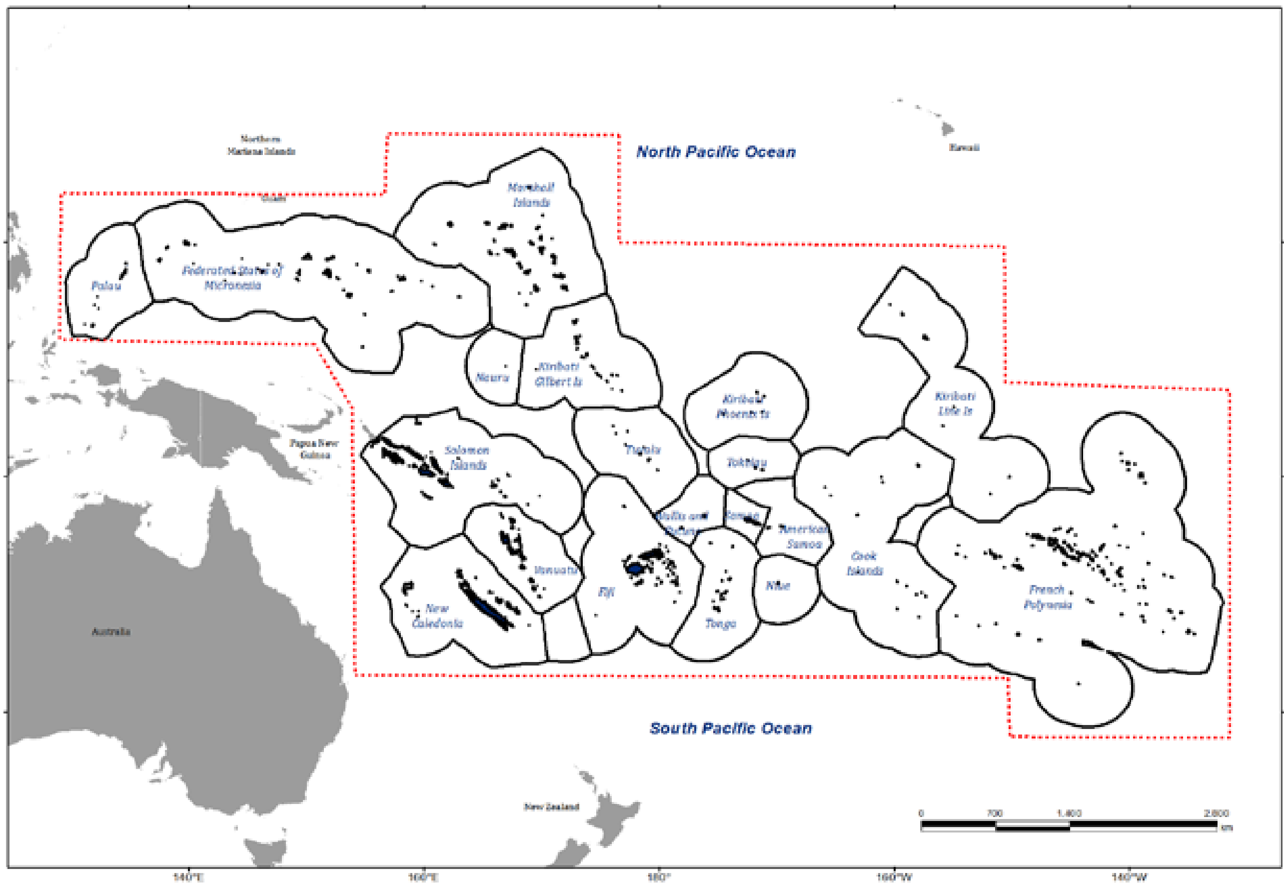

FIGURE 3: Map displaying the Area of Interest (red dotted line) and indicative provisional Exclusive Economic Zones (black solid lines).

Secondly, we chose the boundary between the deepwater versus reef-associated analysis and the size of the smallest analytical unit to be used in each bioregion analyses. Data and ecosystem considerations led to the definition of the boundary of the deepwater analysis as including areas beyond the 200 m depth or 20 km out, whichever was the furthest from land. The reef-associated analysis boundary complemented that: it was those areas within 20 km offshore or shallower than 200 m depth, whichever was furthest from land.

The appropriate resolution of the analytical units for the deepwater and reef-associated analyses was determined based upon the data resolution, purpose and scale of the analysis (i.e. to inform national planning and decision-making) and the influence on the choice of grid size on the computing time. For the deepwater analysis, 140,598 analytical grid units with a 20x20 km resolution were used and for the the shallower reef-associated areas, 45,106 analytical units with a 9x9 km resolution were used. The reef-associated areas were those that included emergent coral reef habitats, sea grasses, mangroves, and other reef-associated habitats such as sand and mudflats out to 20 km offshore or shallower than 200 m depth, whichever was furthest from land.

Third, we collated, and assessed the comprehensiveness and reliability of, environmental and biological data available from open-access sources (Wendt et al. 2018). Data were determined to be adequately comprehensive if they covered the entire AOI with sufficient resolution to enable within-country distinctions in the parameter of interest. Data were assessed to be adequately reliable if collected using methods accepted within peer reviewed literature. Of hundreds of environmental data sourced, 30 deepwater datasets were deemed adequately comprehensive and reliable for use in this classification process. Reef-associated datasets were collated from multiple data providers, but they were not comprehensive. We combined these datasets to build a comprehensive database for all reef-associated taxa. This database was quality-checked for taxonomic consistency. Then, the probability of observation was predicted to all of the unsurveyed near-shore areas with models using biological and environmental variables (see Section 3.3.3).

Fourth, hierarchical cluster analysis was conducted to identify internally homogenous clusters or groups of analytical units that are either subject to similar environmental conditions or support similar species assemblages. The number of clusters was determined by examining the dendrogram and setting a similarity value to break it up into clusters.

The fifth step was refining the resulting clusters using spatial processing and describing each cluster to deliver draft bioregions.

More detail on each of these analytical steps for the deepwater and reef-associated bioregion analysis is provided, below (Sections 3.2 and 3.3).

An important final step was to review and refine the resultant draft bioregions with marine experts in Fiji. This final review is described in Section 6, including both the process of expert review/revision and a map of the finalised bioregions which can be used in national planning in Fiji.

3.2 DEEPWATER BIOREGIONS METHODS

Marine bioregions were developed, firstly, for the deepwater areas across the Southwest Pacific. “Deepwater” for this analysis was defined at the 200 m depth or 20 km out whichever was the furthest from land.

3.2.1 Data used in analysis

The classification groups for the deepwater biological regions were driven by 30 environmental datasets including depth, salinity and sea surface temperature (Table 1) (Tyberghein et al. 2012). A more detailed description and the sources of all the data used can be found in Wendt et al. (2018). These data were served at various resolutions, requiring summary analysis to fit our 20 km resolution (see below). Comprehensive and reliable data were available at depths up to 1000 m. At depths below 1000 m, there were not enough data points in the acquired datasets to be reliable in the deepwater analysis. This was partly due to the sampling design used for the data and partly due to the bathymetry, which meant some places were not deep enough to have data below 1000 m or 2000 m (e.g. temperature at 4000 m)[9].

TABLE 1: Datasets used to derive deepwater bioregions (for more details see Wendt et al. 2018)

	DATASET NAME (SOURCE)	PARAMETER
1	Satellite gravimetry & multibeam data (GEBCO)	Depth (m)
2	Aqua-MODIS (BioOracle)	Calcite Concentration (mol/m³)
3	World Ocean Database 2009 (BioOracle)	Dissolved Oxygen Concentration (ml/l)
4	World Ocean Database 2009 (BioOracle)	Nitrate Concentration (µmol/l)
5	SeaWiFS (BioOracle)	Photosynthetically Available Radiation (Einstein/m²/day) (maximum)
6	SeaWiFS (BioOracle)	Photosynthetically Available Radiation (Einstein/m²/day) (mean)
7	World Ocean Database 2009 (BioOracle)	pH (unitless)
8	World Ocean Database 2009 (BioOracle)	Phosphate Concentration (µmol/l)
9	World Ocean Database 2009 (BioOracle)	Salinity (PSS)
10	World Ocean Database 2009 (BioOracle)	Silicate Concentration (µmol/l)
11	Global Administrative Areas (GADM28)	Distance from Land (m)
12	Aqua-MODIS (NASA)	Chlorophyll a Concentration (mg/m³) (maximum)
13	Aqua-MODIS (NASA)	Chlorophyll a Concentration (mg/m³) (mean)
14	Aqua-MODIS (NASA)	Chlorophyll a Concentration (mg/m³) (minimum)
15	Aqua-MODIS (NASA)	Chlorophyll a Concentration (mg/m³) (range)
16	Aqua-MODIS (NASA)	Sea Surface Temperature (°C) (maximum)
17	Aqua-MODIS (NASA)	Sea Surface Temperature (°C) (mean)
18	Aqua-MODIS (NASA)	Sea Surface Temperature (°C) (minimum)
19	Aqua-MODIS (NASA)	Sea Surface Temperature (°C) (range)
20	Atlas of Regional Seas (CSIRO)	Dynamic height of sea surface with regard to 2000m (m)

[9] www.marine.csiro.au/~dunn/cars2009/c09_distrib_4000mA.jpg

	DATASET NAME (SOURCE)	PARAMETER
21	Atlas of Regional Seas (CSIRO)	Depth of 20 degree isotherm (m)
22	Atlas of Regional Seas (CSIRO)	Mixed Layer Depth (m)
23	Atlas of Regional Seas (CSIRO)	Seawater Temperature (°C) (30m)
24	Atlas of Regional Seas (CSIRO)	Seawater Temperature (°C) (200m)
25	Atlas of Regional Seas (CSIRO)	Seawater Temperature (°C) (1000m)
26	Atlas of Regional Seas (CSIRO)	Nitrate (µmol/l) (1000m)
27	Atlas of Regional Seas (CSIRO)	Dissolved Oxygen Concentration (mg/l) (1000m)
28	Atlas of Regional Seas (CSIRO)	Phosphate Concentration (µmol/l) (1000m)
29	Atlas of Regional Seas (CSIRO)	Salinity (PSS) (1000m)
30	Atlas of Regional Seas (CSIRO)	Silicate Concentration (µmol/l) (1000m)

3.2.2 Data preparation

All raster datasets were projected to a Lambert cylindrical equal-area projection with metre measurement units; this projection allowed us to split the AOI into analysis cells representing equal-sized areas.

The deepwater classification was developed across jurisdictional borders, reflecting the parameters of the natural environment. For the deepwater analysis, the AOI was divided into 20 km by 20 km vector grid cells (164,430 cells). The 20x20 km cells represented the smallest unit of the deepwater regionalisation. All cells that were within 20 km of land or less than 200 m depth were removed (these were classified using higher resolution data to develop reef-associated bioregions, see Section 3.3 below) leaving 140,598 cells of 20x20 km resolution in the deepwater area. The datasets were then assigned to these 20x20 km grid using the QGIS "zonal statistics plugin" algorithm to calculate the mean value of each dataset within each cell. The mean value of each input dataset for each cell were then exported into another database, containing the mean values of all the datasets, for further processing (see also Wendt et al. 2018).

3.2.3 Statistical data analysis

3.2.3.1 RAW REGIONS BASED ON CLUSTER ANALYSIS

The environmental data were processed in the R programming language using the core set of packages (www.r-project.org). The code used for this analysis can be found in Wendt et al. (2018). The data were standardised so that all values were between 0 and 1. Bathymetry is highly influential in determining both benthic ecology/seabed geomorphology as well as benthic: pelagic coupling systems (Sutton et al. 2008, Craig et al. 2010, DeVaney 2016, Vereschchaka et al. 2016). Because of this disproportionate influence of bathymetry upon deepwater habitats and species, the value of the "depth" environmental parameter was weighted by a factor of two in the analysis (Dunstan et al. 2012, Brown and Thatje 2014, Piacenza et al. 2015). Due to computing limitations, we reduced the dimensionality of the 140,598 cells representing the deepwater area by clustering them into 5,000 groups using the k-means function implementing the MacQueen algorithm (MacQueen 1967). The k-means algorithm optimises the classification of items into clusters based on an initial set of randomly chosen cluster centres; the effect of this randomness was ameliorated by repeating the analysis 20 times and then using the classification with the minimum total within-cluster sum of squares: the classification with the best fit. This initial classification step reduced the dataset size to make the creation of a distance matrix possible (a distance matrix for the full deepwater environmental parameter dataset would require 80GB of RAM, which was not available).

A distance matrix was calculated using the centre of gravity of each k-means cluster using the *dist* function and then hierarchically clustered using the *hclust* algorithm with default parameters in the R programming language (www.r-project.org). The hierarchical clustering tree was cut at a height of 0.4 using the *cutree* function, yielding 475 clusters that contained every 20 km by 20 km grid cell. The cutoff height was determined by viewing the relative variability of the clusters as displayed in a dendrogram: a "natural" break in the dendrogram (meaning that there was a greater degree of "distance" between clusters which represented differences in the groupings) (Figure 4).

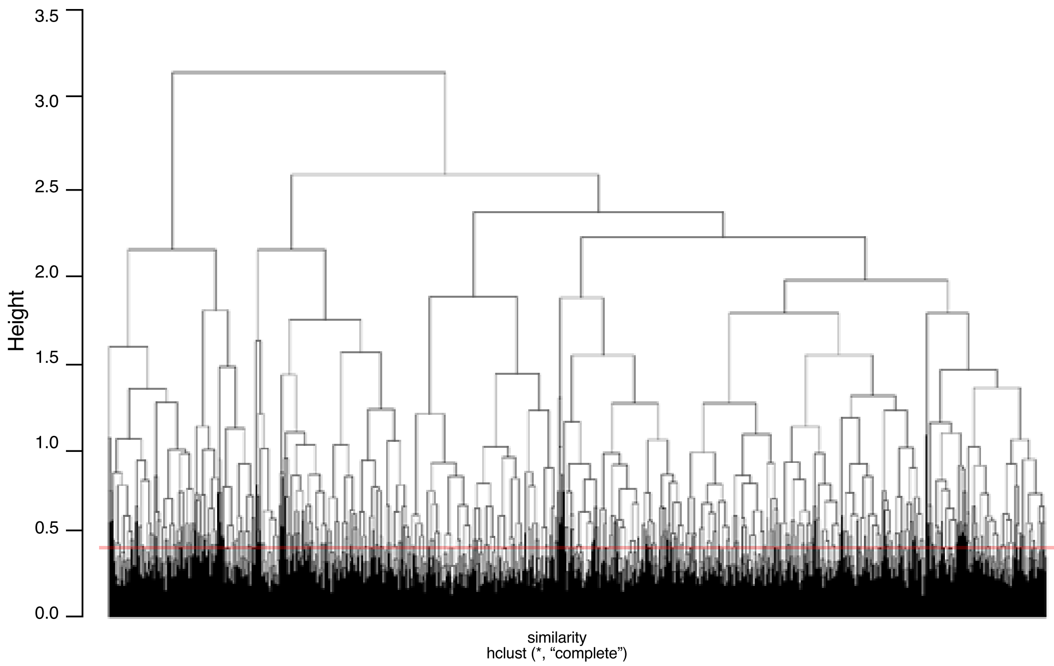

FIGURE 4: Dendrogram for offshore bioregional classification, where the red line shows the cut-off.

When plotted on a map, these clusters described the spatial variability of the SW Pacific. However, due to the necessary use of 20x20 km grid cells in the analyses, the bioregion boundaries had "square" boundaries and, in some instances, isolated irregularities arose where conflicting and intersecting data points occurred within one grid cell (e.g. at bioregion boundaries). To address these issues, a spatial smoothing and quality control step were applied.

3.2.3.2 SMOOTHING AND QUALITY CONTROL

The cluster grid had areas smaller than 4 adjacent cells which were too small to form a bioregion and were removed using the GDAL sieve algorithm[10]. The clusters were smoothed using the GRASS generalize algorithm[11] "snakes" method with default parameters (Figure 5).

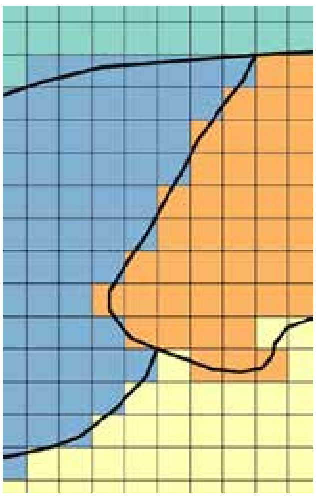

FIGURE 5: Graphic showing the 20km resolution analysis units (coloured) along with the smoothed boundaries (heavy black line).

Where the analysis identified a non-contiguous bioregion with parts that were separated by up to 1000 km, these multi-part bioregions were manually inspected to determine if their geographic locations could be explained by biological

10 www.gdal.org/gdal_sieve

11 grass.osgeo.org/grass73/manuals/v.generalize

connectivity or environmental homogeneity. For example, the environmental conditions described by region 69 occurred in two locations east and west of Fiji. If the geographic locations could be explained by biological connectivity or environmental homogeneity, then the bioregion was retained as a non-contiguous bioregion; if not they were separated into distinct bioregions as was the case for Bioregion 69 (Figure 6).

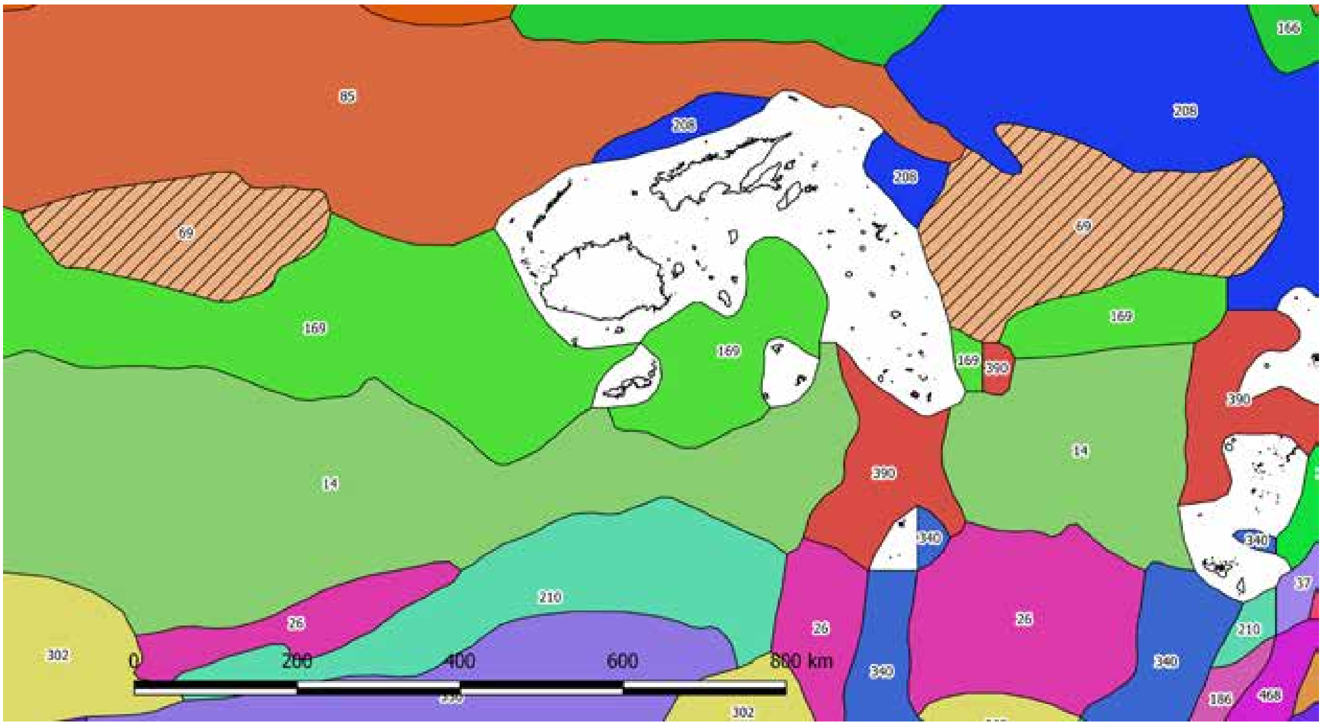

FIGURE 6: Example of post-processing decision making for non-contiguous bioregions.

3.3 REEF-ASSOCIATED BIOREGIONS METHODS

Reef-associated bioregions include shallow coral reef habitats, sea grasses, mangroves, and other reef-associated habitats such as sand and mudflats out to 20 km offshore or shallower than 200 m depth (but see Section 6), whichever was furthest from land.

The total biodiversity in these ecosystems remains largely undersampled, as in, data for reef-associated ecosystems do not exist everywhere. None-the-less, each MACBIO country, and some other Pacific Island countries, had species occurrence data, as well as environmental data, available for their reef systems. Thus, a finer-scale classification of reef-associated areas was possible in these shallower areas where both biological and environmental data were used. There were sampling sites in all MACBIO and other Pacific countries and territories, but their distribution lacked the spatial comprehensiveness and consistency needed for spatial planning (Wilson et al. 2009). Thus, survey records from these sites needed to be extrapolated in space. To provide a spatially contiguous and comprehensive coverage, the survey records were spatially modelled, producing grids of the probabilities of observation. These probability grids were then used to produce the marine coastal classification.

3.3.1 Biological data collation and standardisation

We collated biodiversity records across the study area from a variety of shallow reef-associated habitat surveys and monitoring programmes (4804 fish sampling sites of which 863 sites had hard and soft coral data and 1702 sites had (other) invertebrate data). The sampling methods and species targeted often differed depending on the focus of the intended research or project. Thus, the data across the studies needed to be standardised. All samples were collated to include species data, methods used by data providers, and differences in the type of data provided, for example, whether mean fish species' densities for a standardised area (250 m^2) or presence/absence records. All records were standardised by conversion to presence-absence records for all taxa, which was the most common level from all providers (Table 2).

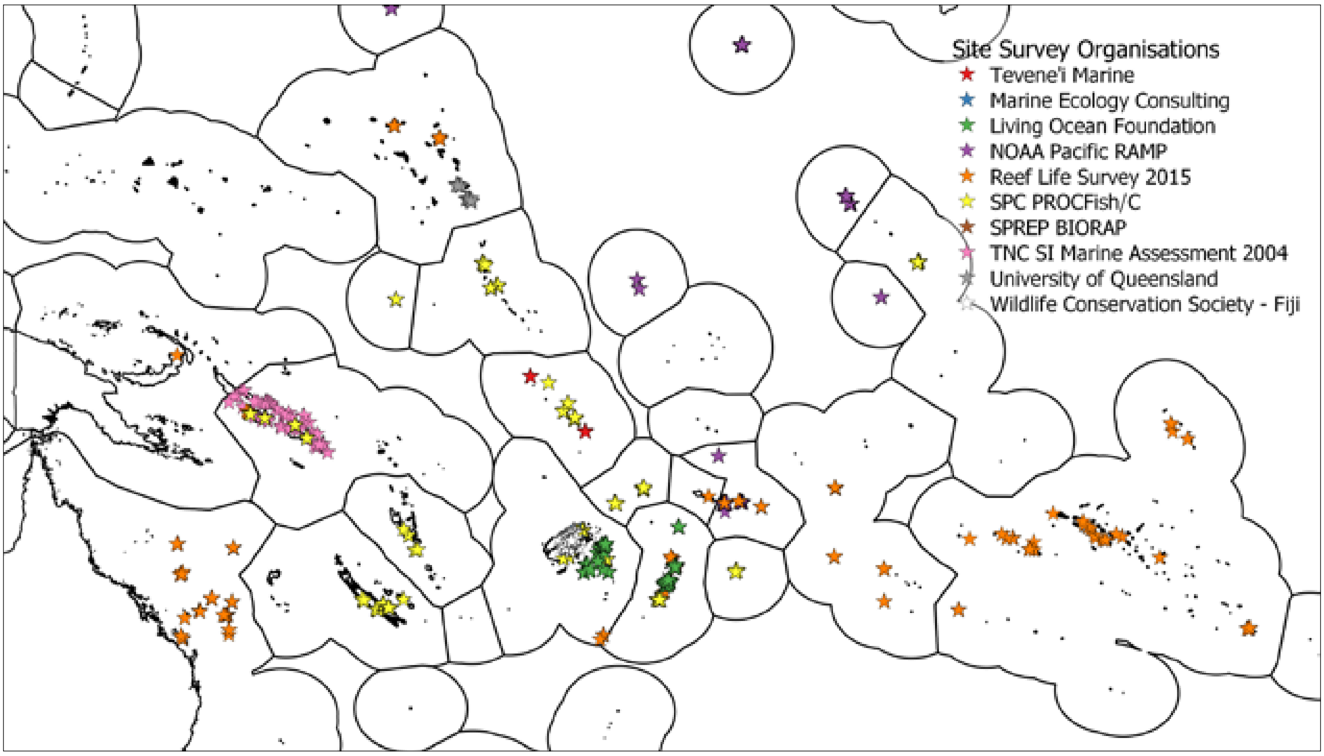

FIGURE 7: Map showing locations of fish, coral and other invertebrate surveys used.

Different numbers of species were included in the database for the three taxa. For fishes, georeferenced reef survey data for 4804 sites were collated for 1405 species. Most species in the dataset are only recorded a few times (Figure 8).

FIGURE 8: Ordered frequency distribution of fish species observations in the dataset, where each column represents one of the 1405 species.

For invertebrates, the database contained 300 mobile species from 1702 sites, and 321 hard coral species and soft coral taxa (genus level) from 863 sites.

The database for fishes contained survey data from a mix of providers (Table 2), which targeted different suites of species in their work. We subset the species data into: a) species covered by all data providers with high confidence in identification (e.g. surgeon fishes); b) species covered by some data providers, but not surveyed by others; and c) species that were encountered only opportunistically by all because they are rare, cryptic, or difficult to identify. We discarded species in (c) because they are known to be difficult to identify with low numbers of sightings and/or there were inconsistencies in the sampling (either with regard to the use of less reliable-that is, not peer reviewed-or variable methods, or observers) which would lead to model uncertainty. The revised fish database contained only the species data for which we had high confidence in their correct identification and in the sampling method. This amounted to 1014 species.

Coral and invertebrate data were all collected using reliable methods and observers. All coral and invertebrate data were either collected as presence-absence data or converted to that from abundance records, using all available records.

3.3.2 Treatment of rare species

Within the list of consistently sampled fish species, after their treatment as described above, there were still many species that were only sighted a few times. This is likely to have two main reasons: 1) they are cryptic everywhere and thus rarely recorded; or 2) they are endemic species that only occur in a limited part of the project area (and few sites were sampled within their distribution). Fish species with low numbers of records (n< 30) that might fit into these categories were listed so that the endemics amongst them can receive special consideration during the spatial planning process. Therefore, species with fewer records than 30 were not modelled, following standard procedure (Elith 2000). For hard corals and invertebrates which were undersampled across the region, we excluded species with fewer than 30 occurrences from modelling, and kept the data for selected undersampled species, again for use in the planning process but not the classification process, as *per* the fish data.

After this treatment of the rare, endemic, cryptic or undersampled corals and invertebrates (as described in Sections 3.3.1 and 3.3.2 above), adequate presence/absence data for the modelling remained for 435 fishes, 258 species of hard and soft corals, and 114 invertebrate taxa.

TABLE 2: Datasets used to derive reef-associated bioregions

	PARAMETER	SOURCE	COUNTRIES
1	Reef fish	Khaled bin Sultan Living Oceans Foundation	Fiji, Tonga
2	Reef fish	Marine Ecology Consulting (Ms Helen Sykes)	Fiji
3	Reef fish	National Oceanic and Atmospheric Administration	Pacific Remote Island Areas (PRIAs), Samoa
4	Reef fish	Reef Life Survey	Tonga, Cook Islands, Niue, French Polynesia, American Samoa, Solomon Islands, Pitcairn, Vanuatu, Marshall Islands
5	Reef fish	Secretariat of the Pacific Community	Fiji, Kiribati, Nauru, New Caledonia, Niue, Solomon Islands, Tonga, Tuvalu, Vanuatu, Wallis and Futuna
6	Reef fish	South Pacific Regional Environment Programme	Tonga, Nauru
7	Reef fish	The Nature Conservancy	Solomon Islands
8	Reef fish	University of Queensland (Dr Maria Beger)	Marshall Islands, Papua New Guinea
9	Reef fish	Dr Daniela Ceccarelli	Tuvalu
10	Reef fish	Dr Daniela Ceccarelli, Ms Karen Stone	Tonga
11	Reef fish	PIPA (Dr Stuart Sandin, Dr Randi Rotjan)	Kiribati
12	Reef fish	WCS	Fiji
13	Coral	University of Queensland, Australia (Dr Doug Fenner)	Marshall Islands
14	Coral	Dr Doug Fenner	Tonga, Nauru
15	Coral	PIPA (Dr Randi Rotjan, Dr Sangeeta Mangubhai)	Kiribati
16	Coral	University of Queensland, Australia (Dr Emre Turak, Dr Andrew Philips, Dr Zoe Richards)	Papua New Guinea
17	Coral	Dr Doug Fenner	American Samoa
18	Coral	TNC Rapid Ecological Assessment (Dr Peter Houk)	Micronesia (Chuuk)
19	Coral	The Nature Conservancy	Solomon Islands
20	Coral	University of British Columbia (Dr Simon Donner)	Kiribati
21	Coral	WCS	Fiji
22	Coral	Museum of Tropical Queensland (Dr Paul Muir)	New Caledonia
23	Invertebrate	Secretariat of the Pacific Community	Fiji, Kiribati, Nauru, New Caledonia, Niue, Solomon Islands, Tonga, Tuvalu, Vanuatu, Wallis and Futuna
24	Invertebrates	Marine Ecology Consulting (Dr Helen Sykes)	Fiji
25	Coral reefs	UNEP-WCMC, (2010).	Global distribution
26	Mangroves	Giri C, et al. (2011).	Global distribution

3.3.3 Predicting probabilities of observation for each species

All the environmental variables across the AOI available from the Bio-Oracle database were initially considered[12] (Tyberghein et al. 2012) at a resolution of 9x9 km. Data were sourced from Bio-Oracle because they were reliable and consistent throughout our AOI (Tyberghein et al. 2012). The variables available represent the four broad dimensions thought to influence the distribution of shallow-water marine organisms: (1) nutrients and dissolved oxygen, (2) cloud cover and (3) temperature and light resources associated with latitudinal patterns (www.oracle.ugent.be, Tyberghein et al. 2012). Some of these parameters co-vary, so to avoid over-parameterization and multicollinearity, we tested all pairs of variables for correlation. For highly correlated predictors ($r > 0.6$), one of the paired variables was excluded based by judging their ecological relevance for coral reef-related organisms. The final predictor set consisted of: calcite, mean chlorophyll alpha concentrations, mean sea surface temperature (SST), pH, maximum photosynthetically available radiation (PAR), mean PAR, and nitrate.

We applied generalised additive modelling (GAM) to create models that use major environmental predictors of species observations to generate spatial predictions of the probabilities to observe species across the entire region. For sites with no species data, these models predict the probability of observing the species using environmental factors thought to influence the suitability of an area for a species (Elith et al. 2006). Using 9x9 km analytical spatial units, we modelled species with a binomial distribution and the best model identified, and predicted species probability for all coastal analytical units, including un-surveyed ones. This analysis used the *gam* function in the "mgcv" package in "MuMIn" in R v.3.2.5. These models were created for 807 species in total, with 435 fishes, 258 hard and soft corals, and 114 invertebrates.

3.3.4 Clustering to create reef-associated bioregions

For all the shallow water sites, we took the species observation probabilities from the models and used hierarchical clustering with Ward (Clarke 1993) to identify clusters of sites with similar assemblages as raw reef-associated bioregions (Figure 9). Cells consisted of a 9 km by 9 km vector grid within 20 km from shore or shallower than 200 m depth, whichever was furthest from land.

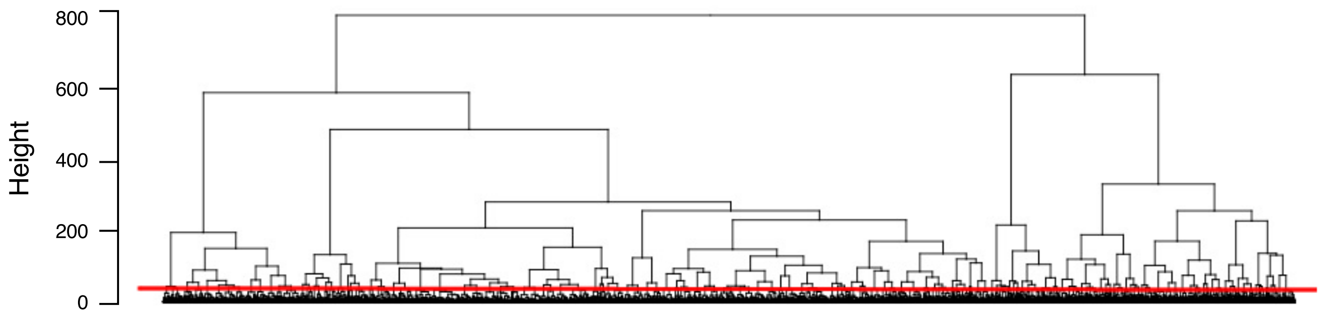

FIGURE 9: Dendrogram for reef-associated bioregional classification

3.3.5 Smoothing and categorising reef-associated bioregions

As in deepwater bioregions, the raw regions derived from clustering were smoothed using the GRASS generalized algorithm "snakes" method with default parameters[13]. Further manual editing was conducted to finalise the smoothing in areas where bioregion boundaries were not adequately smoothed through automated processing.

12 www.oracle.ugent.be

13 grass.osgeo.org/grass73/manuals/v.generalize.html

3.4 BIOREGION NAMES AND DESCRIPTIONS

Finally, the resulting draft bioregions were assigned unique code identifiers, draft names and initial descriptions. Whilst codes and names were assigned to bioregions across the AOI, descriptions were only provided for deepwater bioregions since knowledge of these offshore environments is less well known. Descriptions for the less-well-understood deepwater bioregions were provided to draw attention to habitats and environmental variables that influenced the delineation of each bioregion. These bioregions are now ready to be reviewed and, as necessary, revised based upon in-country marine expert input.

The draft naming system for the bioregions was created based on the following factors:

1. existing geographic place names;
2. geomorphic feature types within each cluster;
3. environmental variables that influence the delineation of each cluster; and
4. notable key underwater features.

Careful consideration was given when assigning names to the deepwater bioregions since most boundaries extend beyond the EEZs of countries.

4 TECHNICAL RESULTS

4.1 DRAFT MARINE BIOREGIONS ACROSS THE SOUTHWEST PACIFIC

The technical bioregionalisation analysis resulted in the division of the entire AOI into draft deepwater and reef-associated bioregions across the Southwest Pacific including Fiji. A total of 262 deepwater bioregions and 102 reef-associated bioregions were defined. Most were contiguous but some had multiple, non-contiguous parts. Many deepwater bioregion boundaries extended beyond countries' EEZs and also into areas beyond national jurisdiction. A majority of the deepwater bioregions share boundaries with neighbouring countries as did many reef-associated bioregions. Names and descriptions of bioregions are provided in Wendt et al. (2018). Note that whilst in-country knowledge of reef systems is relatively high, knowledge of the deep-sea environments is lower. For this reason, we have offered some information about each deepwater bioregion (Wendt et al. 2018) (find this report and spatial data on the bioregions at http://macbio-pacific.info/categories/planning/ and scroll down).

Final numbers of bioregions, per country, is provided in Table 3. Because many bioregions cut across national boundaries they are listed in more than one country. The numbers of bioregions in the table reflect the technical results before in-country expertise is used to refine and revise the bioregions.

TABLE 3: Number of draft deepwater and reef-associated bioregions described per country as an output of this analysis.

COUNTRY NAME	NUMBER OF DEEPWATER BIOREGIONS	NUMBER OF SHARED DEEPWATER BIOREGIONS	NUMBER OF REEF-ASSOCIATED BIOREGIONS	NUMBER OF SHARED REEF-ASSOCIATED BIOREGIONS
American Samoa	9	9	2	2
Cook Islands	30	27	6	4
Fiji	23	23	12	3
French Polynesia	52	23	16	5
Kiribati	54	47	11	2
Marshall Islands	34	19	9	2
Micronesia	41	32	19	4
Nauru	6	6	1	1
New Caledonia	31	24	8	1
Niue	6	6	2	2
Palau	19	18	4	0
Samoa	6	6	1	1
Solomon Islands	33	26	19	6
Tokelau	8	8	2	2
Tonga	35	27	4	3
Tuvalu	13	13	4	3
Vanuatu	20	18	7	3
Wallis and Futuna	9	9	3	3

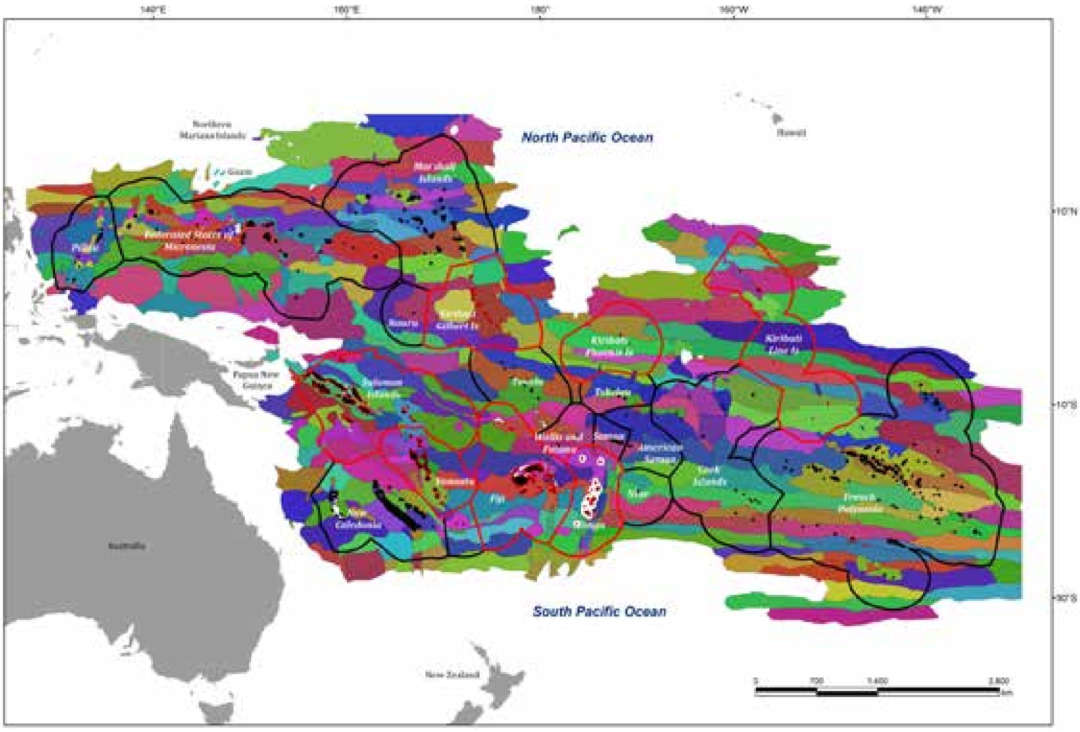

FIGURE 10: Draft deepwater bioregions for the Southwest Pacific including MACBIO countries (red solid line).

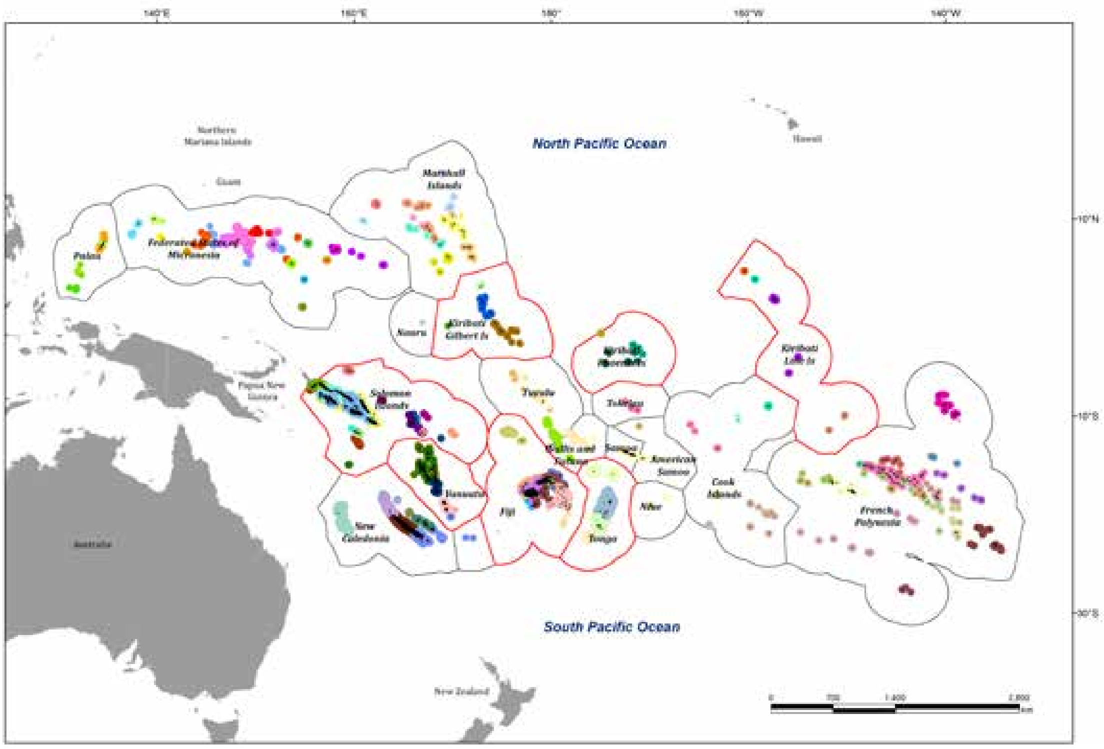

FIGURE 11: Draft reef-associated bioregions for the Southwest Pacific including MACBIO countries (red solid line). Reef areas are exaggerated in this figure for ease of viewing.

In both figures above, the different coloured areas represent different bioregions. Because the colour palette available to both was not sufficient, some different bioregions may appear to be the same colour. Bioregions specific to Fiji are presented in Section 6 and Appendix 6.

5 DISCUSSION

This work was done to support national marine planning efforts in Pacific Island countries and territories. It provides value-neutral, sub-national descriptions of the marine diversity within Pacific Island countries and territories. Whilst spatial planning for ecologically representative marine protected areas in Fiji requires much more than this, our marine bioregions form an important biophysical data layer in the process (Lewis et al. 2017). However, true ecological representativeness also requires using the information you have about habitats, species and ecological processes (Lewis et al. 2017). Additionally, most natural resource managers have social, economic and cultural objectives they wish to achieve so consideration of human uses and values is pivotal to achieving these multiple objectives (Lewis et al. 2017).

Big ocean states in the Pacific, including Fiji, Kiribati, the Solomon Islands, Tonga and Vanuatu, are aiming to do better, in terms of protecting their ocean (e.g. United Nations Ocean Conference Voluntary Commitments[14]). Many Pacific Island Countries, including Fiji, are party to the Convention on Biological Diversity and committed to meeting the CBD goals in implementing an ecologically representative network of marine protected areas[15]. Until now, a mechanism to systematically implement ecologically representative networks of Marine Protected Areas at national scales, within Pacific Island countries, had not been available.

The bioregions resulting from this technical analysis provides, for the first time, marine bioregions across the Southwest Pacific at a scale, which can be used as a basis for comprehensive, in-country consideration of what a representative network of Marine Protected Areas could look like. The methodology is repeatable, statistically robust and based on many sets of comprehensive and reliable data available across the Southwest Pacific.

Even so, the marine bioregions presented here are termed “draft” bioregions because they still require in-country input from Fijian experts (see Section 6). Local marine experts, can, review and revise (as appropriate) the bioregion names, boundaries and descriptions to better reflect their local knowledge of their marine ecosystems. This coupling of technical analysis and expert input ensures a solid basis for future marine planning at a national scale and is a relatively unique approach to the creation of bioregions which normally rely on either one approach or the other – albeit always informed by spatial data (Longhurst 2006, Spalding et al. 2007, UNESCO 2009, O’Hara et al. 2011, Reygondeau et al. 2012, Keith et al. 2013, Kulbicki et al. 2013, Green et al. 2014, Proud et al. 2017).

Even after expert review, the authors acknowledge that the analysis and methods upon which the bioregions are based will still not be perfect, because they are based upon available information, which is incomplete. As more information comes to light the bioregions presented here can be improved and refined.

In particular, it is acknowledged that the epiphotic (or photic), mesophotic, bathyl, abyssal, hadal and benthic ocean zones host asssemblages of organisms that may not vertically align. Sayre et al. (2017), for example, used environmental data to create three-dimensional maps of the ocean, resulting in a comprehensive set of 37 distinct volumetric region units, called ecological marine units (EMUs) at various depths in the oceans, globally. Eleven of these are in the tropical SW Pacific (Sayre et al. 2017); this differentiation in the Pacific is not sufficient to support national planning processes. Thus, in an ideal world, one would describe marine bioregions within each vertical ocean “zone” at a scale useful for national management; however, this was not possible given the data constraints at the time of this work. It is also conceptionally difficult to establish protected zones for different depth zones (Venegas-Li et al. 2017), and the scope of current marine spatial planning work in the region does not include such an approach.

Alternatively, different methods can be used to describe bioregions (see Section 2.1 above). For example, Last et al. (2010) present a framework of ten hierarchical layers of “regions” that describe the seabed only, but at different scales from the ocean basin-scale (biogeographic) to the genetic level. Its in-country utility for national-planning purposes in the Pacific has yet to be explored. The clustering of the reef-associated species data could also have been conducted with other methods, for example where species assemblages are tracked together probabilistically (e.g. Foster et al. 2013), or with a network approach (Vilhena and Antonelli 2015). Each of the many types of methods available has pros and cons; we chose approaches that we considered would best match Pacific Island ocean planning requirements and data constraints.

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14 oceanconference.un.org/commitments, accessed 28/9/17

15 www.cbd.int/information/parties.shtml, accessed 28/9/17

In national planning, of course, many other considerations and data should inform decisions about where to locate marine protected areas – both biophysical and socio-economic. For example, at the finer scale, habitat and species distribution information within bioregions, where available, should be used to complement bioregions to ensure networks of MPAs that represent the entire range of biodiversity within countries (see Ceccarelli et al. 2018). Further, social, economic and cultural management objectives will obviously require consideration of human uses and values as well as biophysical data in decision-making (Lewis et al. 2017).

The marine environment and the organisms that live in the ocean do not respect national boundaries. As such, the data used in these analyses and the resulting draft marine bioregions extend beyond national boundaries (ABNJ) and can contribute, also, to management of the high seas should an ecologically representative approach to planning be desired.

Overall, our results provide a first, unique and essential step to supporting Pacific Island countries and territories, and beyond, to deliver national, ecologically representative networks of marine protected areas.

6 FINALISING MARINE BIOREGIONS OF FIJI

6.1 INTRODUCTION

As discussed (Section 1.1), marine conservation work in a number of Pacific Island nations will benefit from outlining bioregions at a scale appropriate for national marine spatial planning. The previous sections of this report present draft marine bioregions across the Southwest Pacific and the technical methods used to derive them. The original preliminary technical analysis (in 2016) resulted in seven preliminary, draft reef-associated marine bioregions and 18 preliminary, draft deepwater bioregions in Fiji's EEZ (see Figure 12 and Figure 13).

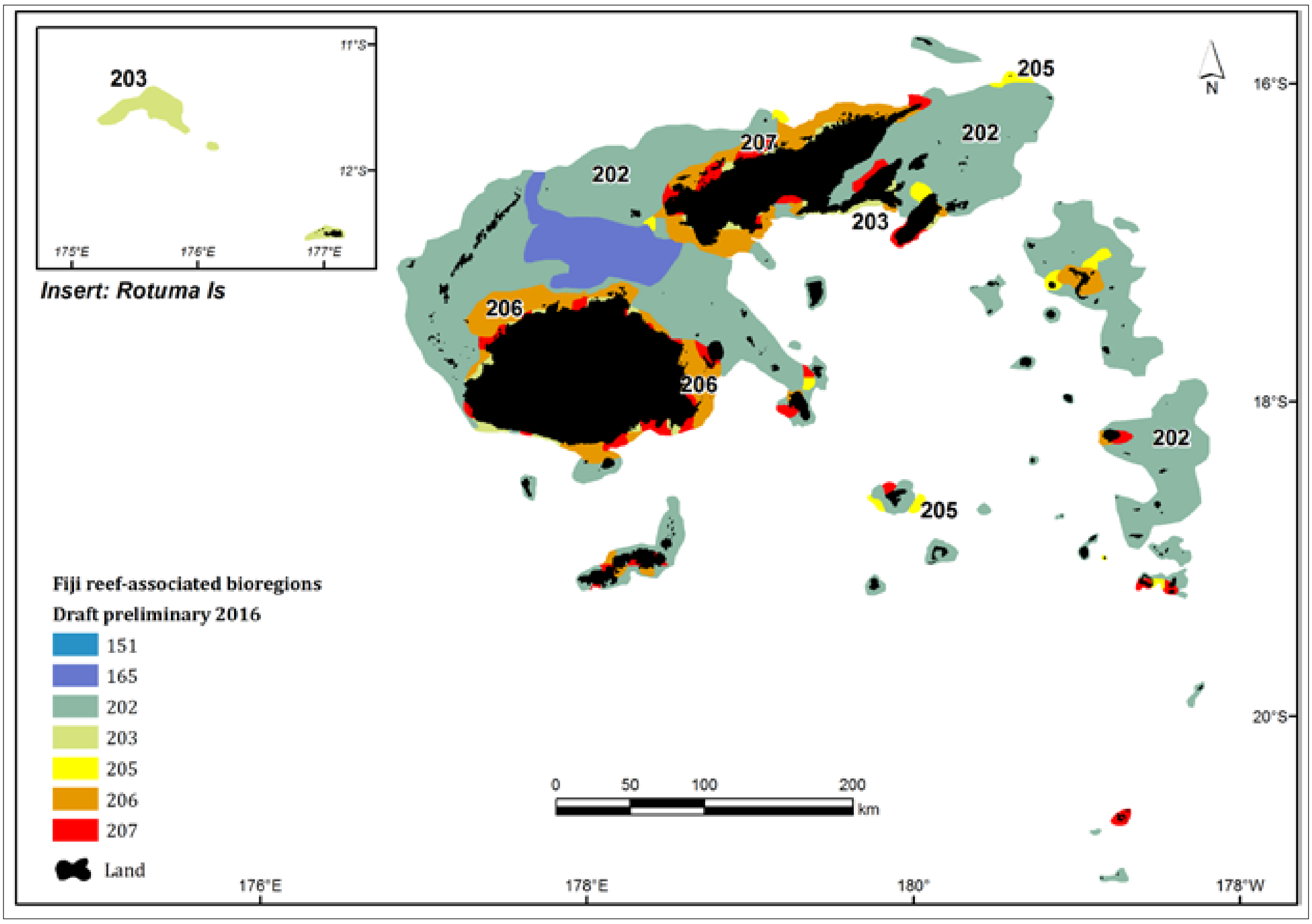

FIGURE 12. Draft, preliminary reef-associated bioregions of Fiji.
These were the outcome of the original preliminary technical analysis in 2016.
Each colour and code represents a different marine bioregion.
This map includes one deepwater bioregion (165), which falls within the reef areas of interest.

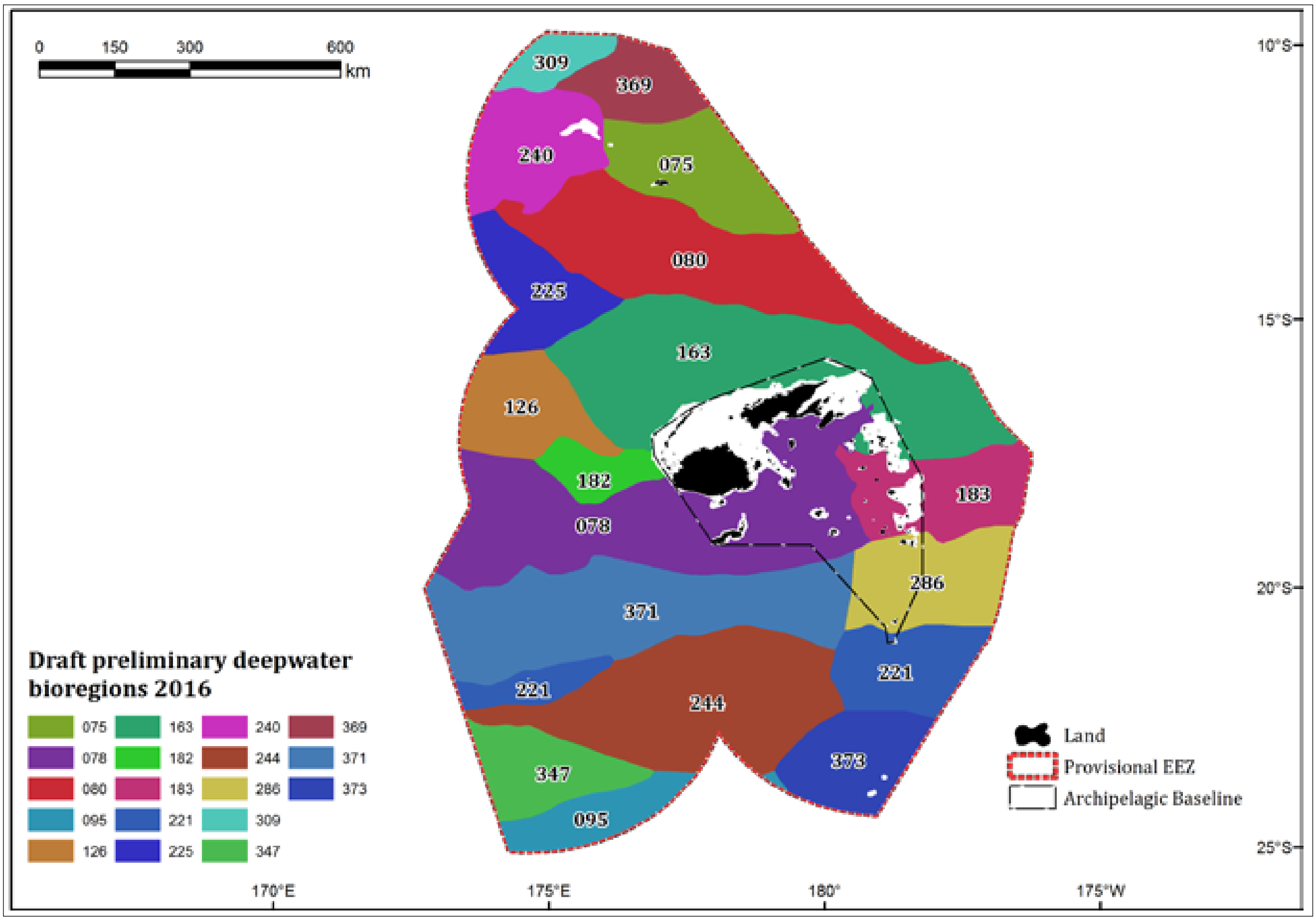

FIGURE 13. Draft, preliminary deepwater bioregions of Fiji.
These were the outcome of the original preliminary technical analysis in 2016.
Each colour and code represents a different marine bioregion.

However, this process would be incomplete without input from experts within Fiji. An important, subsequent, non-analytical step, presented here, was to refine the resultant draft preliminary bioregions with marine experts in Fiji prior to their use in national planning.

This chapter describes the process and outcomes of the workshop, and follow-up work, during which this review was conducted.

6.2 METHODS

The workshop to refine the draft preliminary bioregions in Fiji occurred on 6 December 2016, in the Studio 6 Apartments Conference Room, 1-3 Walu Street, Suva. The workshop was co-hosted by the Department of Environment and the Ministry of Fisheries and Forests. The aim of the workshop was specifically to gather marine expertise in Fiji to review the preliminary, draft marine bioregions identified by the process described above. The workshop agenda (Appendix 1) was circulated to all participants (Appendix 2) and clarified with a Powerpoint presentation at the start of the workshop (Appendix 3).

The workshop initially reviewed the reef-associated bioregions, since it was understood that these areas were more familiar to, and better understood by, the participants. Then the participants reviewed the deepwater bioregions. They were asked to consider each bioregion's draft:

- Location;
- Boundaries;
- Name; and
- Description.

The format in which the information was gathered from participants can be seen in Appendix 4. The 22 participants (Figure 14) were divided into four working groups for the reef-associated bioregions and one for the deepwater bioregions. Each working group had a rapporteur, facilitator and GIS technician.

FIGURE 14. Workshop participants during the 2016 review of Fiji's bioregions.

Supporting material available to the workshop participants included maps of the draft preliminary bioregions (at various scales) for each working group to draw upon, hardcopy maps of biophysical data posted on a "resource wall" and biophysical data available in a GIS (see Appendix 5). The data available were in two groups: data used in developing the bioregions and other biophysical data not used to develop the bioregions.

The participants and working groups were divided/merged in two ways: people with more knowledge about a particular area were allocated to the group dealing with that area; people with more general knowledge chose which group they could work with. Some participants were extremely knowledgeable about more than one area – these individuals were asked to move around the groups which were working on specific geographies.

Based on this work a draft report was prepared and sent to the workshop participants and the Marine Working Group of Fiji's Protected Area Committee for review. The report was then revised on the basis of their input prior to finalisation.

6.3 RESULTS

6.3.1 Bioregions with changes

6.3.1.1 REEF-ASSOCIATED

In Fiji, the workshop participants provided, or facilitated the authors to gain access, to a large amount of additional descriptive information and data (especially for corals and invertebrates) for the reef-associated bioregions. The additional data allowed the authors to repeat the technical analysis in 2017 (as described in Section 3.3). The number of reef-associated bioregions resulting from the final technical analysis therefore changed from the original seven presented at the 2016 workshop, to twelve (Figure 15).

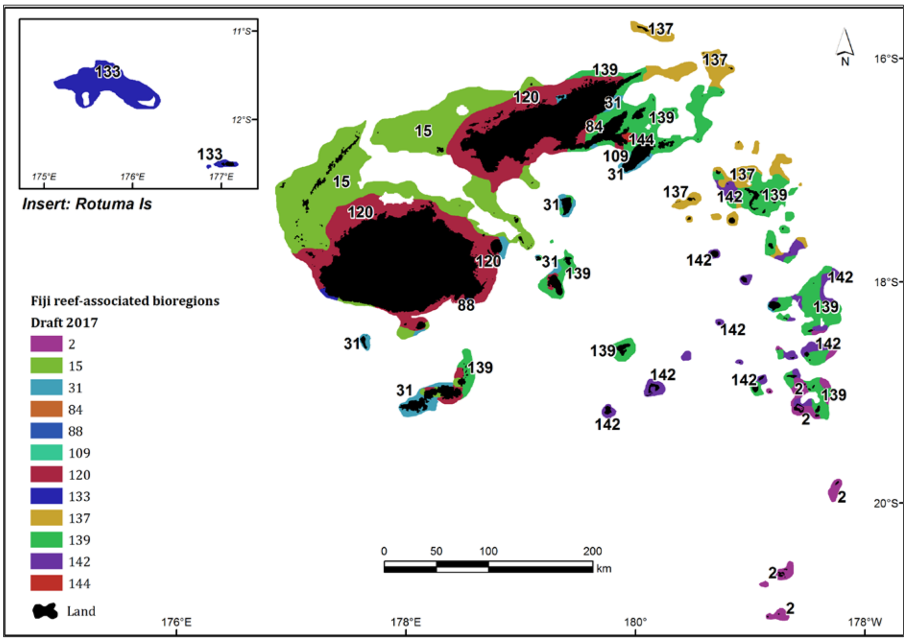

FIGURE 15. Draft reef-associated bioregions of Fiji (outcome of final technical analysis in 2017)

The results were then presented to experts for review in smaller follow-up meetings. These meetings resulted in the twelve reef-associated bioregions to be merged into seven, and finally four accepted reef-associated bioregions (Table 4 and Figure 16).

Advice from in-country experts was to group the bioregions according to the major influences of the surrounding environment, and this advice was followed. They listed three major types of coral reefs in Fiji:

- Sediment-influenced reefs (inclusive of mangroves, estuaries, deltas, mudflats);
- Oceanic-influenced reefs; and
- Shelf habitats.

One bioregion that had been included among the reef-associated bioregions (Deep 165, Bligh Water bioregion), was identified as being generally associated with strong currents, typical deepwater habitats and large coral pinnacles. It was suggested that Bioregion165 would be more appropriately placed in the deepwater category, as there are very few reefs at depths greater than 60 meters (see below). It was therefore absorbed into the deepwater bioregion 204 (North Viti and Vanua Levu basin, Table 5, Appendix 6).

Also, across the expert groups, it was decided to move the outer boundary of the reef-associated bioregions inwards to, approximately, the outer reef-edge boundary (Millenium Reefs, Andréfouët et al. 2006) or the 60m contour if there wasn't a clear reef-edge. The 60-80m depth contour was chosen to refine reef-associated bioregions, because sunlight dependent coral reef ecosystems and reef-associated ecosystems in the Pacific are unlikely to form at depths greater than 60m; of course, individual species that are found in these habitats may be found at greater depths (Brokovich et al. 2010, Slattery et al. 2011, Bridge et al. 2012).

TABLE 4. Summary of workshop process to arrive at final reef-associated bioregions.

N	FINAL REEF-ASSOCIATED BIOREGION	SUMMARY OF WORKSHOP PROCESS
15	Reef influenced, deeper water, more offshore, less land influenced.	Combination of Reef 202 and 205. There was disagreement and confusion about the initial placement of Reef 205, as its description suggested a more offshore position with oceanic influence. There were also suggestions of combining it with Reef 202. Eventually it was changed to Reef 15, allowing for its similarities with Reef 202.
120	Delta, estuarine and land influenced.	Combination of Reef 203, 206 and 207. It was observed that these bioregions were located adjacent to land, and therefore subject to a variety of land-based influenced, which had led to similar reef assemblages. It was suggested by Groups 1, 2 and 4 that they be merged.
133	Rotuma	Changed from Reef 151, with similar boundaries.
139	Oceanic influenced	Creation of a new bioregion representing smaller outer island with a more oceanic influence.

6.3.1.2 DEEPWATER

In Fiji, at the 2016 workshop, participants recommended including, in the technical analysis, five additional environmental variables for habitats at a depth of ~1,000m, and suggested that the weighting given to bathymetry be doubled for the deepwater bioregions due to the disproportionate influence of bathymetry upon oceans habitats and species (NOAA 2017). As with the reef-association bioregions, the technical analysis for the deepwater bioregions was repeated in 2017, and presented to experts for review in smaller follow-up meetings.

At the 2016 workshop, 18 deepwater bioregions were presented to Fijian experts; after the re-analysis using additional information gathered, 23 deepwater bioregions were presented at follow-up meetings (Figure 17).

The re-analysis resulted in a rearrangement of all the bioregions that fell, either entirely or partially, within Fiji's EEZ. One number was retained (240), but the boundary and name changed, from "East Temotu, Banks and west of Rotuma seamounts and the Vityaz Trench" to "Abyssal plain, seamounts and Vityaz trench north Fiji". In ten cases, the descriptions were largely retained, but assigned to new numbers and altered boundaries (Table 5). In all, 23 new bioregions were accepted during the 2017 follow-up meetings.

TABLE 5. Summary of deepwater bioregions in the northern, central and southern parts of Fiji's EEZ presented at the 2016 workshop, and revised bioregions presented and accepted in 2017. Bioregions are arranged roughly in a north-to-south order.

SECTOR	2016	REVISED BIOREGIONS	2017	NAME
North	Deep 309	Abyssal plain and seamount chains bordering Fiji (NW), Tuvalu (SW) and Solomon Islands (SE)	240	Abyssal plain, seamounts and Vityaz trench north Fiji
	Deep 369	Northeast Fiji, southwest Wallis and Futuna, north of Tonga seamounts and abyssal mountains	184	Northwest Rotuma Seamounts and the Vityaz trench
	Deep 240	East Temotu, Banks and west of Rotuma seamounts and the Vityaz Trench	269	North-East Rotuma abyssal mountains and seamounts
	Deep 075	East Rotuma-Futuna-Tuvalu abyssal mountains and seamounts	412	North Fiji ridge chain
	Deep 080	South Rotuma, Isle de Horne, south Futuna and Niuatoputapu underwater hills and seamounts	455	North Fiji Ridge
	Deep 225	Vanuatu, Solomons, Fiji high seas abyssal mountains	270	Rotuma abyssal mountains and seamounts
			243	West Rotuma
			454	Southeast Rotuma plateau
Central	Deep 126	East Vanuatu high seas, West Fiji abyssal hills including hydrothermal vent fields	82	North Fiji Basin
	Deep 163	North Fiji Basin to the south Niuatoputapu hydrothermal vents, canyons and seamounts	204	North Viti and Vanua Levu basin
	Deep 078	East Tafea to Lau Ridge, including abyssal hills, canyons, seamounts and hydrothermal vents	460	Fiji Plateau Deep
	Deep 182	West Viti Levu abyssal mountains	165	Fiji Central
	Deep 183	Eastern Lau to northwest Vava'u plateaus and hydrothermal vents	461	Central Lau plateau and hydrothermal vents
South	Deep 371	East Tafea Province to southern Lau abyssal hills	13	Southern Lau abyssal hills
	Deep 286	Southern Lau to Ha'apai plateaus including canyons and hydrothermal vents	24	Ceva-i-Ra ridge and South Ono-i-Lau
	Deep 221	Ceva'i-Ra Ridge and south Ono'i-Lau to Tongatapu plateaus	206	South Ceva-I-Ra Deep
	Deep 244	Southeastern Ceva'i-Ra seamounts, abyssal hills	325	South Eastern Ceva-i-Ra seamounts abyssal hills
	Deep 347	South New Hebrides Trench and seamounts, abyssal hills	19	Far-Southern Viti
	Deep 095	Far southern Viti and Vanuatu Basin including high seas	228	High Seas Deep
	Deep 373	Minerva to south 'Ata plateaus	382	Southern Lau
			335	Ono-i-Lau, South Lau Ridge
			298	South Fiji Deep
			378	Minerva plateau

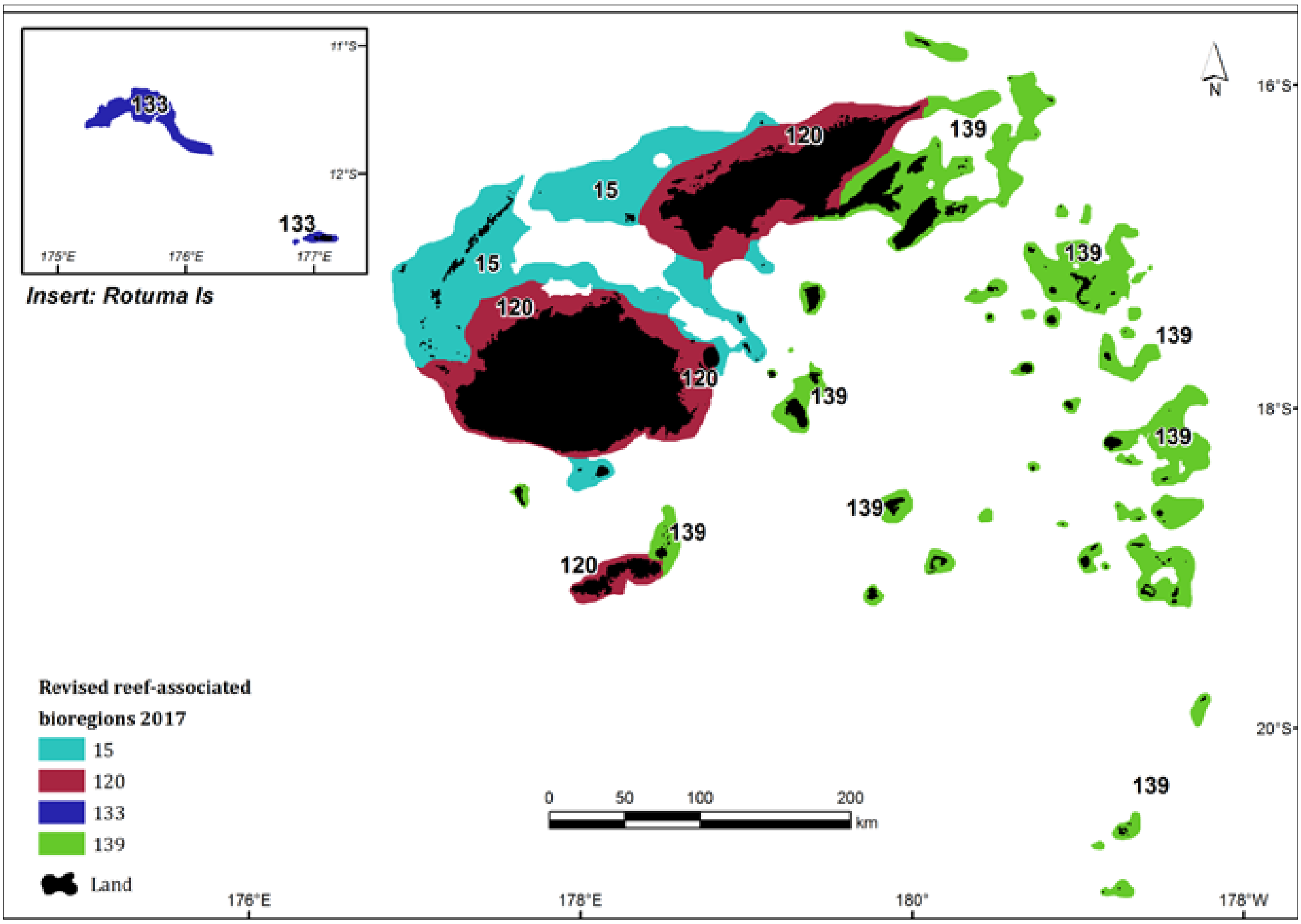

FIGURE 16. Revised reef-associated bioregions of Fiji

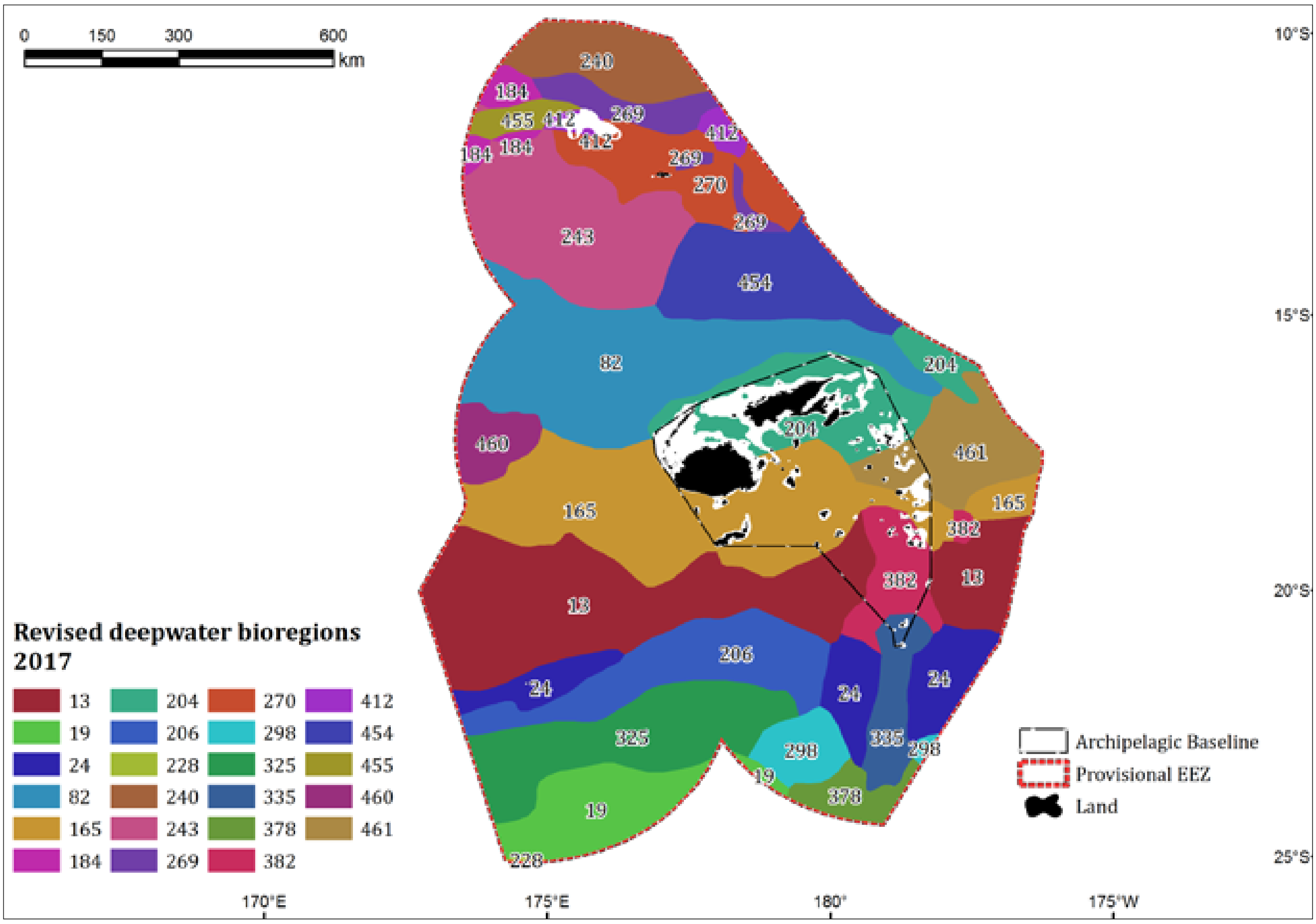

FIGURE 17. Revised deepwater bioregions of Fiji

6.4 CONCLUSIONS

All bioregions were subject to comments and suggested changes during the initial 2016 workshop, based on the workshop participants' knowledge and additional data and information that could be used to repeat the analysis.

As a result, the reef-associated bioregions underwent a series of analytical and expertise-based changes resulting in four reef-associated bioregions. The final merging of some bioregions was based on major influences from their surrounding environment, such as sediment influenced reefs (e.g. those close to mangroves, estuaries, deltas, mudflats); oceanic influenced reefs, and shelf habitats of varying depth. A major change to the reef-associated bioregions was the shifting of the limiting depth contour to 60m, because reef formation tends to cease at this depth (Brokovich et al. 2010, Slattery et al. 2011, Bridge et al. 2012).

The deepwater bioregions were also re-analysed based on additional data, and with more importance placed on bathymetry. The boundaries were re-drawn and many of the bioregions were re-named, and almost all were assigned new numbers. The re-analysis resulted in 23 new deepwater bioregions, which were accepted in 2017.

These marine bioregions now form a robust and technically sound framework upon which, together with other data, to base marine spatial planning decisions in Fiji (see Section 5 for a discussion about this). The final bioregion names and descriptions for Fiji are in Appendix 6, and spatial data for these can be downloaded at: http://macbio-pacific.info/macbio-resources/ click on Marine Spatial Planning and scroll down, or under http://macbio-pacific.info/categories/fiji/.

None-the-less, we acknowledge that marine data for Fiji remain imperfect, and the bioregions should be subject to further review as more data are made available.

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9 APPENDICES

9.1 APPENDIX 1 WORKSHOP AGENDA

Describing the Marine Environment of Fiji

6 December 2016 • Studio 6 Apartments Conference Room, 1–3 Walu St, Suva

TIME	AGENDA ITEM	LEAD
8:30 – 9:00 9:00 – 9:10 9:10 – 9:20 9:20 – 9:40 9:40 – 10:00 10:00 -10:30	Registration Prayer Welcome Remarks **Agenda item 1: Keynote address** Keynote Address: Government Representative **Agenda item 2: Introductions** ▪ Overview of meeting & expectations ▪ Introductions of participants **Agenda Item 3:** *Objective: Understanding of role of bioregions in achieving Fiji's 30% marine protected area commitment* **Presentation:** ▪ Review of process of achieving 30% of ocean as MPA network commitments and where a description of the entire marine environment of Fiji fits in	MACBIO/ WCS TBC Facilitator Seema Deo TBC
10:30-11:00	TEA BREAK	
  11:00 – 11:15 11:15 – 12:40 12:40 – 13:00	**Agenda item 4:** *Objective: Review status of report on Fiji's special and unique marine areas (SUMA)* **Presentation:** ▪ Update from Marine Prioritisation workshop **Agenda item 5a&b:** *Objective: Introduction of a way to describe all of Fiji's marine environment* **Agenda Item 5a:** **Presentation:** ▪ Introduction to the concept of different marine areas (biological regions) for Fiji, how a description of the entire marine environment of Fiji differs from priority areas and examples of how to describe marine environments **Agenda Item 5b:** **Presentations:** ▪ Methods and data used to create draft preliminary inshore and offshore marine areas (biological regions) for Fiji ▪ Introduction to Fiji's draft preliminary marine areas (biological regions)	Helen Sykes Leanne Fernandes Maria Beger/ Hans Wendt Jimaima LeGrand /Hans Wendt/ Jonah Sullivan
13:00-14:00	LUNCH	
14:00 – 15.30	**Agenda Item 6:** *Objective: Review the inshore and offshore marine area boundaries and descriptions* ▪ Description of group work ▪ Breakout into groups ▪ Expert review and revision of Fiji's marine area (biological regions) boundaries and descriptions	MACBIO All
15:30-15:45	AFTERNOON TEA	
15:45 – 16.30	**Agenda Item 6 cont..:** *Objective: Review the inshore and offshore marine area boundaries and descriptions (continued)*	All
16.30- 17.00	**Agenda Item 7:** ▪ Feedback from breakout groups ▪ Next steps	Group rapporteurs MACBIO

9.2 APPENDIX 2 WORKSHOP PARTICIPANTS

PARTICIPANT NAME	AGENCY
Andra Whiteside	MACBIO
Kate Davey	MACBIO
Sione Kaitu	MACBIO
Ropate Natadra	MoF/Offshore
Litia Takalaiyale	MRD
Sangeeta Mangubhai	WCS
Jasha Dehm	MACBIO
Jonah Sullivan	MACBIO
Leanne Fernandes	MACBIO
Visal Nadan	MoF
Stacy Jupiter	WCS
Sikeli Naucunivanua	MoF
Luse Targuci	iTAB/CO
Jimaima LeGrand	MACBIO
Nakita Bingham	MACBIO
Naushad Yakub	MACBIO
Sahar Kirmani	MACBIO
Pretika Kumar	MoF
Katy Miller	Vatuvara
Gandercillar Vosaki	Wildlife Conservation Society (WCS)
Chinnamma Reddy	WWF-Pacific
Hans Karl Wendt	MACBIO
Phillip Gassner	MACBIO
Leba Milller	MACBIO
Helen Sykes	Marine Ecology Consulting
Alitia Bainivalu	MoF/Offshore
Etika Rupeni	IUCN
Mavileko Ramoica	MACBIO
Tavenisa Luisa	RMU
Riibeta Abeta	MACBIO
Seema Deo	Consultant
Maria Berger	Consultant
Aminiasi Qareqare	Dept of Environment

9.3 APPENDIX 3 WORKSHOP PRESENTATION

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Marine and Coastal Biodiversity Management in Pacific Island Countries

Update on bioregions for Fiji

SPREP IUCN giz

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Agenda Item 3. How do biological regions (bioregions) fit into the MPA process?

Background: Regional

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- **2005: Commitment to 30% MPAs at Mauritius SIDS** "…by 2020 at least 30% of Fiji's inshore and offshore marine areas will have come under a comprehensive, ecologically representative network of MPAs…"**(Ministry of Foreign Affairs)**
- **2014 Re-commitment 30% MPAs, Samoa SIDS** "…to effectively protect 30% of its seas by 2020…" **(Ministry of Strategic Planning, National Development and Statistics)**
- **30% MPA commitment in Fiji Green Growth Framework**
- **CBD (Aichi Target): at least 11% ecologically representative MPAs**

NOTE: This commitment is in addition to a goal of sustainable use of 100% of Fiji's marine resources and environment and 100% of coastal waters in locally managed marine areas.

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But how will Fiji achieve this commitment?

MPA process decided by Protected Area Committee and Fisheries MPA Technical Committee: 2015-2020

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1. MPA network vision and objectives
2. Analysis of legal basis for MPAs
3. MPA zone typology
4. Special, unique marine areas
5. Ocean-wide description: marine environment (THIS WORKSHOP)
6. Placement guidelines for zones
7. National consultation on all of the above
8. Draft map of MPAs
9. Consultations on draft map
10. Revisions of draft map
11. Final map for gazettal

MPA process

MACBIO

1. MPA network vision and objectives

Vision:

Comprehensive and ecologically representative networks of MPAs that restore and sustain the health, productivity, resilience, biological diversity and ecosystem services of coastal and marine systems, and promote the quality of life for our communities who depend on them.

MPA process

MACBIO

1. MPA network vision and objectives

The objectives are to help:

- **Ensure food security**
- **Sustain livelihoods**
- **Restore and sustain the health and productivity of marine resources**
- **Minimise conflicts between uses**
- **Build resilience to climate change and disasters**
- **Restore and conserve biological diversity and ecosystem services**

MPA process

MACBIO

2. Legal analysis - recommendations

- An overarching policy be developed to guide and coordinate planning for and implementation of the MPAs
- Consider new, overarching legislation
- Develop regulations to give effect to the MPA Sections of the Offshore Fisheries Decree
- Review and update the National Environment Strategy

MPA process

MACBIO

3. MPA Zone typology (draft)

Zone Name	Objective (abbreviated)
Locally Managed Marine Zone	To benefit qoliqoli owners.
Local Use Zone	To protect local food security livelihoods and biodiversity.
Habitat Protection Zone	To protect the integrity of habitat structure.
No-take Zone	To protect natural biodiversity.
Special, Unique Zone	To protect, conserve and restore specific species.

MPA process : 2015-2020

MACBIO

1. MPA network vision and objectives √
2. Analysis of legal basis for MPAs √
3. MPA zone typology √
4. Special, unique marine areas √ (update next)
5. Description: Fiji's marine environment (THIS WORKSHOP)
6. Placement guidelines for zones
7. National consultation on all of the above
8. Draft map of MPAs
9. Consultations on draft map
10. Revisions of draft map
11. Final map for gazettal

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Agenda Item 4. Status outputs workshop on special, unique marine areas of Fiji

Sangeeta Mangubhai, Helen Sykes

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Identified Priority Areas – previous work

1. FIME report (2003)
   "Setting Priorities for Marine Conservation in the Fiji Islands Marine Ecoregion "
2. PAC gap analysis report
   "Filling the gaps: identifying candidate sites to expand Fiji's national protected area network Outcomes report from provincial planning meeting, 20-21 September 2010"
3. EBSA – areas
   "Secretariat of the Convention on Biological Diversity (2014). Ecologically or Biologically Significant Marine Areas (EBSAs). Special places in the world's oceans."
   https://chm.cbd.int/database/record?documentID=200047
4. National Environment Strategy 1993 – Register of (marine) sites of national significance

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Review of special, unique marine areas of Fiji

- Expert Workshop – 19-20 July 2016
- Report outline approved by Marine Working Group (MWG) of the Protected Area Committee (PAC)
- Report being prepared
- Draft will go to Workshop participants, then the MWG of the PAC, then PAC

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Agenda item 5.a. What are marine biological regions (or bioregions) and why do we care?

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Marine Protected Areas

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Old Paradigm:
- Protected areas: high biodiversity or endemic species

NOW we know
a) Protecting these areas is important
BUT not enough to protect ecosystems AND
a) Imperfect information

Marine Protected Areas

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New Paradigm:
- Ecologically representative network of marine managed areas
  - Convention on Biological Diversity (CBD) Aichi Target 11 is 10% of marine areas effectively managed
  - Includes examples of all habitat types

Incomplete information: so how do we choose "ecologically representative" areas?

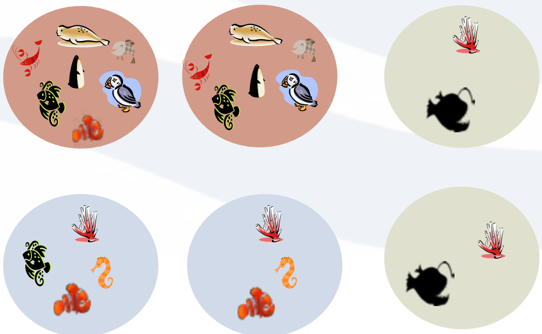
Use biological regions (bioregions)

But what are bioregions?

- Areas of relative similarity
  - Habitats, communities, and physical features within a bioregion are more similar to each other than those in a different bioregion.
- Represent full range of biodiversity
- Classifies habitat, environmental types

Example of Species Assemblages

Sites with Similar Species



Why bioregions?

- Can use environmental data: surrogates for imperfect biological information
- Value-neutral
- Every part of Fiji's marine environment belongs to one bioregion or another.
- All bioregions equally important

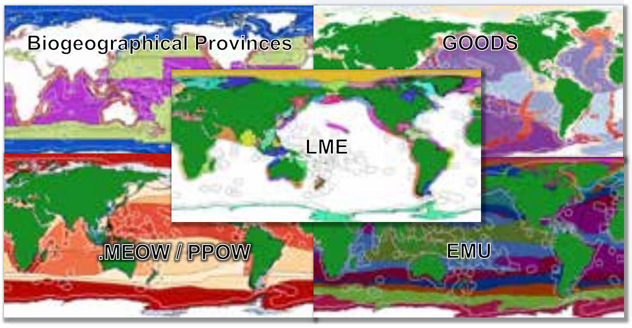
Bioregions as a planning tool

If one objective is:

an <u>ecologically representative</u> network of marine protected areas (e.g. CBD Aichi Target 11)

Then protecting examples of each bioregion will help meet that objective

Existing global bioregions

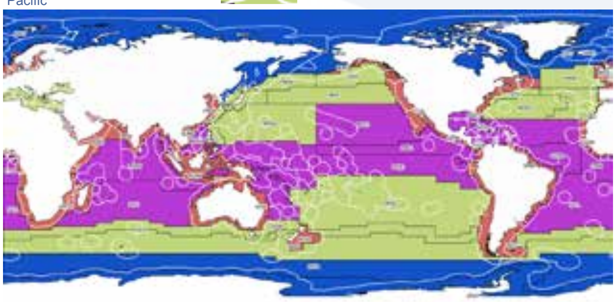


Longhurst, 2010. Biogeographical Bioregions (Provinces)

4 global bioregions (province): 3 in Pacific

52 sub-bioregions (provinces): 9 in Pacific

Factors: Based on biophysical proxies: phytoplankton abundance, mixed layer depth, currents, clarity.
Method: Expert-driven approach



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Bioregions as a planning tool

- MACBIO: 5 countries
- Global-scale bioregions not useful for national-scale marine planning
- Fiji needs finer scale descriptions of its entire marine environment

MPA process : 2015-2020

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1. Vision, objectives √
2. Legal analysis √
3. MPA typology √
4. Special, unique areas √ (update next)
5. Description Fiji's marine environment (THIS WORKSHOP)
6. Placement guidelines for zones
7. National consultation
8. Draft map of MPAs (using ALL information)
9. Consultations on draft map
10. Revision of draft map
11. Final map

Questions?

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Marine and Coastal Biodiversity Management in Pacific Island Countries

Agenda Item 5.b. Methods used to create bioregions for Fiji

Hans Wendt

SPREP IUCN giz

2 Types of Bioregions

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- Deep water bioregions
- Reef-associated bioregions (shallow)

Building Deep Water Bioregions

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Environmental data (27 datasets) + Biological data (1 dataset) → Identify similar areas → Draft preliminary Bioregions

Calcite, oxygen, nitrate, solar irradiance, pH, phosphate, silicate, salinity, depth, 20°C isotherm, mixed layer depth, temperature at surface, 30m, 200m, 1000m, dynamic height of sea surface, distance from land

Chlorophyll

Methods: Analysis unit size 20 x 20 km

Clustering hierarchical clustering

Methods: GIS analysis

Clustering Algorithm

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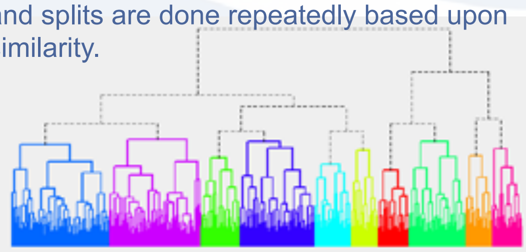
Hierarchical Clustering: a hierarchy of clusters; all observations start in one cluster and splits are done repeatedly based upon similarity.



Result: Deep Water Bioregions

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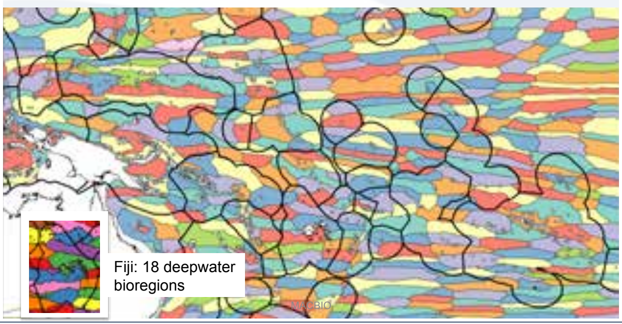
400 Deepwater Bioregions in SW Pacific; 18 Deepwater Bioregions in Fiji



Building Reef-Associated Bioregions

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Remotely sensed data | Site-specific survey data

Environment + Biological data (7 datasets) + Fish data → Combine fish data with remotely sensed data → Identify similar areas → Draft preliminary Bioregions

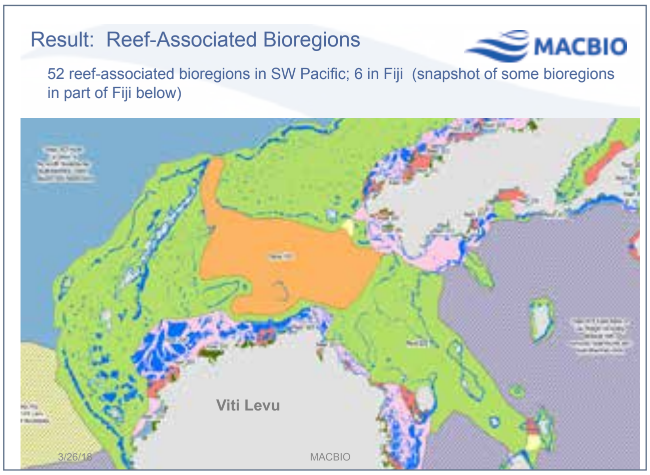
Calcite, nitrate concentrat'n solar irradiance pH, sea temperature + chlorophyll

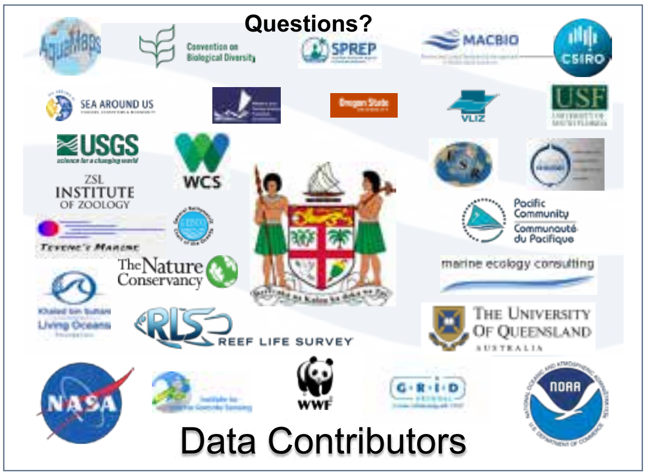
3,846 sites 435 fish species

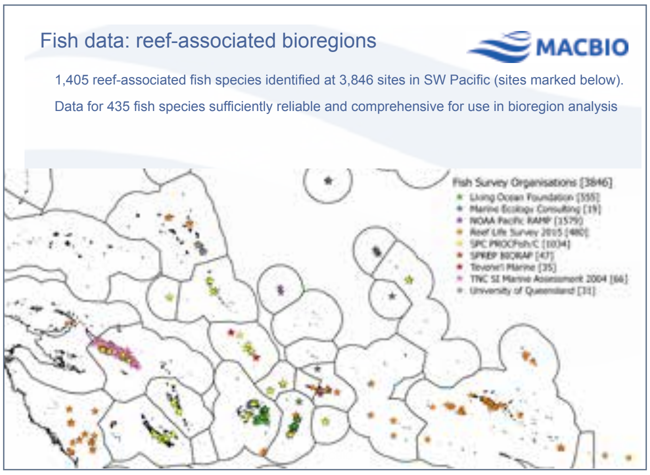
General Additive Models of the probability of observing each fish species

Methods: Analysis unit size 9 x 9 km **Clustering** hierarchical clustering

Methods: GIS analysis


Result: Reef-Associated Bioregions
MACBIO
52 reef-associated bioregions in SW Pacific; 6 in Fiji (snapshot of some bioregions in part of Fiji below)
Viti Levu
3/26/18
MACBIO


Questions?
SPREP
MACBIO
CSIRO
SEA AROUND US
USF
USGS
WCS
ZSL INSTITUTE OF ZOOLOGY
Pacific Community
Communauté du Pacifique
marine ecology consulting
The Nature Conservancy
REEF LIFE SURVEY
THE UNIVERSITY OF QUEENSLAND
AUSTRALIA
NASA
WWF
NOAA
Data Contributors


Fish data: reef-associated bioregions
MACBIO
1,405 reef-associated fish species identified at 3,846 sites in SW Pacific (sites marked below).
Data for 435 fish species sufficiently reliable and comprehensive for use in bioregion analysis


WCS
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Marine and Coastal Biodiversity Management in Pacific Island Countries
Agenda item 5.b. Introduction to Fiji's marine bioregions and seabed geomorphology
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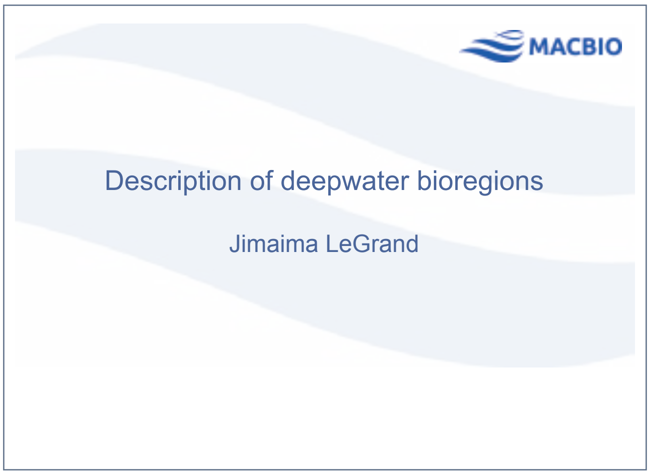
IUCN
giz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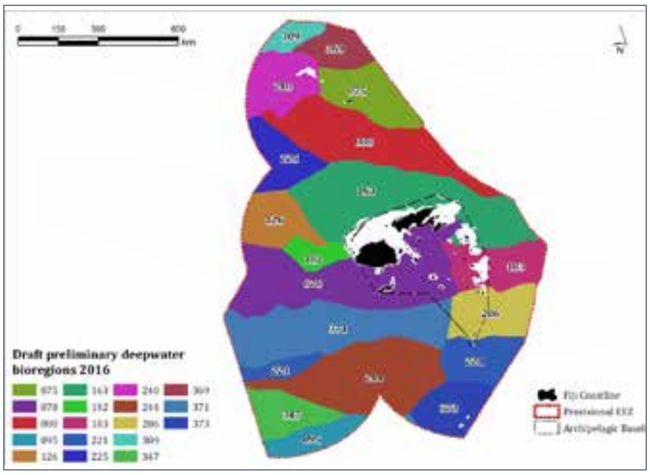
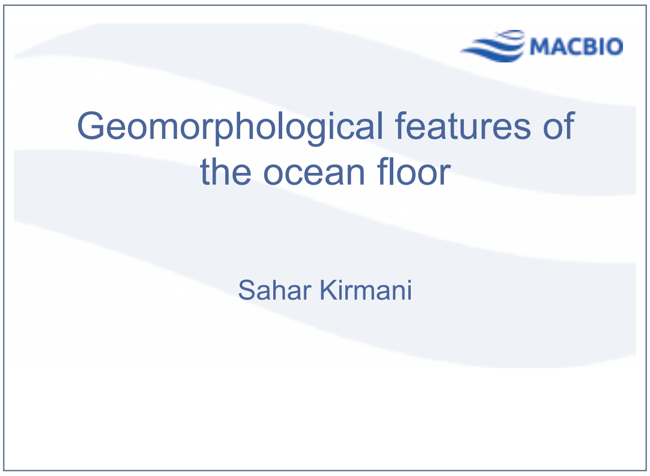
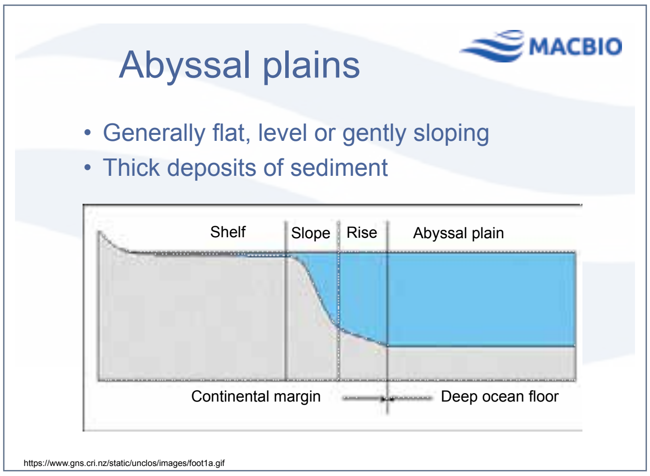
Description of deepwater bioregions
Jimaima LeGrand

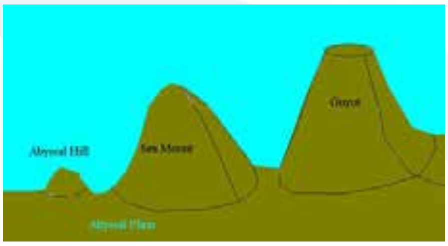

Draft preliminary deepwater bioregions 2016


MACBIO
Geomorphological features of the ocean floor
Sahar Kirmani


Abyssal plains
MACBIO
• Generally flat, level or gently sloping
• Thick deposits of sediment
Shelf
Slope
Rise
Abyssal plain
Continental margin
Deep ocean floor
https://www.gns.cri.nz/static/unclos/images/foot1a.gif

Abyssal hills

- Small elevations
- Peak height between 300 – 1000 m above seafloor



http://bclearningnetwork.com/LOR/media/es11/unit8/U08L02/hillmountguyot.JPG

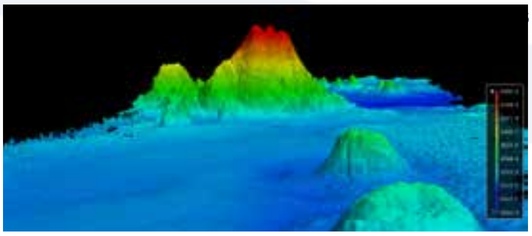
Abyssal mountains

- Submarine mountains
- Peak height greater than 1000 m
- Includes seamounts and ridges

http://bclearningnetwork.com/LOR/media/es11/unit8/U08L02/hillmountguyot.JPG

Seamounts

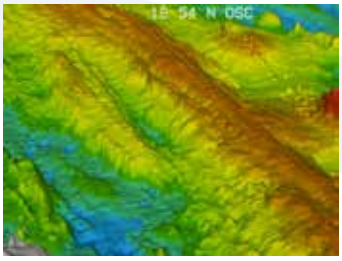
- Large conical shaped mountains
- Peak height greater than 1000 m from seafloor
- Isolated or in groups



http://ccom.unh.edu/sites/default/files/slide_images/seamount-discovery-2014/fig3_seamount_SE_3d_view.jpg

Ridges

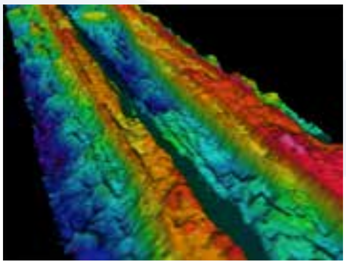
- Long, narrow elevations with steep sides
- Peak height greater than 1000 m from seabed



http://www.livescience.com/images/i/000/073/788/original/east-pacific-rise.jpg?interpolation=lanczos-none&downsize=*:1000

Rift valleys

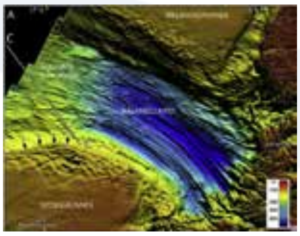
- Long valleys
- Found between spreading ridges



http://oceanexplorer.noaa.gov/explorations/05galapagos/logs/dec5/media/multibeam_ridge_600.jpg

Troughs

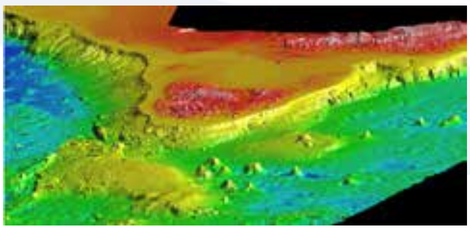
- Large deep areas
- From 100 m to over 1000 m depth



https://www.researchgate.net/profile/Martin_Jakobsson2/publication/282377233/figure/fig5/AS:281937424994341@1444230529290/Fig-6-a-Multi-beam-bathymetric-data-showing-a-submarine-palaeo-ice-stream-bed-ice-fl.png

Plateaus

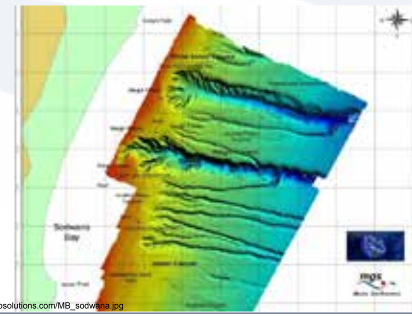
- Mostly flat, large, elevated areas
- Sudden drop off on one or more sides



https://www.researchgate.net/profile/Peter_Harris14/publication/284032480/figure/fig5/AS:297399898656781@1447917069918/Figure-613-Bathymetric-image-from-Geoscience-Australia-showing-a-three-dimensional-view.png

Submarine canyons

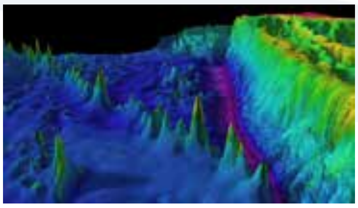
- Steep-walled, winding valleys over 1000 m deep
- Associated with high biomass and biodiversity
- Relatively high productivity



https://www.marinegeosolutions.com/MB_sodwana.jpg

Trenches

- Very deep (6 – 10 km), long and narrow depressions of ocean floor
- Part of the Hadal zone (depths of 6000 m or more)
- Highly specialised and often endemic fauna

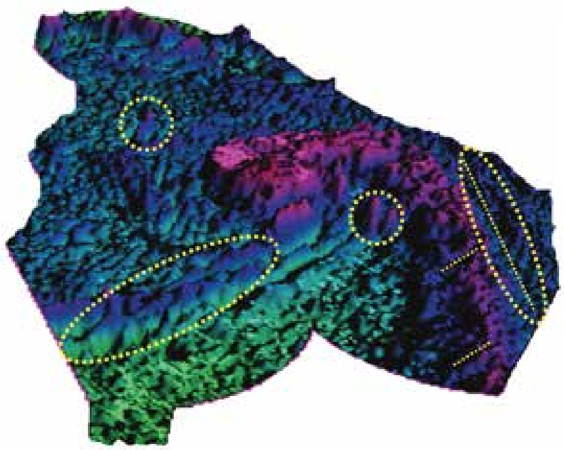


https://www.whoi.edu/cms/images/kermadec_trench_x_415673.jpg

Hydrothermal vents

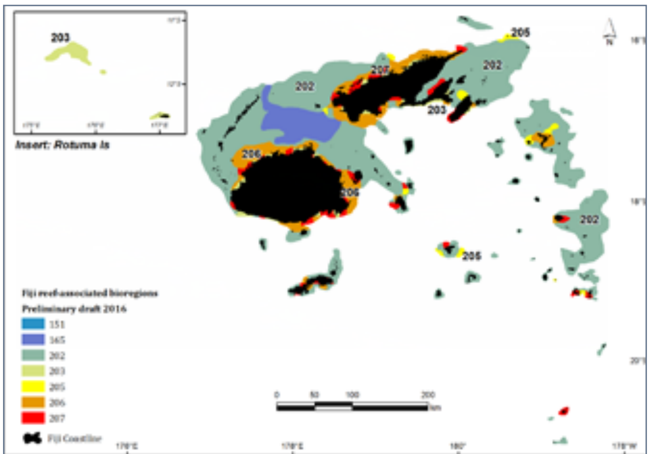
- Mineral rich, geothermally heated seawater rises towards ocean crust, cools and forms vent structures
- Unique biodiversity

http://www.divediscover.whoi.edu/images/vent-smoker.jpg



Describing Fiji's reef-associated bioregions

Jimaima LeGrand



Groups are to review

- Bioregion locations
- Bioregion boundaries
- Bioregion names
- Add to or provide bioregion descriptions

Describing Fiji's entire marine environment – Expert Workshop

9.4 APPENDIX 4 WORKSHOP INFORMATION GATHERING

GUIDANCE FOR FACILITATORS

DEEP WATER BIOREGIONS (1H 30 MIN)

In groups, please:

1. *5–10 min:* (in pairs or individually) briefly view the 'summary' provided for the deepwater bioregions.
2. *15 min:* Looking at the environmental factors that were used to determine the bioregions can you see any patterns or major influences? i.e., chlorophyll, sea surface temperature, mixed layer depth, bathymetry?
3. *15 min:* Are there any bioregions that stand out or that you can provide any further comments/ details on (geomorphology, productivity)?
4. *15 min:* Looking at the bioregion boundaries – please provide guidance or feedback on their boundaries
5. *10 min:* Looking at the bioregion names – can you provide any further guidance/suggestions?
6. *25 min:* Reporting back key findings

REEF ASSOCIATED BIOREGIONS (2H 15MIN)

In groups, please:

1. *5–10 min:* Take time to become familiar with the 'general descriptions' provided for each of the 6 reef associated bioregions.
2. Looking at each of the reef associated bioregions:
   a. *15 min:* Identify the environmental conditions/characteristics that are similar **WITHIN** the bioregions i.e. current strength, proximity to land, rivers, wind, habitat/community types, localised upwellings etc
   b. *15 min:* Provide any further information to add to the expert input description
   c. *15 min:* Identify parts of the bioregion that do not make sense (i.e. look like they don't share the same environmental conditions)

4\. *15 min:* Looking at the bioregion boundaries – does the bioregion capture the correct features? Should it be moved towards or away from reefs/rivers etc?

5\. *15 min:* Looking at the bioregion names – can you provide any further guidance/suggestions?

6\. *30 min:* Reporting back key findings

NOTE: rapporteurs entered data from working groups directly into an Excel spreadsheet.

9.5 APPENDIX 5 DATA AVAILABLE TO WORKSHOP PARTICIPANTS

RESPONSE MAPS (FOR PARTICIPANTS TO DRAW UPON)

MAPS OF DRAFT, PRELIMINARY REEF-ASSOCIATED BIOREGIONS

Central Division and surrounds (including reefs, mangroves, seagrasses and major rivers)

Eastern Division and surrounds (including the same information as above)

Western Division and surrounds (including the same information as above)

Northern Division and surrounds (including the same information as above)

MAPS OF DRAFT, PRELIMINARY DEEPWATER BIOREGIONS

EEZ-wide maps provided to the working group for the deepwater bioregions (including underlying bathymetry and seabed geomorphology)

MAPS AVAILABLE IN HARDCOPY ON THE RESOURCE WALL

Note: RED fonts include some of the data that were used to derive the draft bioregions. The fonts in black indicate data that were NOT used to derive bioregions but directly related to the environmental conditions and biological information including on how species are distributed in the ocean.

1. Fiji Bathymetry
2. Fiji Geomorphology
3. Fiji Benthic Marine Species Richness
4. Fiji Chlorophyll-a Concentration (mg/m^3) (2002–present)
5. Fiji Cold Water Coral Habitat Suitability
6. Fiji Ecologically or Biologically Significant Marine Areas (EBSAs)
7. Fiji Hydrothermal Vents
8. Fiji Mangroves, Seagrass, Reefs
9. Fiji Marine Important Bird and Biodiversity Areas (IBAs)
10. Fiji Mixed Layer Depth
11. Fiji Modelled Reef Fish Species Richness
12. Fiji Named Cyclones (1980–2015)
13. Fiji Pelagic Marine Species Richness
14. Fiji Photosynthetically Available Radiation (PAR)
15. Fiji Productivity (gC/m^2/yr)
16. Fiji Reef Conditions
17. Fiji Sea Surface Currents (1992–2016)
18. Fiji Sea Surface Temperature (2002–present)
19. Fiji Seamount Morphology
20. Fiji Tuna Catch (2001–2010)

SPATIAL DATA AVAILABLE FOR GIS

All of the above resource wall data were available in the GIS as well as the following data.

BASE LAYERS

1. Fiji Coastline
2. Division Boundaries
3. Fiji Archipelagic Baseline
4. Fiji Provisional EEZ Boundary
5. Millennium Coral Reefs

ENVIRONMENTAL VARIABLES

1. Temperature at 1000 meters depth
2. Temperature at 200 meters depth
3. Temperature at 30 meters depth
4. Depth of 20 degree isotherm
5. Salinity
6. pH
7. Nitrate
8. Calcite
9. Silicate
10. Phosphate

BIOPHYSICAL DATA

Geomorphological features

a. High, medium and low shelf
b. Escarpment
c. Basin
d. Bridge
e. Guyot
f. Seamount
g. Rift valley
h. Trough
i. Ridge
j. Spreading ridge
k. Terrace
l. Trench
m. Plateau
n. Abyssal mountains, hills, plains
o. Slope
p. Hadal

9.6 APPENDIX 6 DESCRIPTION OF REVISED BIOREGIONS OF FIJI

Descriptions of bioregions are not constrained to national boundaries and, therefore, most of these descriptions relate to entire bioregions which may span across two or more EEZs.

HABITAT	No.	NAME	DESCRIPTION
Deepwater	13	Southern Lau abyssal hills	Includes large abyssal hills and mountains, a large plateau towards the east and isolated pockets of seamounts, spreading ridges and Moore Ridge. The eastern non-contigous portion consists of plateaus and spreading ridges. SST is low and variable, Chl a is low and variable, salinity is moderate and stable, dissolved oxygen is low and variable, deepwater temperature is deep, 20°C isotherm is deep, mixed layer depth is shallow, solar irradiance is low, pH level is moderate, silicate level is moderate, phosphate level is low, nitrate level is moderate, calcite is low. Contains all of seamount type 4 (small with deep peak, most isolated type). Contains one active and inferred hydrothermal vent in the North Fiji Basin region. Generally, the shallowest depth is 2,000m and the lower depth is 3,500m. Has high abundances of tuna (yellowfin, albacore and bigeye), barracuda, mahimahi and walu. Tuna caught here are much up to twice the size of those caught further north. Other pelagic species are less abundant than in bioregions further north.
Deepwater	19	Far-Southern Viti	Deep bioregion with mostly abyssal plains and hills, with a large cluster of seamounts toward the western side of the bioregion cutting through spreading ridges. SST is low, Chl a is low and stable, salinity is high and variable, dissolved oxygen is moderate and stable, deepwater temperature is moderate, 20°C isotherm is shallow, mixed layer depth is shallow, solar irradiance is low, pH level is low, silicate level is low, phosphate level is low, nitrate level is moderate, calcite is low. Generally, the shallowest depth is 3,500m and the lower depth is 4,500m.
Deepwater	24	Ceva-i-Ra ridge and South Ono-i-Lau	Very small and relatively shallow bioregion. Western portion consist of ridges, plateaus and abyssal mountains. Eastern non-contigous portion contains mainly plateaus and spreading ridges with a few canyons and a few seamounts. SST is low and stable, Chl a is low and variable, salinity is moderate and variable, dissolved oxygen is low and stable, deepwater temperature is moderate, 20°C isotherm is moderate, mixed layer depth is generally shallow but deep in the east towards Tonga, solar irradiance is low, pH level is moderate, silicate level is moderate to high towards the east, phosphate level is low, nitrate level is moderate, calcite is low. Contains the highest percentage (19%) of both canyon types within Fiji's provisional EEZ and 27% of blind canyon types. Generally, the shallowest depth is 1,500m and the lower depth is 3,000m. Has high abundances of tuna (yellowfin, albacore and skipjack), mahimahi, wahoo and marlin. Albacore and yellowfin tuna are usually caught from shallower than 300m, while skipjack are caught from waters deeper than 300m.
Deepwater	82	North Fiji Basin	Mainly abyss, trough and plateau with several seamounts in the central part of the bioregion formed on ridges and abyssal mountains. Rift valleys and spreading ridges cut across the bioregion from north to south. SST is moderate and stable, Chl a is low and variable, but higher in more productive waters towards land, salinity is low and variable, dissolved oxygen is low and variable, deepwater temp is deep, 20°C isotherm is deep, mixed layer depth is generally shallow, solar irradiance is moderate, pH level is high towards the west, silicate level is moderate and low towards west, phosphate level is low, nitrate level is generally low, calcite is low. Contains 67% of seamount type 3 (intermediate, large tall and deep) and contains 15% of all seamount types within Fiji's provisional EEZ. Contains three active and inferred hydrothermal vents and one inactive vent. Generally, the shallowest depth is 2,500m and the lower depth is 3,500m. Has high abundances of tuna (yellowfin, albacore and skipjack), mahimahi, wahoo and marlin. Albacore and yellowfin tuna are usually caught from shallower than 300m, while skipjack are caught from waters deeper than 300m. Balmoral Reef, a seamount with its peak at 15 m, attracts mahimahi, walu, wahoo, barracuda, and snappers.

HABITAT	No.	NAME	DESCRIPTION
Deepwater	165	Fiji Central	Very big and long bioregion running west to east. Western deeper region with mainly abyssal hills and dominated by a plateau in the east. The middle regions include many deeper seamounts formed on top of abyssal mountains. Connected to the reef-associated bioreions within Fiji by a ridge slope. SST is moderate and variable, Chl a is low towards the west and high and variable close to Land (Viti Levu and nearby islands), salinity is low and variable, dissolved oxygen is low and stable, deepwater temperature is deep, 20°C isotherm is deep, mixed layer depth is generally shallow, solar irradiance is generally low, pH level is moderate to high towards the west, silicate level is moderate to high (east of bioregion), phosphate level is low, nitrate level is moderate, calcite is generally low except close to land (Fiji Islands). Possible presence of a small eddy west of the main island group. Contains 22% of Fiji's shelf incising canyon area and the second highest percentage of both canyon types combined. Contains two active hydrothermal vents (one confirmed and one inferred) located in the North Fiji Basin and Lau Basin. Generally, the shallowest depth is 500m and the lower depth is 3,000m. Three areas have yellowfin, albacore and skipjack tuna aggregations: southwest of Viti Levu, south of Kadavu and the Lomaiviti group. Tuna caught here are much up to twice the size of those caught further north. Other pelagic species, such as barracuda, mahimahi and walu (caught as bycatch) are in the Lomaiviti group between Ovalau and Gau, and around Koro. Albacore and yellowfin tuna are usually caught from shallower than 300m, while skipjack are caught from waters deeper than 300m.
Deepwater	184	Northwest Rotuma Seamounts and the Vityaz trench	Mostly abyssal with several seamounts and deep, structurally complex ridges. Deep abyssal mountains form the base of the seamounts. The Vityaz Trench bisects the two ridges and connects to the Cape Johnson Trough with steep escarpments. SST is moderate and stable, Chl a is low and variable, salinity increases eastward and is stable, dissolved oxygen is low and stable, deepwater temperature is moderate, 20°C isotherm is shallow, mixed layer depth is shallow closer to land, solar irradiance is moderate, pH level is moderate and variable, silicate level is low, phosphate level is low, nitrate level is low, calcite is low. Contains one active and inferred hydrothermal vent in the North Fiji Basin region. Generally, the shallowest depth is 3,000m and the lower depth is 4,500m.
Deepwater	204	North Viti and Vanua Levu basin	Dominated by plateaus and ridges with seamounts, shelf dropoffs and large ridges in the west connected together by canyons. This is a shallow bioregion. SST is moderate and variable, Chl a is high closer to land (Viti Levu and Vanua Levu) and low towards the east, salinity is low and variable, dissolved oxygen is low and variable, deepwater temperature is deep, 20°C isotherm is deep, mixed layer depth is shallow, solar irradiance is moderate, pH level is moderate, silicate level is high, phosphate level is moderate, nitrate level is moderate, calcite is generally low but high close to land (Fiji main islands - Viti Levu and Vanua Levu). Contains 64% of Fiji's shelf incising canyon area. Generally, the shallowest depth is 0m and the lower depth is 500m. Has high abundances of tuna (yellowfin, albacore and skipjack), mahimahi, wahoo and marlin, especially around Cikobia Island. Albacore and yellowfin tuna are usually caught from shallower than 300m, while skipjack are caught from waters deeper than 300m.
Deepwater	206	South Ceva-I-Ra Deep	Narrow and long non-contiguous bioregion stretching east-west. Very deep trough with ridges, basins, and abyssal mountains forming the base of several seamounts. SST is low and stable, Chl a is low and stable, salinity is moderate, dissolved oxygen is low and stable, deepwater temperature is moderate, 20°C isotherm is moderate, mixed layer depth is shallow, solar irradiance is low, pH level is moderate, silicate level is moderate, phosphate level is low, nitrate level is moderate, calcite is low. Generally, the shallowest depth is 2,500m and the lower depth is 4,000m.
Deepwater	228	High Seas Deep	Only a very tiny part of this bioregion is in Fiji, in the very southern-most tip of the EEZ. Dominated by an abyssal plain and hills with pockets of abyssal mountains forming the base of several seamounts. A non-contiguous part of the bioregion to the west fully consists of trough and basin. SST is low and stable, Chl a is low and stable, salinity is high, dissolved oxygen is moderate and variable, deepwater temperature is low, 20°C isotherm is shallow, mixed layer depth is medium, solar irradiance is low, pH level is low, silicate level is low, phosphate level is low, nitrate level is moderate, calcite is low. Contains all of seamount type 8 (small and short with very deep peak depth). Generally, the shallowest depth is 3,500m and the lower depth is 4,500m.

HABITAT	No.	NAME	DESCRIPTION
Deepwater	240	Abyssal plain, seamounts and Vityaz trench north Fiji	Very deep bioregion with abyssal plains, the Vityaz Trench and ridges with a chain of seamounts. Becomes less structured in the southern part. SST is high and stable, Chl a is low and variable, salinity is moderate and stable, dissolved oxygen is low and stable, deepwater temperature is moderate, 20°C isotherm is deep, mixed layer depth is shallow, solar irradiance is moderate, pH level is variable, silicate level has a left to right gradual increase, phosphate level is low, nitrate level is low, calcite is low. Generally, the shallowest depth is 4,000m and the lower depth is 5,000m. May support populations of bigeye tuna.
Deepwater	243	West Rotuma	Mostly abyssal, with several seamounts, ridges and spreading ridges. Deep abyssal mountains form the base of the seamounts. This bioregion takes up most of the south of the Vityaz Trench and connects to the high seas with spreading ridges. SST is high and stable, Chl a is low and variable, salinity is low, dissolved oxygen is low and variable, deepwater temperature is deep, 20°C isotherm is deep, mixed layer depth is medium, solar irradiance is high, pH level is moderate, silicate level is moderate, phosphate level is moderate, nitrate level is low, calcite is low. Contains the highest percentage (22%) of all seamount types within Fiji's provisional EEZ, with 59% of seamount type 11 (intermediate size, largest basal area and deepest peak depth), and 37% of seamount type 10 (large and tall with shallow peak: shallow). Contains two inactive hydrothermal vents. Generally, the shallowest depth is 2,000m and the lower depth is 3,500m. Has high abundances of tuna (yellowfin, albacore and skipjack), mahimahi, wahoo and marlin. Albacore and yellowfin tuna are usually caught from shallower than 300m, while skipjack are caught from waters deeper than 300m.
Deepwater	269	North-East Rotuma abyssal mountains and seamounts	Large bioregion with abyssal hills and mountainous area consisting of ridges and seamounts. SST is moderate and stable, Chl a is low and variable, salinity is low, dissolved oxygen is low and stable, deepwater temperature is deep, 20°C isotherm is deep, mixed layer depth is medium, solar irradiance is high, pH level is low, silicate level is moderate, phosphate level is moderate, nitrate level is moderate, calcite is low. Generally, the shallowest depth is 2,500m and the lower depth is 4,500m. Has high abundances of tuna (yellowfin, albacore and skipjack), mahimahi, wahoo and marlin. Albacore and yellowfin tuna are usually caught from shallower than 300m, while skipjack are caught from waters deeper than 300m.
Deepwater	270	Rotuma abyssal mountains and seamounts	Very deep bioregion consisting of abyssal hills and mountains, cutting across large ridges and deep escarpments. Large seamounts and guyots are also represented in the bioregion from east to west. SST is high and stable, Chl a is low and variable, salinity is low, dissolved oxygen is low and stable, deepwater temperature is moderate, 20°C isotherm is deep, mixed layer depth is medium, solar irradiance is moderate, pH level is low, silicate level is moderate, phosphate level is moderate, nitrate level is moderate, calcite is low. Generally, the shallowest depth is 1,000m and the lower depth is 3,500m. Has high abundances of tuna (yellowfin, albacore and skipjack), mahimahi, wahoo and marlin. Albacore and yellowfin tuna are usually caught from shallower than 300m, while skipjack are caught from waters deeper than 300m.
Deepwater	298	South Fiji Deep	Small, non-contiguous bioregion split into 4 parts with very distinct geomorphology. This part of the bioregion consist of plateau, spreading ridge, trough and abyssal hill. SST is low and stable, Chl a is low and stable, salinity is moderate, dissolved oxygen is low and variable, deepwater temperature is moderate, 20°C isotherm is moderate, mixed layer depth is shallow, solar irradiance is low, pH level is moderate, silicate level is moderate, phosphate level is low, nitrate level is moderate, calcite is low. Generally, the shallowest depth is 2,000m and the lower depth is 4,000m.
Deepwater	325	South Eastern Ceva-i-Ra seamounts abyssal hills	Deep bioregion with the western edge defined by Moore Ridge, extending East to Lau Ridge. Mainly abyssal hills with a few isolated seamounts, south of Ceva-i-Ra. SST is low and stable, Chl a is low and variable, salinity is moderate and variable, dissolved oxygen is low and variable, deepwater temperature is mderate, 20°C isotherm is moderate, mixed layer depth is medium, solar irradiance is low, pH level is moderate, silicate level is low, phosphate level is low, nitrate level is low, calcite is low. Generally, the shallowest depth is 4,000m and the lower depth is 4,500m.

HABITAT	No.	NAME	DESCRIPTION
Deepwater	335	Ono-i-Lau, South Lau Ridge	Non-contiguous bioregion spread over a plateau and cutting through large canyons, ridges and a few small seamounts. SST moderate and stable, Chl a is low generally, but high close to land (southern Lau Islands), salinity is moderate and stable, dissolved oxygen is moderate and stable, deepwater temperature is moderate, 20°C isotherm is medium, mixed layer depth is medium, solar irradiance is generally low, pH level is moderate, silicate level is moderate, phosphate level is low, nitrate level is moderate, calcite is low generally, but high close to land (southern Lau Islands). Generally, the shallowest depth is 500m and the lower depth is 2,000m. Has high abundances of tuna (yellowfin, albacore and skipjack), mahimahi, wahoo and marlin. Albacore and yellowfin tuna are usually caught from shallower than 300m, while skipjack are caught from waters deeper than 300m.
Deepwater	378	Minerva plateau	Large bioregion on a slope consisting of abyssal plain and hill, plateau and trough with overlying ridges, canyons, seamounts and escarpment. SST is low and stable, Chl a is low and variable, salinity is high, dissolved oxygen is moderate and stable, deepwater temperature is moderate, 20°C isotherm is moderate, mixed layer depth is shallow, solar irradiance is low, pH level is moderate, silicate level is moderate, phosphate level is low, nitrate level is moderate, calcite is low. Generally, the shallowest depth is 500m and the lower depth is 2,500m.
Deepwater	382	Southern Lau	Large, shallow and non-contiguous bioregion around a number of small islands, consisting of mainly plateaus and ridges. Includes a number of seamounts and canyons in the eastern part of the bioregion. SST moderate and variable, Chl a is generally moderate but high close to land (soutern Lau group), salinity is moderate, dissolved oxygen is moderate and variable, deepwater temperature is medium, 20°C isotherm is medium, mixed layer depth is medium, solar irradiance is moderate, pH level is moderate, silicate level is moderate, phosphate level is low, nitrate level is moderate, calcite is generally low but high closer to land (southern Lau group). Generally, the shallowest depth is 500m and the lower depth is 2,000m. Has high abundances of tuna (yellowfin, albacore and skipjack), barracuda, mahimahi and walu. Albacore and yellowfin tuna are usually caught from shallower than 300m, while skipjack are caught from waters deeper than 300m.
Deepwater	412	North Fiji ridge chain	Small bioregion consisting of 4 non-contiguous parts spread from east to west. Formed on deep, structurally complex ridge tops with abyssal hill as base and cutting through seamounts and canyons. SST is high and stable, Chl a is generally low but high toward the west, salinity is low and variable, dissolved oxygen is low and stable, deepwater temperature is medium, 20°C isotherm is deep, mixed layer depth is medium, solar irradiance is moderate, pH level is moderate, silicate level is moderate, phosphate level is moderate, nitrate level is moderate, calcite is low. Generally, the shallowest depth is 500m and the lower depth is 2,500m.
Deepwater	454	Southeast Rotuma plateau	Very lage bioregion consisting of abyssal hills and plateaus. Includes a large seamount and cuts through a number of smaller seamounts and ridges. SST is high, especially compared to other bioregions in Fiji, and stable, Chl a is low and stable, salinity is low and variable, dissolved oxygen is low and stable, deepwater temperature is deep, 20°C isotherm is deep, mixed layer depth is medium, solar irradiance is moderate, pH level is moderate, silicate level is moderate, phosphate level is moderate, nitrate level is moderate, calcite is low. Generally, the shallowest depth is 2,000m and the lower depth is 5,500m. Has high abundances of tuna (yellowfin, albacore and skipjack), mahimahi, wahoo and marlin. Albacore and yellowfin tuna are usually caught from shallower than 300m, while skipjack are caught from waters deeper than 300m.
Deepwater	455	North Fiji Ridge	Deep bioregion formed on abyssal mountains and cutting through deep, structurally complex ridges. The bioregion runs alongside the Vityaz Trench and is comprised of a number of large seamounts with different morphologies. SST is high and stable, Chl a is low and stable, salinity is moderate, dissolved oxygen is low and stable, deepwater temperature is medium, 20°C isotherm is deep, mixed layer depth is medium, solar irradiance is moderate, pH level is moderate, silicate level is moderate, phosphate level is moderate, nitrate level is low, calcite is low. Generally, the shallowest depth is 1,500m and the lower depth is 3,000m.

HABITAT	No.	NAME	DESCRIPTION
Deepwater	460	Fiji Plateau Deep	Small deep bioregion with abyssal hills and mountains, rift valleys and spreading ridges with a seamount. SST moderate and variable, Chl a is low and stable, salinity is moderate, dissolved oxygen is moderate and stable, deepwater temperature is deep, 20°C isotherm is deep, mixed layer depth is shallow, solar irradiance is low, pH level is low, silicate level is low, phosphate level is moderate, nitrate level is low, calcite is low. Contains two active and confirmed and one inactive hydrothermal vents. Generally, the shallowest depth is 2,500m and the lower depth is 3,000m. Tuna caught here are much up to twice the size of those caught further north. Other pelagic species (caught as bycatch) are present in low abundance. Albacore and yellowfin tuna are usually caught from shallower than 300m, while skipjack are caught from waters deeper than 300m.
Deepwater	461	Central Lau plateau and hydrothermal vents	Shallow bioregion with mostly plateaus, ridges and spreading ridges, with a few seamounts in the east. SST moderate and stable, Chl a is low and stable, salinity is low and variable, dissolved oxygen is low and stable, deepwater temperature is deep, 20°C isotherm is deep, mixed layer depth is medium, solar irradiance is medium, pH level is low, silicate level is moderate, phosphate level is low, nitrate level is moderate, calcite is low but high closer to land (Lau Island group). Contains one active but inferred hydrothermal vent. Generally, the shallowest depth is 1,000m and the lower depth is 2,500m. Has high abundances of tuna (yellowfin, albacore and skipjack), barracuda, mahimahi and walu. Albacore and yellowfin tuna are usually caught from shallower than 300m, while skipjack are caught from waters deeper than 300m.
Reef-associated	15	Shelf slopes	No major rivers, less land influenced, more oceanic and continous reef system influenced. Patch and fringing reefs are evident.
Reef-associated	120	Estuarine, land and bay influenced	Land influenced, large rivers, fringing and barrier reefs, coastal habitat influenced.
Reef-associated	133	Rotuma	Northern, remote oceanic islands with reef-associated habitats
Reef-associated	139	Oceanic influenced outer islands	Smaller outer islands with often interconnected reef systems with oceanic influence

Rerevaka na Kalou ka doka na Tui

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