MARINE BIOREGIONS OF VANUATU

LONG GOD YUMI STANAP

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 Vanuatu. 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 and Coastal Biodiversity Management in Pacific Island Countries

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

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EXECUTIVE SUMMARY

In 2014, the Council of Ministers (Decision No. 172/2014) decided to start implementation of, amongst other things, a Marine Spatial Plan for the nation. This planning includes aiming 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. To progress the work, the Government established the Ocean Policy Sub-Committee to guide this process as well as to develop an Ocean Policy (launched in 2017). Now, as the Ocean Policy Implementation Sub-Committee, one of their tasks was to identify Vanuatu's marine bioregions – to enable the government to identify "ecologically representative" Marine Protected Areas as part of their Marine Spatial Plan.

Currently, means for countries, like Vanuatu, who have 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 in the Pacific. 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).

This report presents, for the first time, marine bioregions across the Southwest Pacific in general, and Vanuatu 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 20x20km 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 setting 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 6,500 sites. We combined these datasets, which were quality-checked for taxonomic consistencyand 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 9x9km 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 analysiswas 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 25 deepwater bioregions and seven reef-associated bioregions for Vanuatu.

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 Vanuatu 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 nine deepwater and seven reef-associated marine bioregions being finalised for use in national planning in Vanuatu. By including adequate Marine Protected Areas (MPAs) within each bioregion, Vanuatu can now implement an ecologically representative network of MPAs which will help ensure achievement of their social, economic, cultural and environmental objectives as well as their national and international commitments.

1 INTRODUCTION

Pacific Island countries, including Vanuatu, 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 Vanuatu is small, it has authority over a large ocean space within its Exclusive Economic Zones (EEZs), with 98% of the country being ocean.

Pacific Island countries who are signatory to the CBD, like Vanuatu, 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, Vanuatu has committed to a national Marine Spatial Plan inclusive of an ecologically representative network of Marine Protected Areas in their Ocean Policy (passed by the Council of Ministers in August 2016), at the United Nations Ocean Conference (#OceanAction21632, #OceanAction21628) and new National Biodiversity and Action Plan (draft 2018).

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.

More specifically, in Vanuatu in 2014, the Council of Ministers (Decision No. 172/2014) decided to start implementation of, amongst other things, a Marine Spatial Plan for the nation. This planning includes aiming 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. To progress the work, the Government established the Ocean Policy Sub-Committee to guide this process as well as to develop an Ocean Policy (launched in 2017).

However, for Vanuatu, there was 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 the scales needed for Vanuatu's national marine spatial planning, and decisions about locations of ecologically representative MPAs within and across the nation.

Recognising this, the Ocean Policy Implementation Sub-Committee identified one of their tasks as describing Vanuatu's marine bioregions at a scale useful for national planning – to enable the government to identify "ecologically representative" Marine Protected Areas as part of their Marine Spatial Plan. They asked the MACBIO project to assist in this effort.

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 2011–2020such 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 Program (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 managingMPAs, including payments for environmental services, are demonstrated at selected sites.

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

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 for use by Pacific Island countries, including Vanuatu, in their national marine spatial and marine protected area planning processes. By including adequate Marine Protected Areas (MPAs) within each bioregion, Vanuatu can now implement an ecologically representative network of MPAs which will help ensure achievement of their social, economic, cultural and environmental objectives as well as their national and international 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, theirnational 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 Vanuatu have been presented to the marine experts and government of Vanuatu for review. The resulting marine bioregions of Vanuatu 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 marine protected areas, including ecologically representative marine protected areas, 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. in prep). 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 marine spatial planning: the development of marine bioregions.

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[3]. This includesat 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).

Many marine classification schemes are often based on specific taxonomic groups or habitats occurring in the target region. These include schemes based on shallow coral reef fishes (Kulbicki et al. 2013), or Scleractinian corals (Keith et al. 2013). Others use a mix of species distributions, environmental parameters, and expert opinion (Spalding et al. 2007, Kerrigan et al. 2011, Terauds et al. 2012). Most schemes do not explicitly classify offshore or pelagic areas, which have often been seen as largely homogeneous and have been classified into very large scale ecoregions, such as in the Pacific (Longhurst 2006, Sherman et al. 2009, Spalding et al. 2012, Watling and et al. 2013, Sutton et al. 2017).

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).

[3] oceanconference.un.org/ commitments accessed 28/9/17

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, temp 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), and in some cases, models might be improved by considering SST and chlorophyll alpha (CHLa) together and to include Nitrate. Changes in diversity of plankton assemblage drives changes inthe 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 species (HAB) 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 SST (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 SS 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 varCHLa), but also any with upwelling changes. This shows that CHLa 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

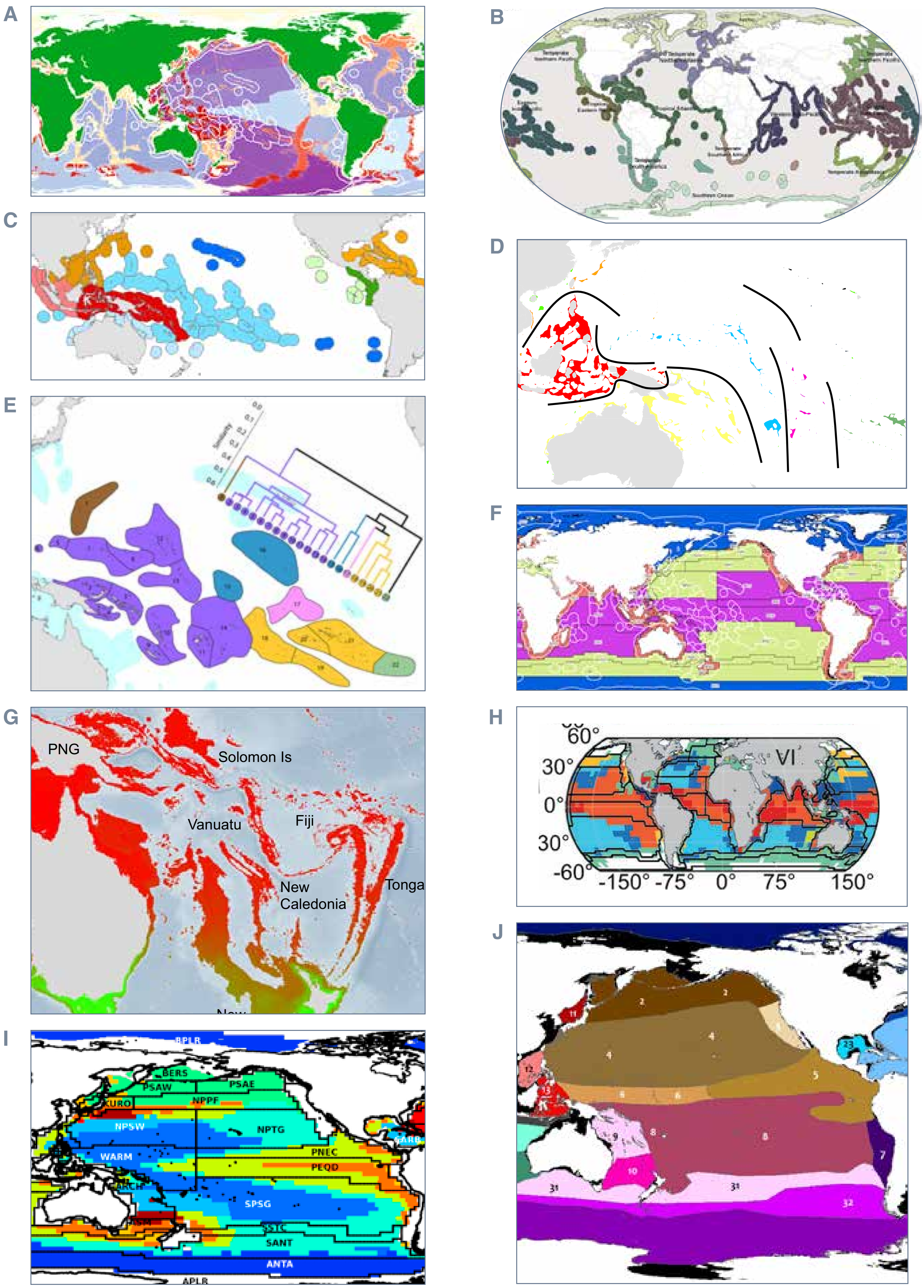

FIGURE 1: Maps of selected existing classification schemes. a) GOODS (UNESCO 2009); b) MEOW (Spalding et al. 2007); c) coral reef fishes (Kulbicki et al. 2013); d) Scleractinian corals (Keith et al. 2013); e) Veron et al. 2015; f) Biogeochemical provinces (Longhurst 2006); g) Deepwater ophiurods (O'Hara 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).

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.

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 Southwest 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 52sub-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 Bathyal (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 Vanuatu. 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 Southwest Pacific.

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.

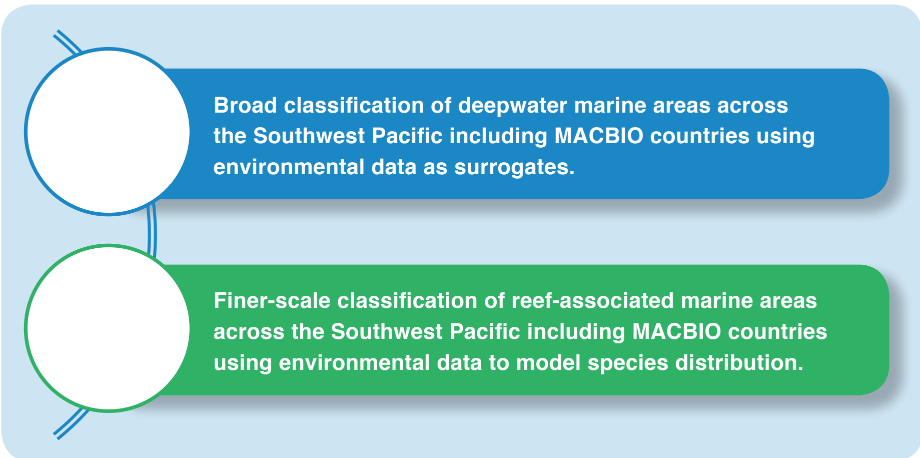

FIGURE 2: MACBIO's two-pronged integrated marine classification approach.

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 Southwest 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.

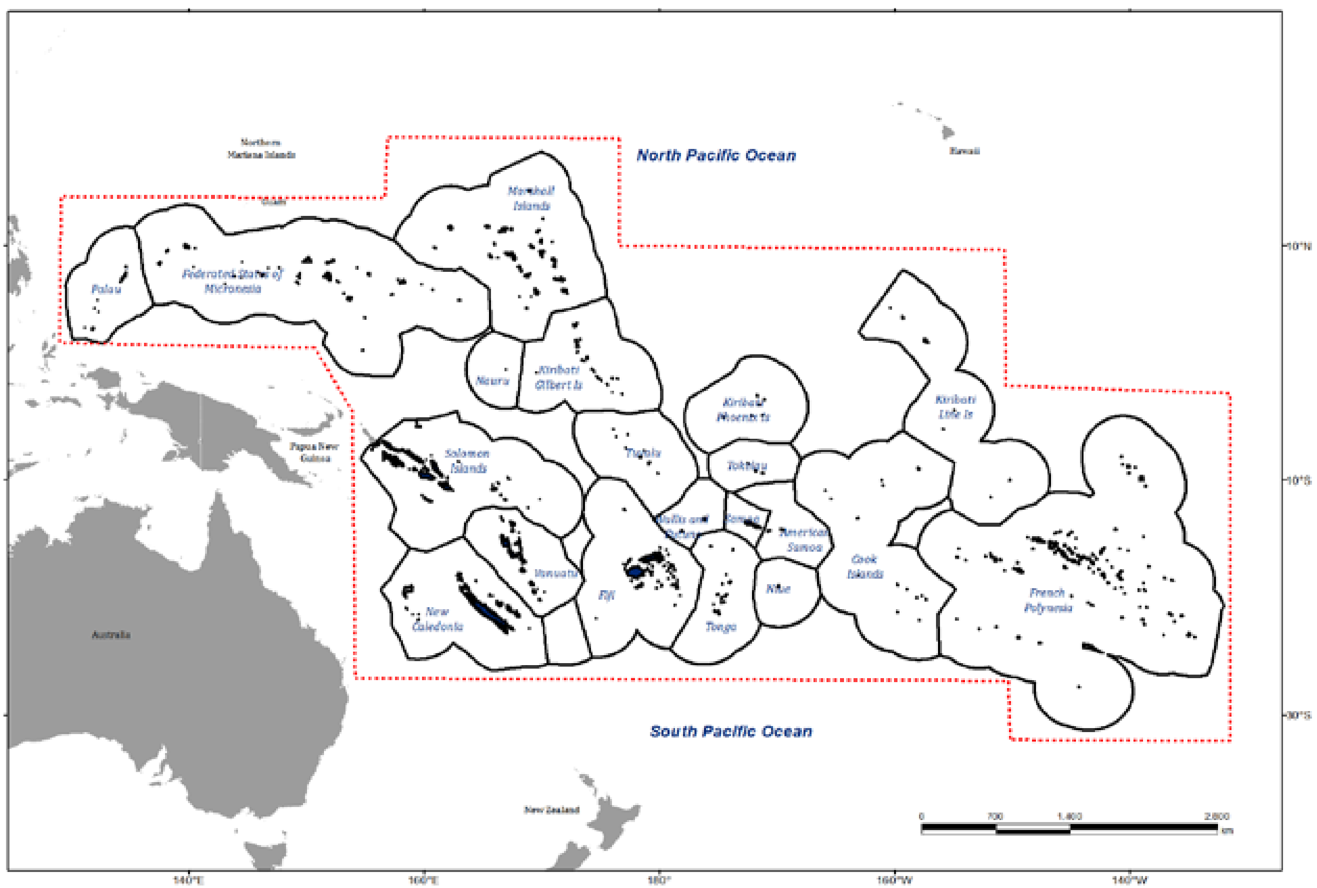

FIGURE 3: Map displaying the Area of Interest (red dotted line) and indicative provisional Exclusive Economic Zones (black solid lines).

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 3.2and 3.3).

An important final step was to review and refine the resultant draft bioregions with marine experts in Vanuatu. 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 Vanuatu.

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 1,000 m. At depths below 1,000 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 1,000 m or 2,000 m (e.g. temperature at 4,000 m[4]).

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/m^3)
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/m^2/day) (maximum)
6	SeaWiFS (BioOracle)	Photosynthetically Available Radiation (Einstein/m^2/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/m^3) (maximum)
13	Aqua-MODIS (NASA)	Chlorophyll a Concentration (mg/m^3) (mean)
14	Aqua-MODIS (NASA)	Chlorophyll a Concentration (mg/m^3) (minimum)
15	Aqua-MODIS (NASA)	Chlorophyll a Concentration (mg/m^3) (range)
16	Aqua-MODIS (NASA)	Sea Surface Temperature (°C) (maximum)
17	Aqua-MODIS (NASA)	Sea Surface Temperature (°C) (mean)

4 www.marine.csiro.au/~dunn/cars2009/c09_distrib_4000mA.jpg), accessed 28/9/17

	DATASET NAME (SOURCE)	PARAMETER
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)
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 political 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 (164,430cells). The 20x20 km cells represented the smallest unit of the deep water regionalization. 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 3.3below) 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 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 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 clustered 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 deep water 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[5]. The hierarchical

[5] (www.r-project.org), accessed 28/9/17

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).

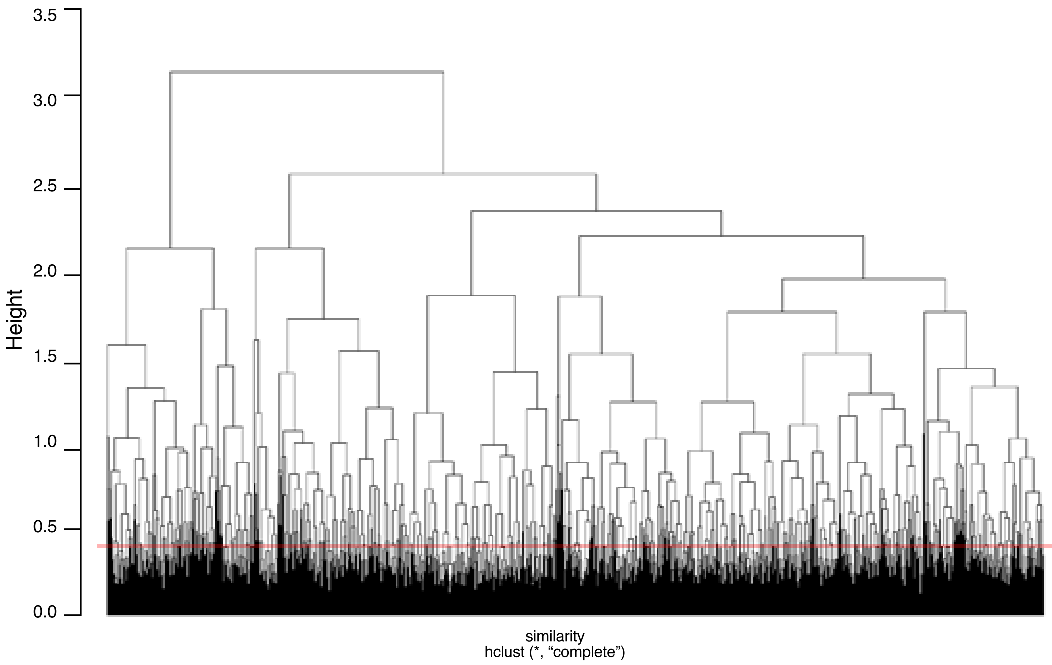

FIGURE 4: Dendrogram for offshore bioregional classification, where the red line shows the cut-off.

When plotted on a map, these clusters described the spatial variability of the SW Pacific. However, due to the necessary use of 20x20km 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 removed using the GDAL sieve algorithm[6]. The clusters were smoothed using the GRASS generalize algorithm[7] "snakes" method with default parameters (Figure 5).

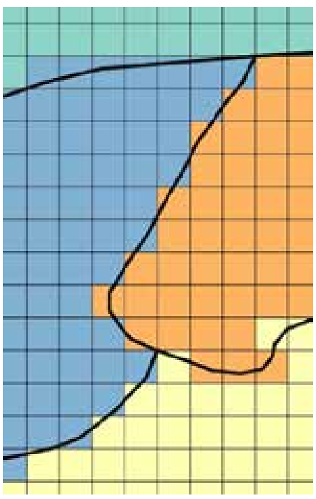

FIGURE 5: Graphic showing the 20km resolution analysis units (coloured) along with the smoothed boundaries (heavy black line).

6 www.gdal.org/gdal_sieve, accessed 28/9/17

7 grass.osgeo.org/grass73/manuals/v.generalize, accessed 28/9/17

Where the analysis identified a non-contiguous bioregion with parts that were separated by up to 1,000km, these multi-part bioregions were manually inspected to determine if their geographic locations could be explained by biological 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).

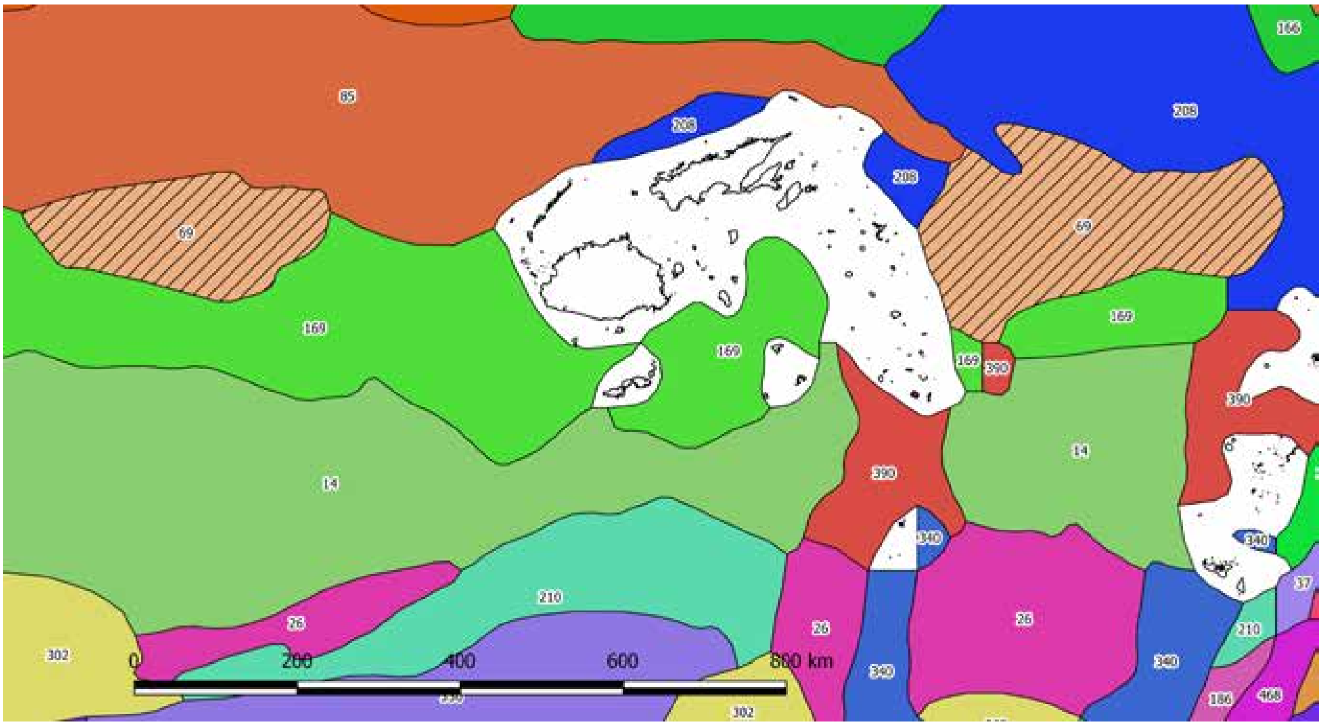

FIGURE 6: Example of post-processing decision making for non-contiguous bioregions.

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 (4,804 fish sampling sites of which 863 sites had hard and soft coral data and 1,702 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).

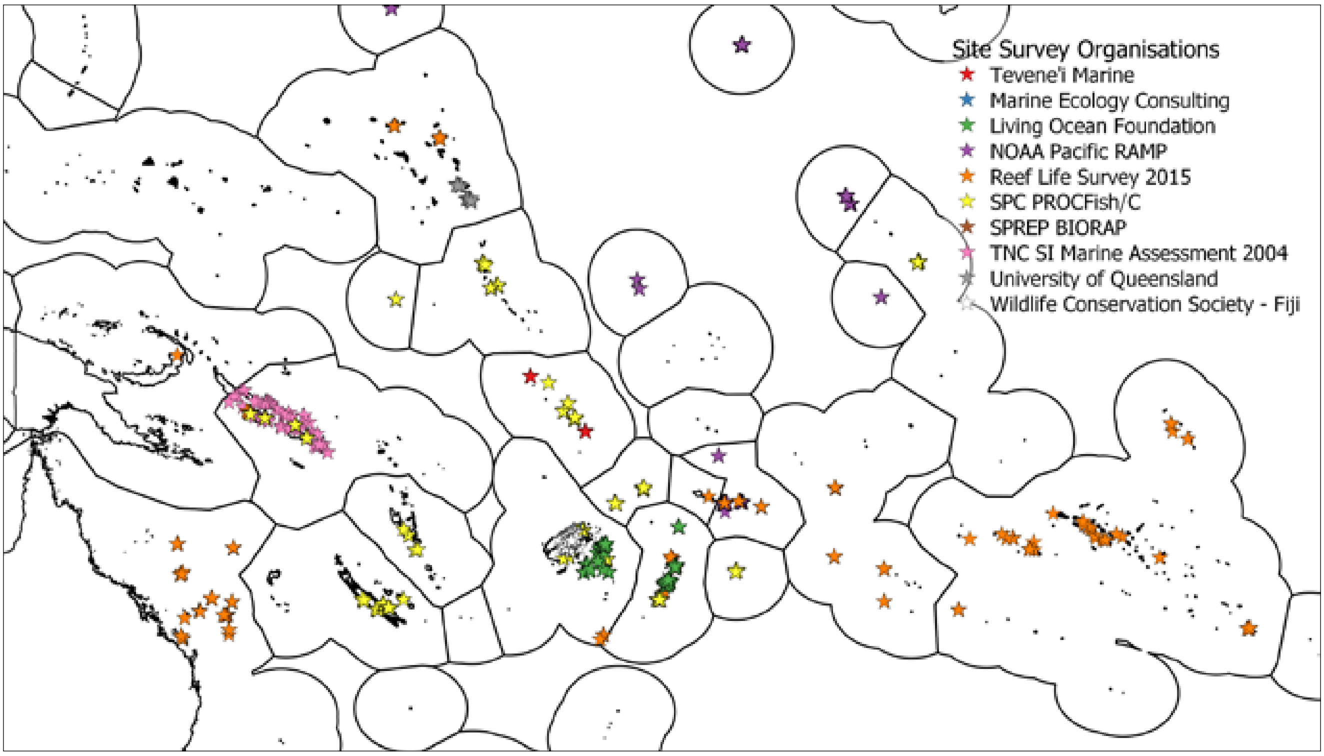

FIGURE 7: Map showing locations of fish, coral and other invertebrate surveys used.

Different numbers of species were included in the database for the three taxa. For fishes, georeferenced reef survey data for 4,804 sites were collated for 1,405 species. Most species in the dataset are only recorded a few times (Figure 8).

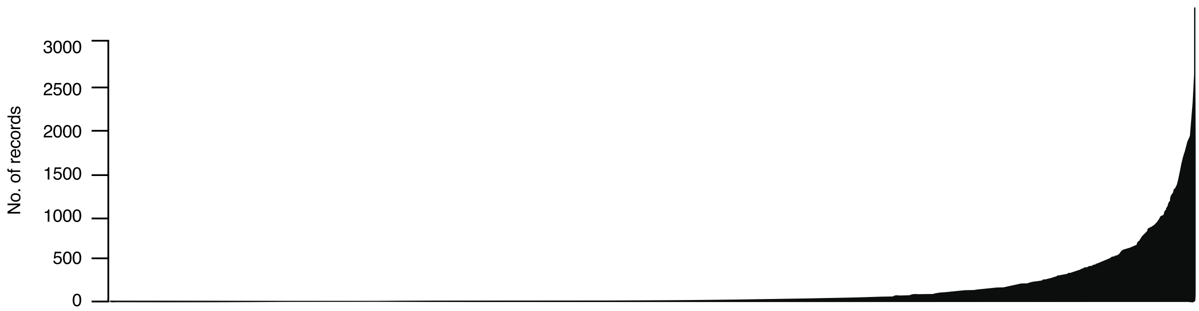

FIGURE 8: Ordered frequency distribution of fish species observations in the dataset, where each column represents one of the 1405 species.

For invertebrates, the database contained 300mobile species from 1,702 sites, and321 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 use of variable methods or observers) which would lead to model uncertainty. The revised fish database contained onlythe species data for which we had high confidence in their correct identification and in the sampling method. This amounted to 1,014 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[8] (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[13] (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 9x9km 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 8). 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.

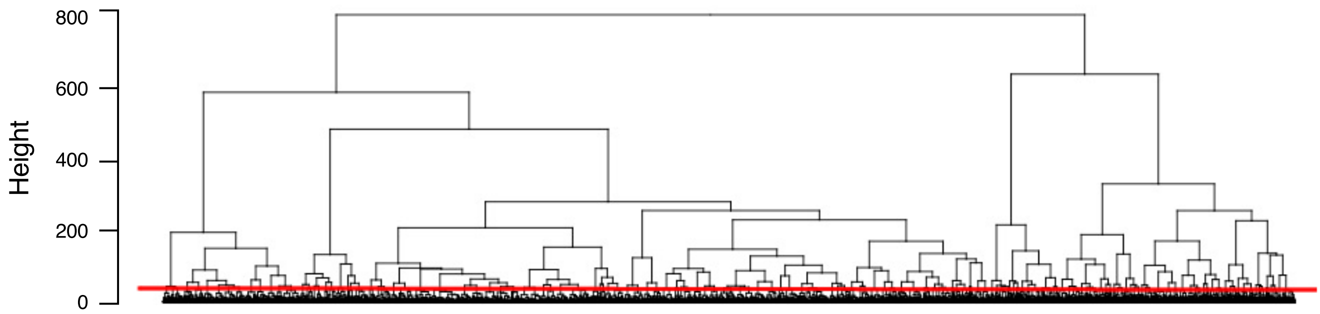

FIGURE 9: Dendrogram for reef-associated bioregional classification

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[9]. Further manual editing was conducted to finalise the smoothing in areas where bioregion boundaries were not adequately smoothed through automated processing.

[8] www.oracle.ugent.be, accessed 28/9/17

[9] grass.osgeo.org/grass73/manuals/v.generalize.html, accessed 28/9/17

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 intodraft deepwater and reef-associated bioregions across the Southwest Pacific including Vanuatu. 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).

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

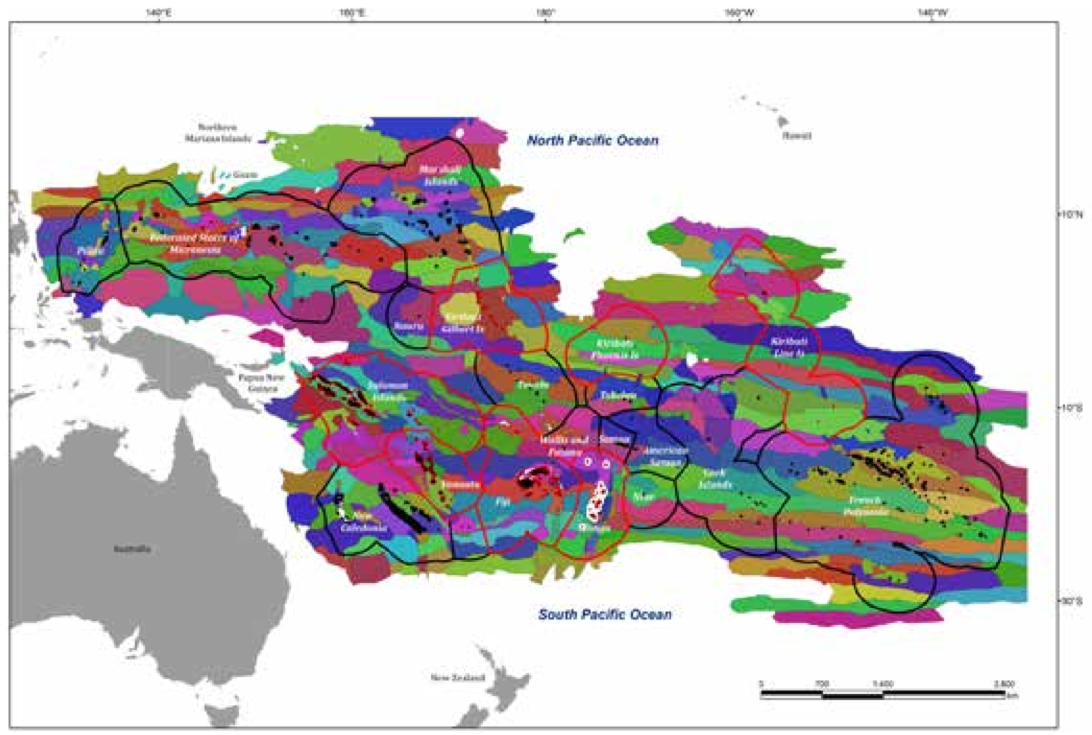

FIGURE 10: Draft deepwater bioregions for the Southwest Pacific including MACBIO countries (red solid line).

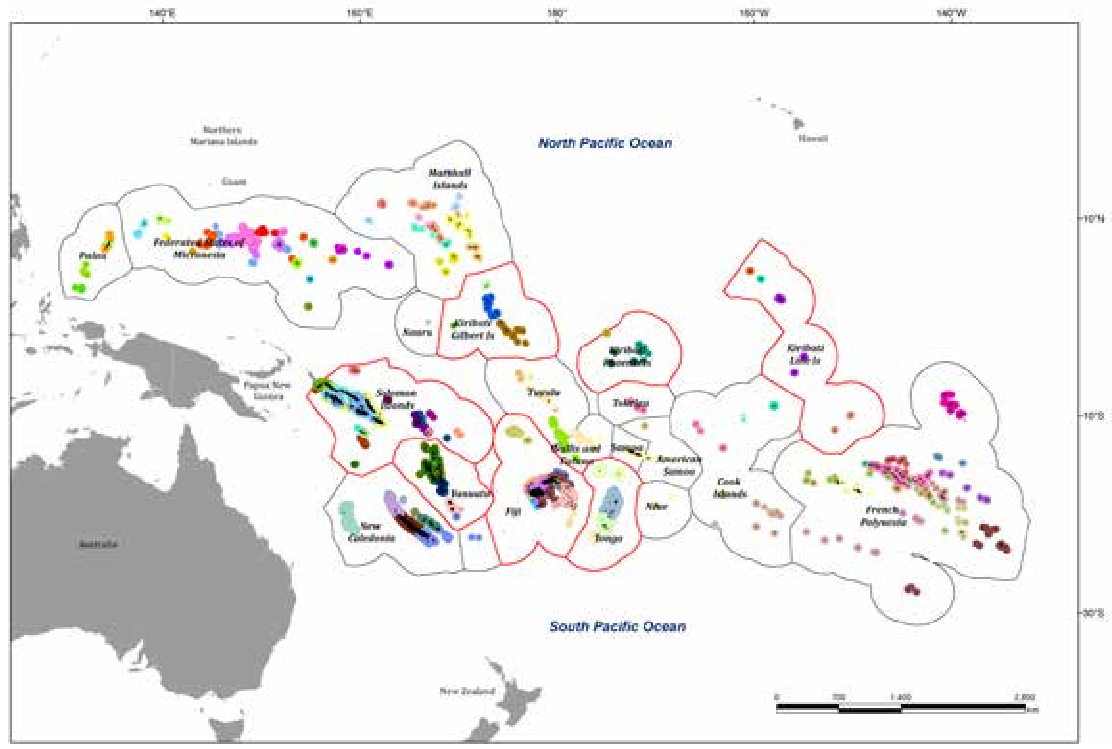

FIGURE 11: Draft reef-associated bioregions for the Southwest Pacific including MACBIO countries (red solid line). Reef areas are exaggerated in this figure for ease of viewing.

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 Vanuatu are presented in Section 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 Vanuatu 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[10]). Many Pacific Island Countries, including Vanuatu, 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[11]. 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 ni-Vanuatu 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 often 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.

[10] oceanconference.un.org/commitments, accessed 28/9/17

[11] 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. in prep). 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 VANUATU

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, including Vanuatu, 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 25 preliminary, draft deepwater draft preliminary bioregions in Vanuatu's EEZ (see Figure 12 and Figure13).

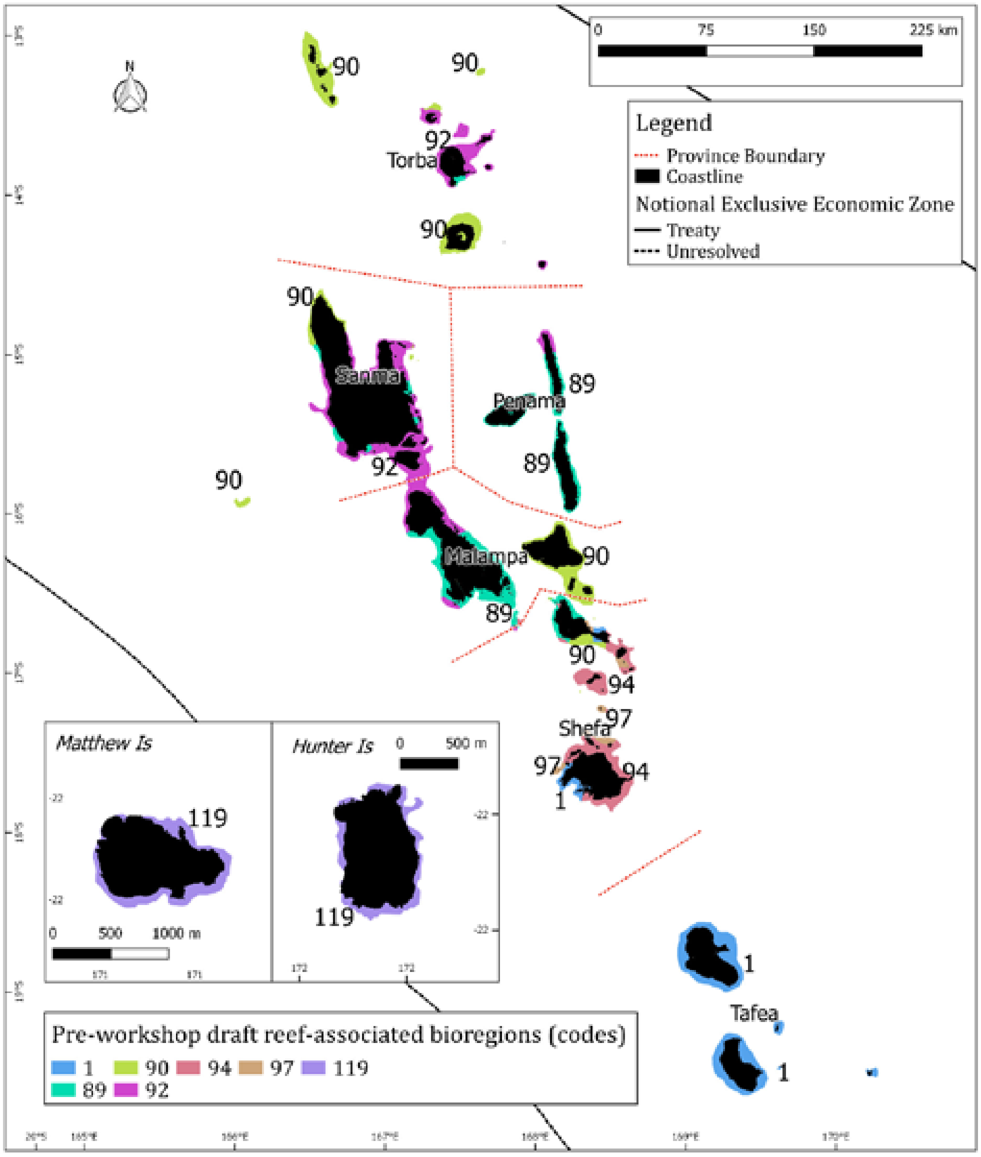

FIGURE 12. Draft reef-associated bioregions of Vanuatu.
These were the outcome of the original technical analysis in 2016.
Each colour and code represents a different marine bioregion.

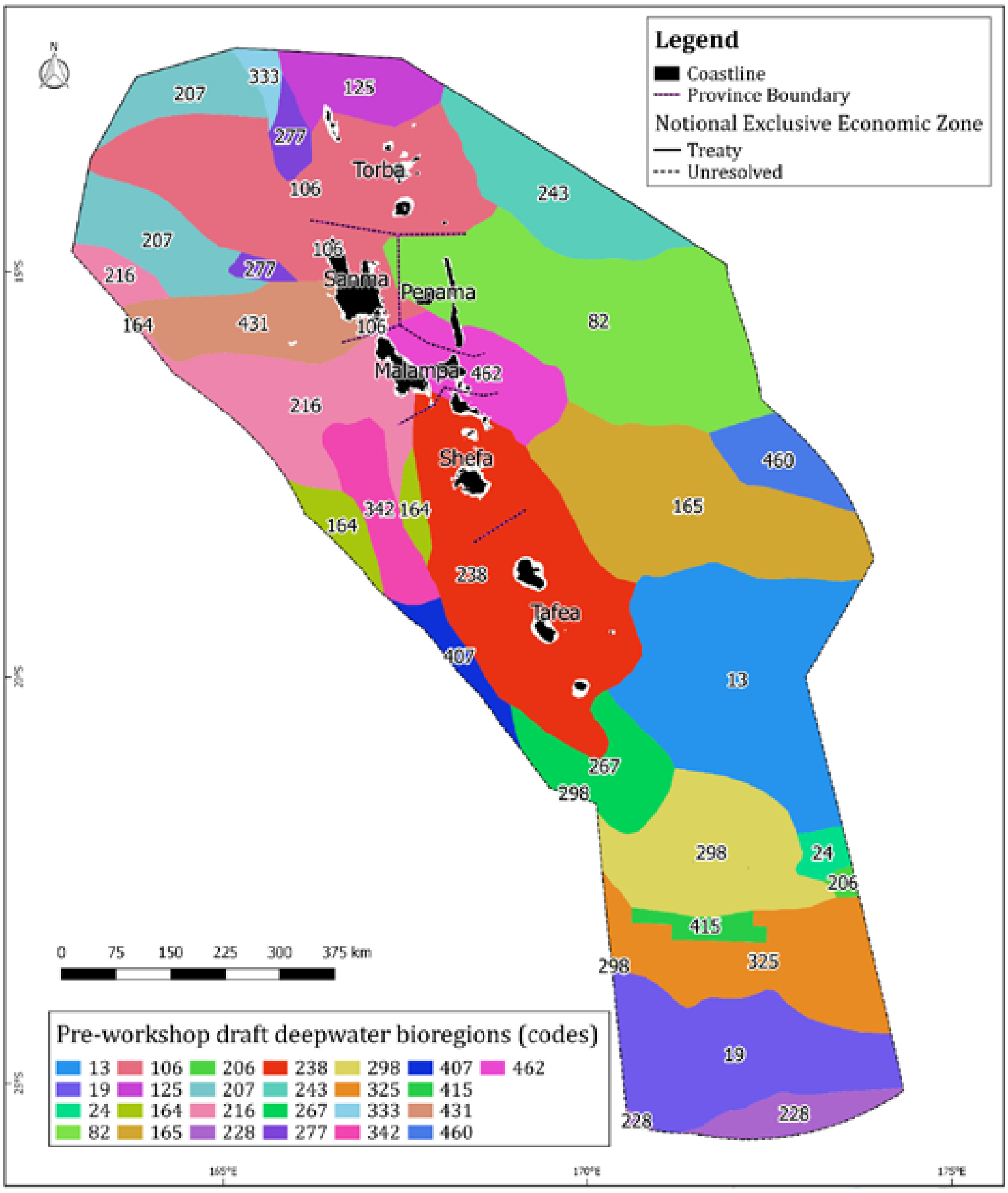

FIGURE 13. Draft deepwater bioregions of Vanuatu.
These were the outcome of the original technical analysis in 2016.
Each colour and code represents a different marine bioregion.

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

This chapter describes the process and outcomes of the workshop during which this review was conducted.

6.2 METHODS

The workshop to refine the draft bioregions of Vanuatu was hosted by the Government of Vanuatu through the Ocean Policy Implementation Committee. It took place on 14th March 2018, at the Melanesian Hotel, Port Vila, and was opened by Mrs Roline Tekon, Acting- Director-General, Ministry of Foreign Affaris, International Cooperation and External Trade (also Co-Chair of the Ocean Policy Implementation Committee). The aim of the workshop was specifically to gather marine expertise in Vanuatu to review the draft 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 49 participants (Figure 14) were divided into 3 working groups, according to geographic area of expertise (North, Central, and Southern group),

For each reef-associated and deepwater bioregion, participants were asked to consider:

- The bioregion location and boundaries – do any boundaries need to change? Do any bioregions need to be merged or split?
- The bioregion name – to be provided by participants; and
- The bioregions description – review & add to the deepwater bioregion descriptions; create descriptions for the reef-associated bioregions.

Each working group had a rapporteur, facilitator and GIS technician.

FIGURE 14. Workshop participants during the 2018 review of Vanuatu's bioregions.

Generally, there was discussion about the limit of boundary between the reef-associated and deepwater bioregions. Initially, a 200m depth limit was suggested for defining the outer limits of inshore areas; however, poulet and deepwater snapper, still considered reef fishes, range from 80m to 500m. Furthermore, around volcanic islands, deepwater may be quite close to shore due to the steepness of the slope, which would place their range into deepwater bioregions. Similarly, reef-associated bumphead parrotfish can reach depths of 800m. But finally, it was suggested that the limit of reef-associated bioregions be shifted to the depth contour of 60-80m, because reef formation tends to cease at this depth (Brokovich et al. 2010, Slattery et al. 2011, Bridge et al. 2012).

6.3 RESULTS

6.3.1 Reef-associated

Overall, workshop participants suggested changes that resulted in altered positions and boundaries for the reef-associated bioregions, but retained seven bioregions in total.

Reef-associated Bioregion 1 was named "Tafea", and includes all the fringing reefs around the Tafea Region. Before the workshop, it also encluded a small area on the western side of Efate Island, but this was removed during the workshop.

Bioregion 89 originally included large areas of fringing reefs throughout the central Vanuatu area, including the Penama, Sanma and Malampa regions, as well as a small area on the southern side of Vanua Lava Island. Some changes occurred to the extent and placement of this bioregion to reflect habitats dominated by mangroves and frequented by dugongs, turtles and, in some locations, crocodiles.

Bioregion 90 remained associated with reefs around the northernmost islands, especially those adjacent to deep waters inhabited by pelagic species such as tuna and marlin. There were no changes suggested to Reef-associated Bioregions 119 (Keamu, encompassing the fringing reefs around Matthew and Hunter Islands).

Bioregion 92 was split into two bioregions around Santo Island, where some areas (especially the west-facing reefs) were absorbed into Bioregion 90, and the rest was split as follows: "Santo East" was designated to start from fromthe Wairua area to the Sarakata river mouth, from Nadui to Tariboi on Malo island, from the Palekula area in southeastern Santo to Port Olry in eastern Santo. These areas are rich in seagrasses that attract foraging turtles, mangroves, extended coral reefs reefs and estuaries. Marine species biodiversity is high and the lagoons and river mouths host trochus, green snails, coconut crabs and lobsters. Mangroves are found from Tangis Island in southern Santo to Matantas village in Big Bay. On the western side of Santo Island, deep water lies close to coast, bringing abundant deep-water and pelagic fishes. Long stretches of black sand beaches that drop off into deep waters are found all along this coast; this was designated as Bioregion 90 during the workshop.

Bioregions 94 and 97 were more clearly defined by the Green Group, which determined that Efate Island should be split into a seaward side (Bioregion 94), exposed to the prevailing southeasterly trade winds, and a leeward side (Bioregion 97).

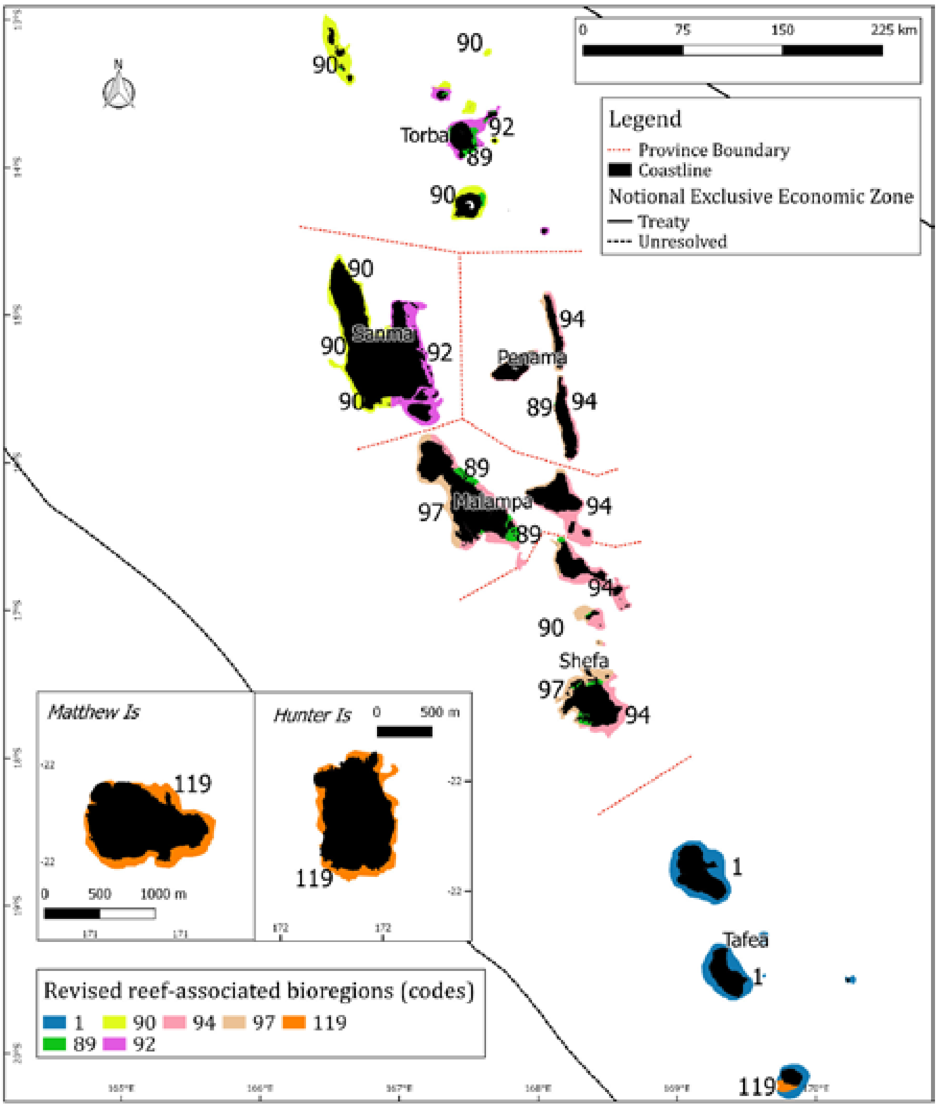

FIGURE 15. Revised reef-associated bioregions of Vanuatu.

6.3.2 Deepwater

Overall, workshop participants suggested changes that resulted in altered positions and boundaries for the deepwater bioregions, and consolidated 25 bioregions into nine.

In the northern region, the Brown Group suggested that Bioregions 125, 333, 207, 106 and 277 were characterized by the group of seamounts located between Ravenga and Mota Lava, and tuna grounds located between Mota and Mota Lava and towards the southeastern part of Mota. Among these, Bioregion 106 was singled out for high tuna and poulet abundance. These bioregions were combined under Bioregion 106.

In the central regions, the Green Group identified several broad areas distinguished by different tuna abundance as indicated by catch rates, which are influenced by biophysical attributes such as temperature, nutrients and upwellings, salinity and currents. In this way, tuna catch was an indicator for both tuna productivity as well as a range of other environmental parameters including productivity overall (Bertignac et al. 1998, Lehodey 2001). Low tuna productivity was identified for the new "Region 6", which encompasses Bioregions 207, 106, 277, 333, 125. Medium tuna productivity occurs in Region 2 (Bioregions 460, 342, 164, 165, 238, 216) and Region 4 (Bioregions 267, 407, 238, 342, 164). All other bioregions were said to have high tuna productivity (Region 1: 243, 82, 106, 462; Region 3: 165, 460, 238, 13, 267, 298 and Region 5: 342, 21, 462, 431, 207). Therefore, these regions (Regions 1-6) were used to reconfigure and combine the existing Bioregions, leading to a smaller number of larger deepwater bioregions in central Vanuatu (Retaining the Bioregion numbers 13, 82, 165 and 216).

Changes were also suggested to the southern region by the Pink Group, including the reduction of the number of bioregions from eight to four whilst maintaining the Futuna Trough as a separate bioregion. The four new bioregions suggested include:

- Bioregion 238, with a change to the boundary from zone 13, where it curves, through a straight line to end above Bioregion 228, and cutting the elongated curve in 238 to merge with 267 and to include all seamounts. The words "submarine volcano" should be added to Bioregion 238's description;
- A combination of Bioregions 298, 267, 24 and 206, (into one coded 298) which share a similar geomorphology;
- Bioregions 415 and 407 (combined and coded 415), with the curve expanded to follow the New Hebrides Trench; and
- A combination of Bioregions 325, 19 and 228 into one coded 325, because these all share similar geomorphology and fish biota.

The resulting four southern deepwater bioregions are 238, 298, 325 and 415.

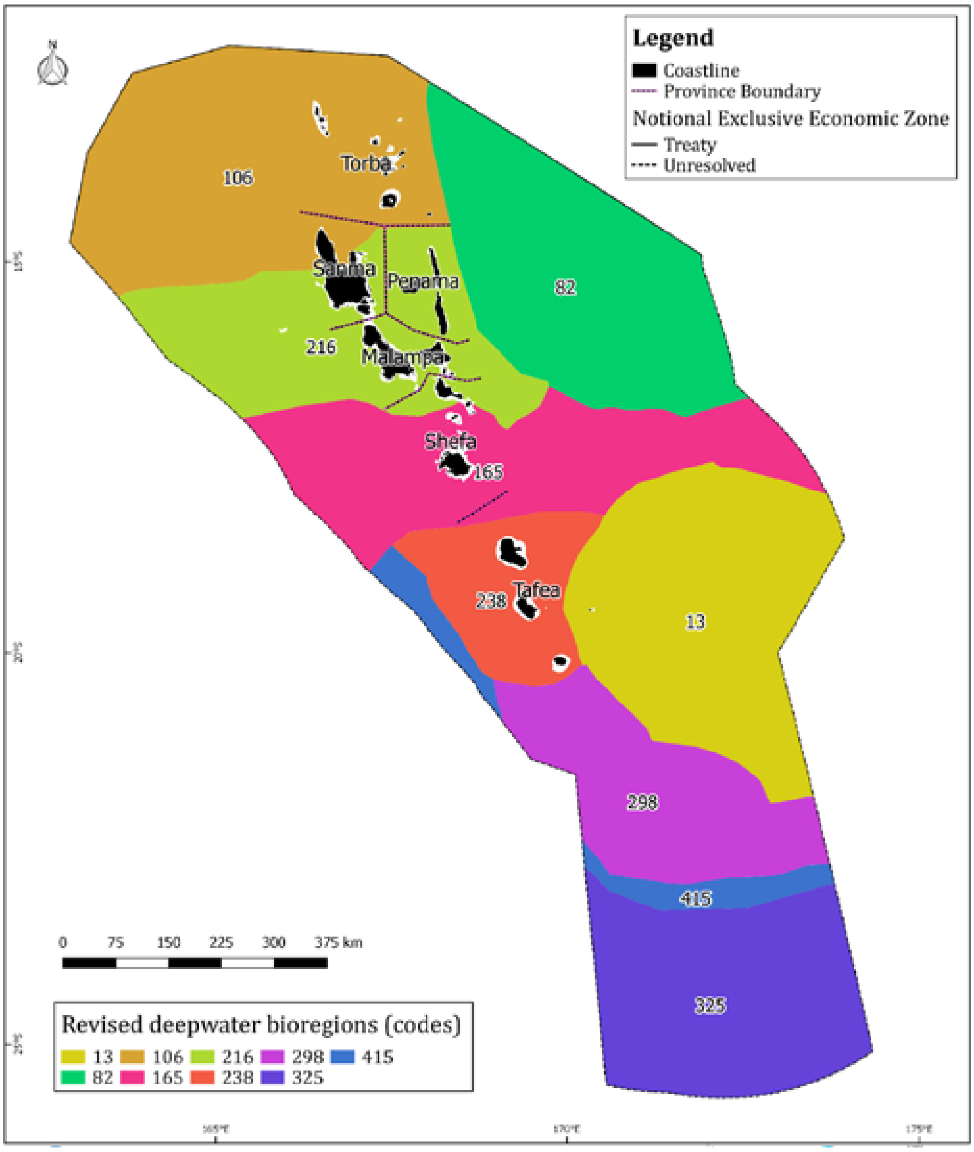

FIGURE 16. Revised deepwater bioregions of Vanuatu.

6.4 CONCLUSIONS

All bioregions were subject to comments and suggested changes during the 2018 workshop, based on the workshop participants' knowledge.

As a result, all the reef-associated bioregions boundaries were changed, even though the original seven bioregions were retained. Bioregion boundaries were changed according to their latitudinal position within the island group, and the major habitats present, driven by influences from land (which resulted in a dominance of mangroves and seagrass beds) or the ocean (which resulted in clear-water drop-offs that also attract pelagic species). 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 all modified, mostly by combining bioregions according to either geophysical similarities or information about pelagic ecology provided by tuna fisheries data. This resulted in a simplification of the bioregions from 25 to nine.

These marine bioregions now form a robust and technically sound framework upon which, together with other data, to base marine spatial planning decisions in Vanuatu[12]. In particular, including adequate examples of every bioregion in the nation's marine protected areas (MPAs) will help ensure achievement of Vanuatu's social, economic, cultural and environmental objectives as well as their national and international commitments.

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

[12] The final bioregion names and/or descriptions for Vanuatu are in Appendix 6, and spatial data for these can be downloaded at: http://macbio-pacific.info/macbio-resources/ under the "Planning" tab or under http://macbio-pacific info/vanuatu.

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9 APPENDICES

9.1 APPENDIX 1 WORKSHOP AGENDA

8.30AM – 4.30PM, WEDNESDAY 14TH MARCH 2018, MELANESIAN HOTEL, CONFERENCE ROOM

WORKSHOP OBJECTIVE: *To provide expert review of draft preliminary descriptions and boundaries of marine biological regions (bioregions) of Vanuatu*

TIME	AGENDA ITEM	LEAD
8:30 – 9:00 9:00 – 9:05 9:05 – 9:15 9:15 – 9:25 9:25 – 9:40 9:40 – 9: 50 9:50 – 10:00	Registration Prayer Opening statement **Agenda item 1: Introductions** Introduction of participants Overview of meeting **Agenda Item 2:** *Objective*: Reviewing Vanuatu's marine spatial planning process **Presentation:** Review of the current process to achieve a national marine spatial plan **Agenda item 3:** *Objective*: Review status of report on Vanuatu's special and unique marine areas (SUMA) **Presentation:** Key outcomes and status or report on the National Marine Prioritization workshop, which identified special, unique marine areas Meeting expectations and questions	 Mrs RolineTekon Mr Toney Tevi Mr Tony Tevi Mr Vatu Molisa Mr Vatu Molisa ALL
10:00-10:30	TEA BREAK	
    10:30 – 10:40 10:40 – 10:50 10:50 – 11:10 11:10 – 11:20	**Agenda item 4:** *Objective*: Introduction of approach used to describe Vanuatu's marine environment and results **Presentations:** 4.1 Introduction to the concept of different marine biological regions(bioregions) for Vanuatu, how a description of the entire marine environment of Vanuatu differs from special, unique marine areas 4.2 Methods and data used to create draft preliminary marine biological regions (bioregions) for Vanuatu 4.3 Introduction of Resources and Seabed geomorphological features found in Vanuatu 4.4. Draft marine bioregions of Vanuatu	 Mr Hans Wendt Ms Marian Gauna Mr Hans Wendt
11:20 – 13:00	**Agenda Item 5:** *Objective*: Review the deep-water and reef-associated marine bioregion boundaries, names and descriptions **Presentation:** Description of group work and breakout into groups Expert review and revision of Vanuatu's deep-water and reef-associated marine biological region boundaries, names and descriptions	 Dr Leanne Fernandes Break-out groups
13:00 – 4:00	LUNCH	
14:00 – 15.15	**Agenda Item 5: continued** Group work	 Break-out groups
15:15 – 15:30	AFTERNOON TEA	
15:30 – 16.30	**Agenda Item 5: continued** Feedback from breakout groups	 Group rapporteurs
16.45 – 17.00	**Agenda Item 6:** Review participants' meeting expectations Next steps	Mr Toney Tevi

9.2 APPENDIX 2 WORKSHOP PARTICIPANTS

GROUP	NAME	ORGANISATION
Malampa and Penama Province (Green)	Douglas Koran	Vanuatu Environmental Science Society (VESS)
	Sharon Boe	Lands Dept& GIS Support
	Peter Joshua	VanuaTai Resource Monitor SE Ambrym
	Noel Kaipapa	VanuaTai Resource Monitor SWB Malekula
	Michael Kearney	WSB
	Kate McPheron	DEPC
Shefa Province (Green)	Mimosa Bethel	DEPC
	John Ronneth	Island Reach
	Francis Hickey	Cultural Centre
	Jason Raubani	SPC
	Donald James	WSB
	Emil Samuel	RESSCUE Project/ Live & Learn
	Hans Wendt	(MACBIO/IUCN) & GIS Support
	Trinison Tari	DEPC
	Ruben Neriam	Aneityum Area Council Secretary
Tafea Province (Pink)	James Norau	VanuaTai Resource Monitor Tanna
	Rolenas Bareleo	DEPC
	SharonBoe	Lands GIS Support
	Toney Tevi	Foreign Affairs
	Ajay Arudere	Fisheries Department
	Joby Csiba	Fisheries Department
	Kalo Pakoa	FisheriesDepartment
	Camillia Garae	Geology & Mines
Sanma and Torba Province (Brown)	Alsen Obed	SANMA provincial Fisheries
	Karae Vurobaravu	GIS Support and OGCIO
	Ionie Bolenga	Foreign Affairs
	Alphonse Jerry	VanuaTai Resource Monitor Vanua Lava
	Lulu vula	VanuaTai Resource Monitor Santo
	Peter Nehapi	Vanuatu Fisheries Department
	Roel Tari	Foreign Affairs
Roaming	Dave Loubser	SPREP

9.3 APPENDIX 3 WORKSHOP PRESENTATION

MACBIO

Describing the entire marine environment of Vanuatu

Wednesday 14th March 2018

SPREP IUCN giz

MACBIO

Opening statement

Mrs Roline Tekon

Acting-Director-General, Ministry of Foreign Affairs, International Cooperation and External Trade and Co-Chair Ocean Policy Implementation Committee

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MACBIO

Agenda Item 1: Meeting Context

Mr Toney Tevi

Director, Ocean and Maritime Affairs, Ministry of Foreign Affairs, International Cooperation and External Trade

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MACBIO

Agenda Item 1

Participant introductions

MACBIO

Agenda Item 1: Meeting overview

a) This meeting and its outputs are part of Vanuatu's broader marine spatial planning process

b) This meeting will provide expert review of draft descriptions and boundaries of marine biological regions (bioregions) of Vanuatu which describe the entire marine environment of the country

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MACBIO

Agenda Item 2: Background

- 2012: Ocean Governance Workshop
- Need for Ocean Policy and Marine Spatial Plan identified then
- Support from MACBIO since 2014
- In August 2016, after many years of work, Vanuatu's Council of Ministers approved the country's first Ocean Policy
- Sets the framework for coordinated management of Vanuatu's ocean across government Ministries
- Supported by extensive national consultations at all levels within and beyond government, private sector, communities

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MACBIO

Vision

Ocean Policy vision: **To conserve and sustain a healthy and wealthy ocean for the people and culture of Vanuatu, today and tomorrow**

Vision to be implemented through the Ocean Policy

MACBIO

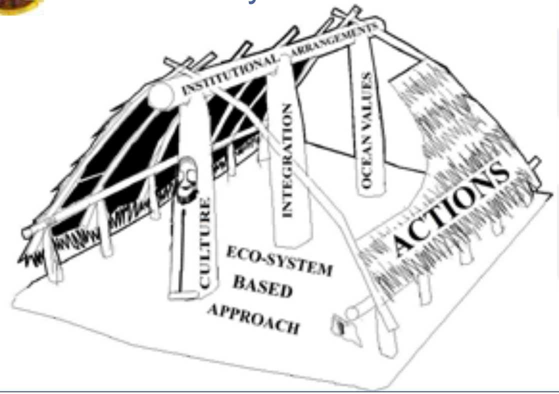
Ocean Policy

Structure of Ocean Policy emulates the traditional Nakamal: house of chiefs/ meeting house

Foundation: ecosystem-based approach
Pillars: culture, integration and ocean values
Beams: institutional arrangements
Roof: actions

Ocean Policy structure

MACBIO



Novel initiative

MACBIO

Novel component of Ocean Policy: **ocean-wide marine spatial planning** (MSP)

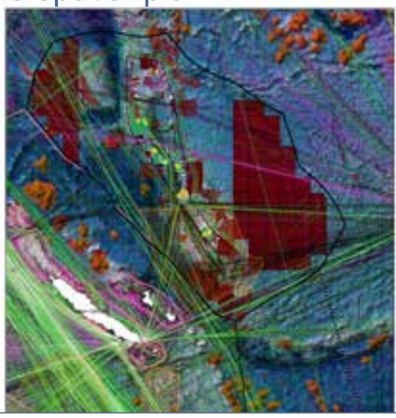
Vision MSP: **By 2020, a healthier ocean for our people and our culture, today and tomorrow**

Objective: By 2020, have, throughout Vanuatu's ocean, spatial zoning that identifies priority areas for development and for conservation, that separates conflicting uses and builds resilience to climate change impacts and disasters

Why a marine spatial plan?

MACBIO

Green lines – cargo vessel traffic
Purple lines – fishing vessel traffic
Red grids – highest tuna catch areas
Yellow areas – Key Biodiversity Areas
Orange areas – seamounts
Irregular reddish-brown shapes – deep sea mining exploration tenements



Marine Spatial Planning

MACBIO

- Marine spatial planning is the most novel part of the OP
- Government has decided that implementing the OP is one of its priorities
- This workshop contributes to marine spatial planning

Marine Protected Areas

MACBIO

Ocean Policy also has an action area for Marine Protected Areas, in which it seeks to establish:

A national network of Marine Protected Areas by 2020

A network of Marine Protected Areas will be part of the Marine Spatial Plan

United Nations Ocean Conference (UNOC)

MACBIO

Vanuatu attended the UNOC in New York in June where the government made internationally know its commitments to a:

-National Oceans Office by 2020
-National Marine Spatial Plan by 2020
-National network of Marine Protected Areas by 2020

Work on MSP to date

MACBIO

Preparatory work (supported by the cross-government Ocean Policy Implementation Sub-Committee, Chaired by Ministry of Foreign Affairs,International Cooperation and External Trade and Ministry of Climate Change Adaptation, Meteorology, Geo-Hazards, Environment and Energy):

1. Draft workplan to 2020 prepared
2. Legislative analysis done
3. Data collated
4. Draft typology prepared (July, 2017)
5. Special, unique marine areas defined (Oct, 2017)
6. Draft biological regions mapped (to be reviewed TODAY)

1. MSP Workplan

MACBIO

• Legal review - done	2015
• Develop draft Ocean mgt objectives – done	2015
• Finalise Ocean Policy - done	2016
• Build consultation/communication plan	mid-2017
• Build draft zone typology	mid - 2017
• Identify biologically special or unique areas	end-2017
• **Develop biophysical description of Vanuatu's ocean**	**early - 2018**
• Design zone placement guidelines	early - 2018
• Public consultation – what kinds of uses/protection where?	2018
• Draft marine spatial plan	late 2018
• Preparation for consultation	late 2018
• National/public consultation on draft spatial plan	2019
• Revise and finalise draft spatial plan	late 2019
• Informal consultation within government/stakeholders	late 2019
• Formal Government Gazette	2020
• Inform public of new Ocean Plan	2020

2. Legal review

Review of legislative support for integrated ocean management and marine spatial planning

- 69 instruments reviewed
- Many were supportive of marine spatial planning
- Several gaps in existing instruments need to be addressed

3. Data

Open source/freely available spatial data collated so far:

- Physical: 64
- Biological: 40
- Uses: 10
- Risks: 4

4. Ocean zone typology

- On 20th July 2017, over 20 government and non-government experts helped to decide what types of ocean zones Vanuatu wants to have in its Marine Spatial Plan
- They describe a range of draft Ocean Zones for application in Vanuatu's Marine Spatial Plan.
- These zones form one of the first, and one of the most important, foundation stones for Vanuatu's proposed Marine Spatial Plan.
- The zones described have the following names and objectives.

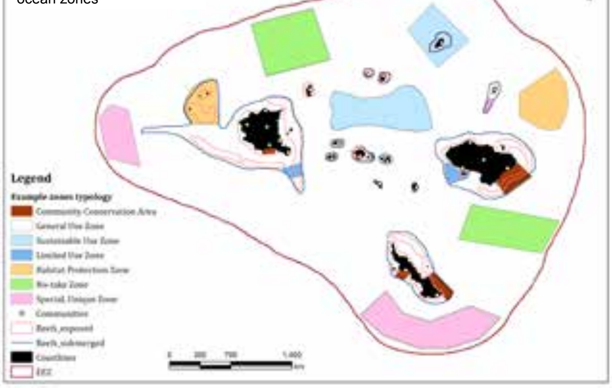
Ocean Zone/Solwota Eria Name	Objective
General Use Zone (GUZ)/ Akses Solwota Eria (ASE)	To allow for and manage multiple uses of Vanuatu's marine environment.
Community Conservation Area (CCA)/ Kastom Manejmen Eria (KME)	To benefit local communities by sustainable marine resource use and biodiversity protection as determined by communities. (NOTE: this "zone" already exists)
Sustainable Use Zone(SUZ)/Garen Solwota Eria (GSE)	To allow for sustainable use of Vanuatu's renewable marine resources including non-artisanal commercial fishing for export.
Limited Use Zone (LUZ)/ Neseri Solwota Eria (NeSE)	To protect local food security, livelihoods and biodiversity by allowing limited fishing, including artisanal fishing, and promoting non-extractive activities.
No-take6 Zone (NTZ)/ Notek Solwota Eria (NoSE)	To protect natural biodiversity along with its underlying ecological structure and supporting environmental processes, and to promote education and recreation by restricting all extractive and damaging uses and activities.
Special Zone (SZ)/ Spesel Solwota Eria (SSE)	To protect, conserve and restore specific species, habitats or cultural values of concern by eliminating the key threats.

4. Purpose of ocean zones

- Ocean zones will be used to separate conflicting uses, promote some uses in some areas, control other uses in other areas and protect some areas
- IMPORTANTLY, communities will be supported to retain all their traditional uses and management practices
- Offshore, ocean zones will prescribe what activities can occur in what locations

	General Use Zone (GUZ)/ Akses Solwota Eria (ASE)	Community Conservation Area (CCA)/ Kastom Manejmen Eria (KME)	Sustainable Use Zone(SUZ)/ Garen Solwota Eria (GSE)	Limited Use Zone (LUZ)/ Neseri Solwota Eria (NeSE)	No-take6 Zone (NTZ)/ Notek Solwota Eria (NoSE)	Special Zone (SZ)/ Spesel Solwota Eria (SSE)
Activities						
Commercial mining including exploration, prospecting (incl sand, gravel, aggregate, deep sea, oil, gas)*	Yes	No	No	No	No	No
Non-commercial sand, gravel and aggregate mining	Yes	tbd per site[4]	No	No		No
Industrial fishing*[1]	Yes	No	Yes	No	No	No
Other non-artisanal fishing* includes take of sea cucumber, trochus, aquarium fish, coral, live rock, reef fish and charter fishing [2]	Yes	tbd per site[4]	Yes	No	No	No
Benthic disturbance (trawling/ dredging, weighted lines)*	Yes	tbd per site[4]	Yes	No	Bl	No
Fish Aggregating Devices (FADs)*	Yes	tbd per site[4]	Yes	No	No	tbd per site[4]
Anchoring (including for cruise ships)	Yes	tbd per site[4]	Yes	No	No	tbd per site[4]
Walking/standing	Yes	tbd per site[4]	Yes	No	No	tbd per site[dz]
Use of traps	Yes	tbd per site[4]	Yes	No	No	tbd per site[4]
Gleaning	Yes	tbd per site[4]	Yes	No	No	tbd per site[4]
Hand spearing	Yes	tbd per site[4]	Yes	No	No	tbd per site[4]
Netting (3 finger mesh, gill, cast, etc)	Yes	tbd per site[4]	Yes	No	No	tbd per site[4]
Hand-line fishing	Yes	tbd per site[4]	Yes	Yes	No	tbd per site[4]
Trolling	Yes	tbd per site[4]	Yes	Yes	No	tbd per site[4]
Non-extractive uses (diving, swimming, snorkelling, kayaking/canoeing, sailing, boating etc) except research	Yes	tbd per site[4]	Yes	Yes	Yes	tbd per site[4]
Ecosystem restoration e.g. coral re-introduction, stock enhancement[8], clams, removal of crown-of-thorns	Yes	tbd per site[4]	Yes	Yes	Yes	Yes
Research*	Yes	tbd per site[4]	Yes	Yes	Yes	Yes
Mariculture[3]	Yes	tbd per site[4]	Yes	No	No	No
Hull maintenance/cleaning	Yes	tbd per site[5]	No	No	No	No
Artificial modification* e.g. beach nourishment, restocking[6], artificial reefs	By licence only	tbd per site[4]	By licence only			
Works* (dredging, reclamation, building, laying of cables)	By licence only	tbd per site[5]	By licence only	No	No	No
Dumping of solid and liquid waste including sewage and ballast water from marine vessels beyond 12nm from shore[7]						

Example of application of ocean zones



5. Biophysically special, unique marine areas

- Workshop held last October
- Agenda Item 3 to discuss this in more detail

1. MSP Workplan

- Legal review - done 2015
- Develop draft Ocean mgt objectives – done 2015
- Finalise Ocean Policy - done 2016
- Build consultation/communication plan mid-2017
- Build draft zone typology mid - 2017
- Identify biologically special or unique areas end-2017
- **Develop biophysical description of Vanuatu's ocean early - 2018**
- Design zone placement guidelines early - 2018
- Public consultation – what kinds of uses/protection where? 2018
- Draft marine spatial plan late 2018
- Preparation for consultation late 2018
- National/public consultation on draft spatial plan 2019
- Revise and finalise draft spatial plan late 2019
- Informal consultation within government/stakeholders late 2019
- Formal Government Gazette 2020
- Inform public of new Ocean Plan 2020

Agenda Item 3
Special, unique marine areas report
Mr Vatu Molisa

Expert workshop held Oct 2017

Aim: To describe special, unique marine areas in Vanuatu for use in national planning, in permit and licencing decisions, in EIAs, etc.

Agenda Item 3: Criteria

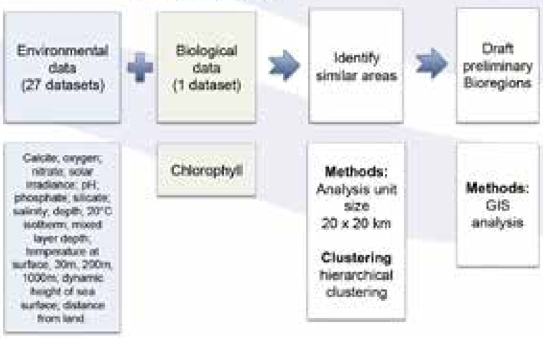
- Justification
- Geographic explicitness
- Type of information source(s)
- Number of information sources
- National or international obligations

- Scoring system: 3 = very good; 2 = good; 1 = minimal
- Assess on a RELATIVE basis

Justification

- Amount, detail and nature of justification
- Consider whether there are:
  - rare, vulnerable or unique habitats or species
  - species of concern
  - important life stages of key species (feeding, breeding, nesting, migration),
  - physically or biologically outstanding attributes e.g. unique geomorphology or high species diversity
  - habitats of high complexity or size
- Score 3 = if more than 5 justifications; 2 = 3-4 justifications; 1 = two or less justifications

Building Deep Water Bioregions



Type of information sources

Type of information sources:
- Are the information source(s) reliable and verifiable?

Score 3 = at least one peer reviewed scientific paper or report discusses this site

2 = no peer reviewed papers are available but there are good reports and expert advice available

1 = mainly anecdotal and inferred information

Number of information sources

Number of information sources
– information is more likely to be correct and can be cross-referenced and triangulated if multiple information sources are used.

Score 3 = if four sources or more

2 = two to three sources

1 = just one source

National/International obligations

Are the areas associated with species or habitats for which the country has:
- national obligations (e.g. under law) &/ or
- international obligations (e.g. under Conventions) or

Score 3 if more than one species/habitat with obligations

2 = one species/habitat; 1 = nil known

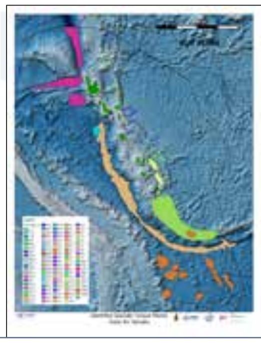
Agenda 3: Results

MACBIO

- 98 inshore special, unique marine areas defined
- 11 Offshore special, unique marine areas defined
- Draft report being prepared

Agenda 3: Results – 98 inshore, 11 offshore SUMAs

MACBIO



Inshore e.g.

TAF4,Mystery Island Aneityum

Offshore e.g

SO1,Futuna Trough

NOTE: much of the VUT ocean is NOT in SUMAs but it still matters!

MSP Workplan

MACBIO

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- Build draft zone typology mid - 2017
- Identify biologically special or unique areas end-2017
- **Develop biophysical description of Vanuatu's ocean early - 2018**
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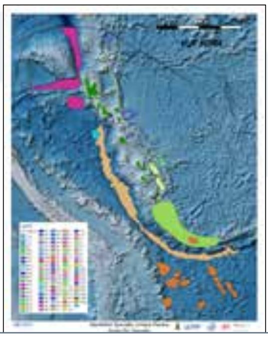
Special Zone (SZ)/ Spesel Solwota Eria (SSE)	To protect, conserve and restore specific species, habitats or cultural values of concern by eliminating the key threats.

98 inshore, 11 offshore Special, Unique Marine Areas

MACBIO



Inshore e.g.

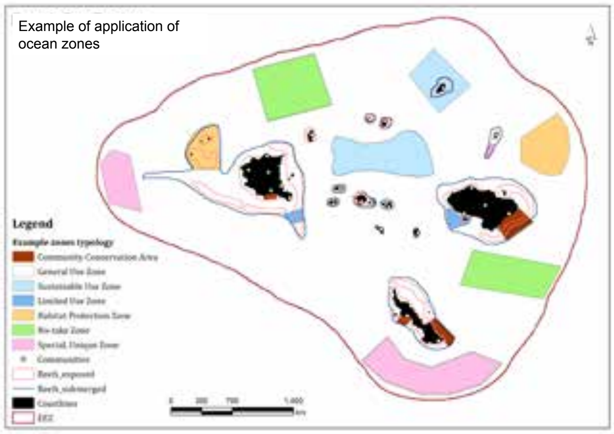
TAF4,Mystery Island Aneityum

Offshore e.g

SO1,Futuna Trough

NOTE: much of the VUT ocean is NOT in SUMAs but it still matters!

Example of application of ocean zones



Meeting Expectations

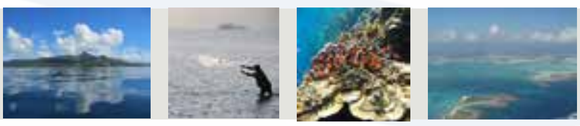
MACBIO

Given this background
– what are everyone's meeting expectations?
- does anyone have any questions?

Then break for morning tea

MACBIO
Marine and Coastal Biodiversity Management in Pacific Island Countries

Agenda item 4.1: Describing Vanuatu's entire marine environment – expert workshop - Hans Wendt



SPREP IUCN giz

What are bioregions and why do we care?

Old paradigm

- Protect areas where we know there is high biodiversity
- Protect areas with endemic species

NOW we know

a) Protecting these areas is important BUT not enough to protect the ecosystems AND
b) We have imperfect information about these anyway

New Paradigm

Ecologically representative network of marine protected areas

- Convention on Biological Diversity (CBD)
- Includes examples of all habitat types

We don't have complete information about biodiversity in the marine environment so how do we choose "ecologically representative" (versus special, unique) areas to protect?

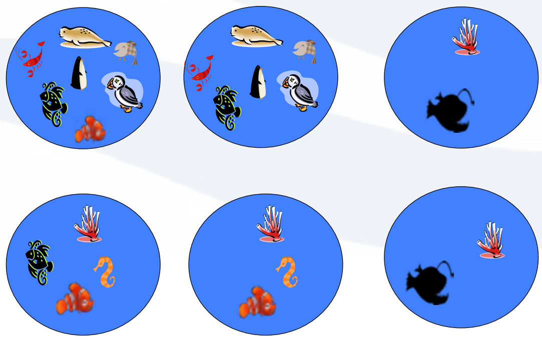
Solution: use bioregions

- It is a value-neutral way to describe the entire marine environment of Vanuatu.
- Bioregions can be described using comprehensive layers of environmental data: surrogates for imperfect biological information.
- Every part of Vanuatu's marine environment belongs to one bioregion or another.
- No bioregion is more important than any other.

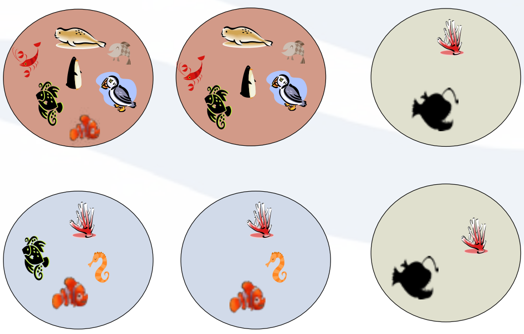
But what are bioregions?

- **Areas of relative similarity**
  - **Habitats, communities, and physical features within a bioregion (e.g. fish, invertebrates, seamounts, coral reefs, water column) are more similar to each other than those same features in a different bioregion.**
- A way to represent the full range of biodiversity
- A classification of habitat and environmental types

Example of Species Assemblages



"Bioregions" with similar (not exactly the same) species

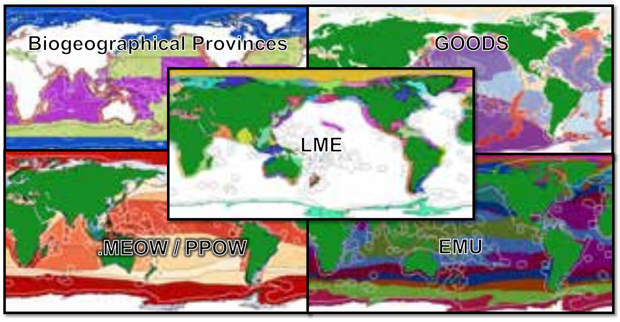


Bioregions as a planning tool

If one objective is an ecologically representative network of marine protected areas covering a minimum percentage (10% or 30%) of the marine environment with the goal of enhancing biodiversity

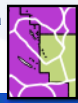
Then a protected area target of this percent for each bioregion will help meet that objective

Existing global bioregions

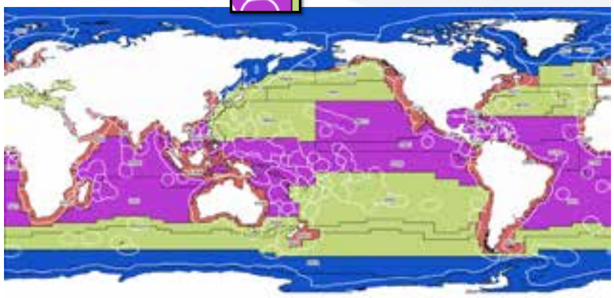


Longhurst, 2010. Biogeographical Provinces

4 global provinces: 3 in Oceania
52 sub-provinces: 9 in Oceania
TWO in Vanuatu



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



6/13/18 MACBIO

Bioregions as a planning tool

- The MACBIO project is working with 5 countries to support Marine Spatial Planning within their EEZs.
- Global-scale bioregions are not useful for national scale marine planning and management.
- Vanuatu needs finer scale descriptions of its entire marine environment

Questions?

MACBIO
Marine and Coastal Biodiversity Management in Pacific Island Countries

Agenda Item 4.2. Methods used to create bioregions for Vanuatu (& SW Pacific)
Hans Wendt

SPREP IUCN giz

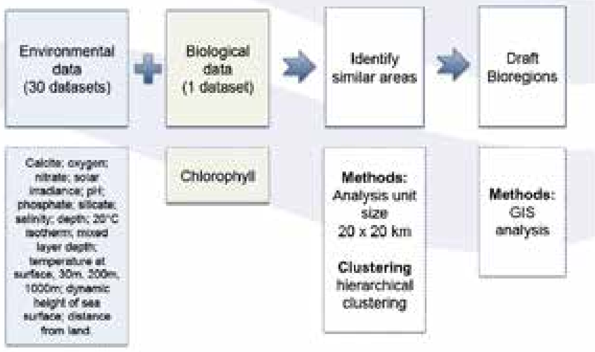
2 Types of Bioregions

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

NOTE: in working across the five MACBIO countries it was realised that building five different sets of bioregions didn't make biological sense: so we built one set of bioregions across the entire SW Pacific

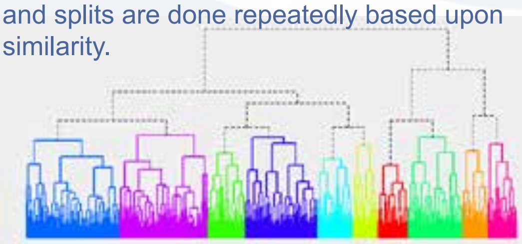
Can then also support OTHER countries doing national MSP

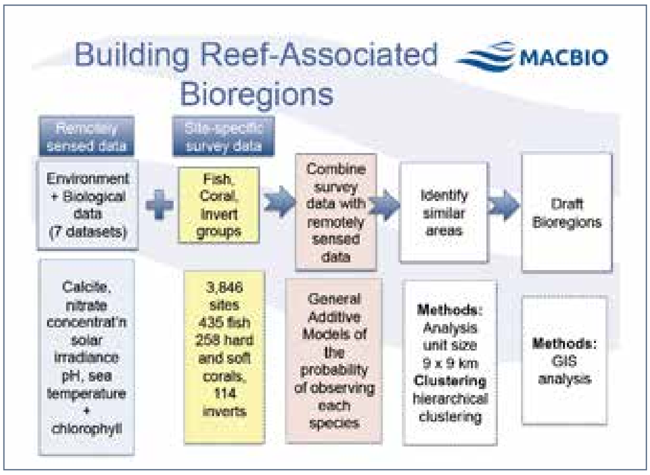
Building deepwater bioregions



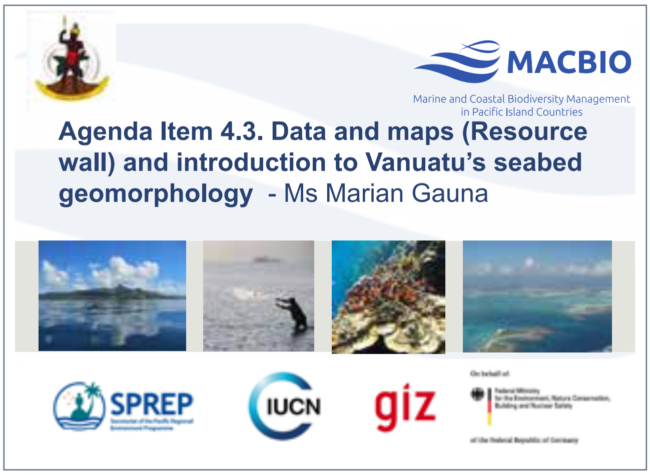
Clustering Algorithm

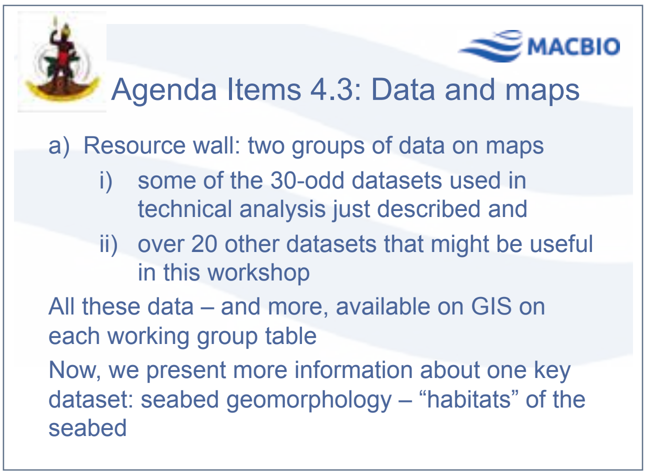
Hierarchical Clustering: a hierarchy of clusters; all observations start in one cluster and splits are done repeatedly based upon similarity.

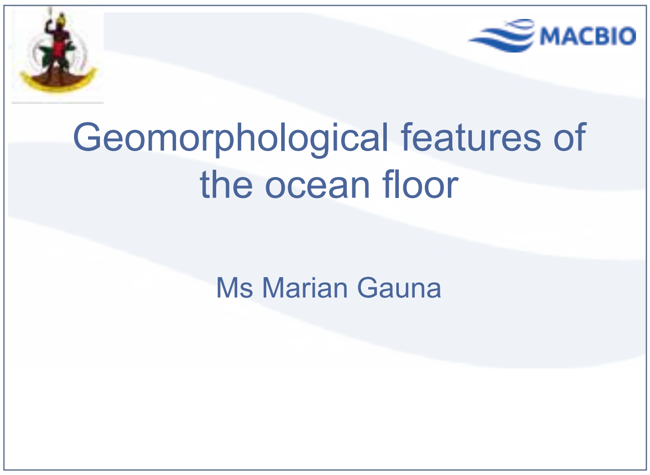


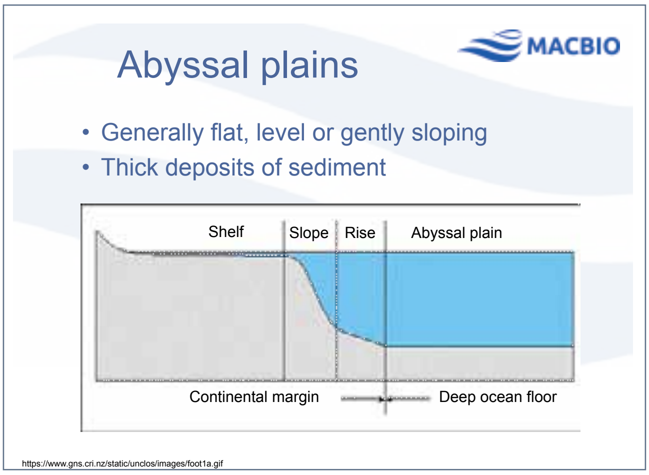

Building Reef-Associated Bioregions
MACBIO
Remotely sensed data
Site-specific survey data
Environment + Biological data (7 datasets)
Fish, Coral, Invert groups
Combine survey data with remotely sensed data
Identify similar areas
Draft Bioregions
Calcite, nitrate concentrat'n solar irradiance pH, sea temperature + chlorophyll
3,846 sites 435 fish 258 hard and soft corals, 114 inverts
General Additive Models of the probability of observing each species
Methods: Analysis unit size 9 x 9 km Clustering hierarchical clustering
Methods: GIS analysis

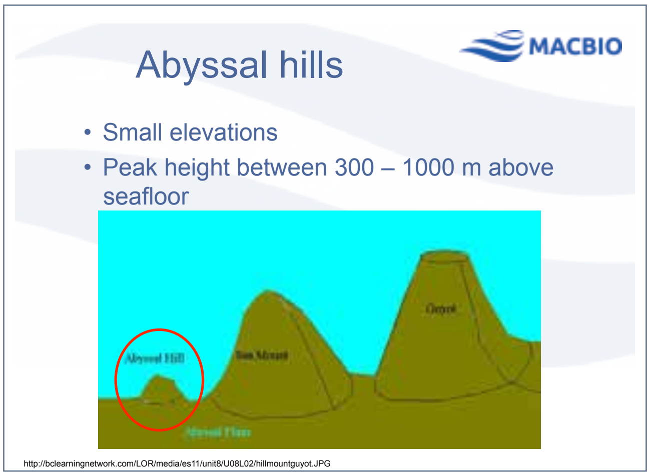

AquaMaps
Convention on Biological Diversity
SPREP
MACBIO
CSIRO
SEA AROUND US
Oregon State
VLIZ
USF
USGS
science for a changing world
WCS
ZSL INSTITUTE OF ZOOLOGY
Pacific Community
Communauté du Pacifique
NASA
WWF
G·R·I·D
NOAA
Data Contributors

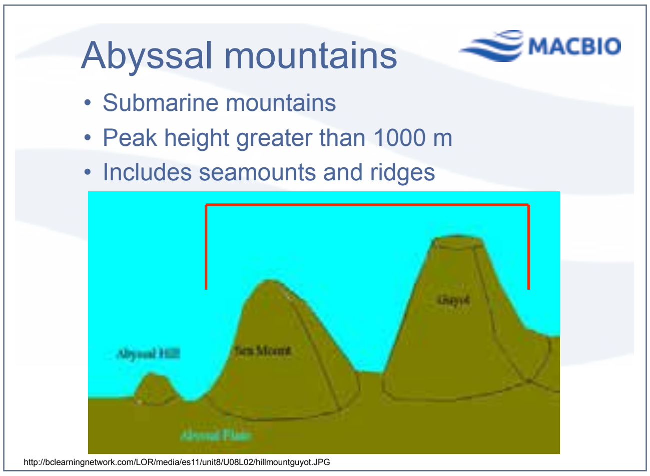

MACBIO
Marine and Coastal Biodiversity Management in Pacific Island Countries
Agenda Item 4.3. Data and maps (Resource wall) and introduction to Vanuatu's seabed geomorphology - Ms Marian Gauna
SPREP
IUCN
giz


MACBIO
Agenda Items 4.3: Data and maps
a) Resource wall: two groups of data on maps
i) some of the 30-odd datasets used in technical analysis just described and
ii) over 20 other datasets that might be useful in this workshop
All these data – and more, available on GIS on each working group table
Now, we present more information about one key dataset: seabed geomorphology – "habitats" of the seabed


MACBIO
Geomorphological features of the ocean floor
Ms Marian Gauna

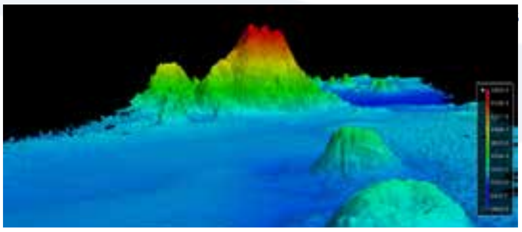

Abyssal plains
MACBIO
• Generally flat, level or gently sloping
• Thick deposits of sediment
Shelf
Slope
Rise
Abyssal plain
Continental margin
Deep ocean floor
https://www.gns.cri.nz/static/unclos/images/foot1a.gif


Abyssal hills
MACBIO
• Small elevations
• Peak height between 300 – 1000 m above seafloor
http://bclearningnetwork.com/LOR/media/es11/unit8/U08L02/hillmountguyot.JPG


Abyssal mountains
MACBIO
• Submarine mountains
• Peak height greater than 1000 m
• Includes seamounts and ridges
http://bclearningnetwork.com/LOR/media/es11/unit8/U08L02/hillmountguyot.JPG

Seamounts

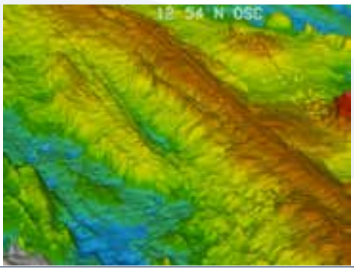
- Large conical shaped mountains
- Peak height greater than 1000 m from seafloor
- Isolated or in groups



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

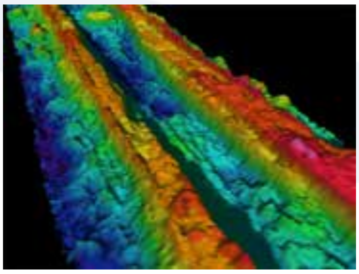
Ridges

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



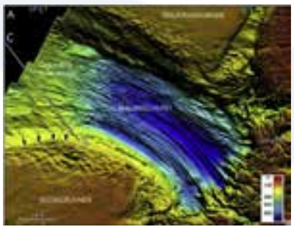
Rift valleys

- Long valleys
- Found between spreading ridges



Troughs

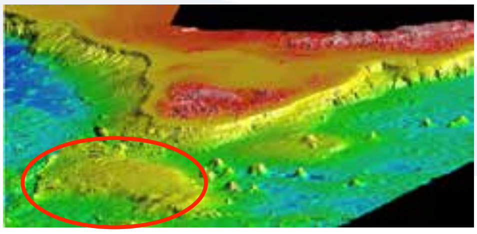
- Large deep areas
- From 100 m to over 1000 m depth



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

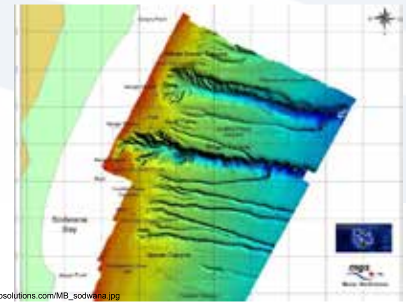
- Mostly flat, large, elevated areas
- Sudden drop off on one or more sides



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

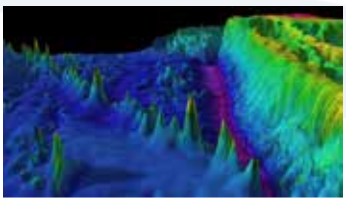
- Steep-walled, winding valleys over 1000 m deep
- Associated with high biomass and biodiversity
- Relatively high productivity



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

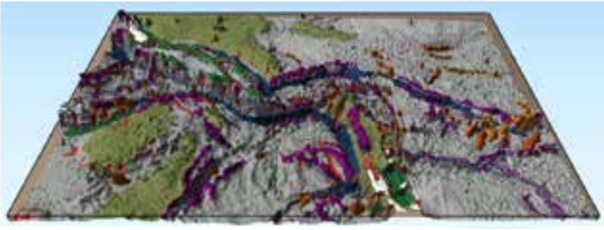
Hydrothermal vents

- 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

3-D Geomorphology

MACBIO



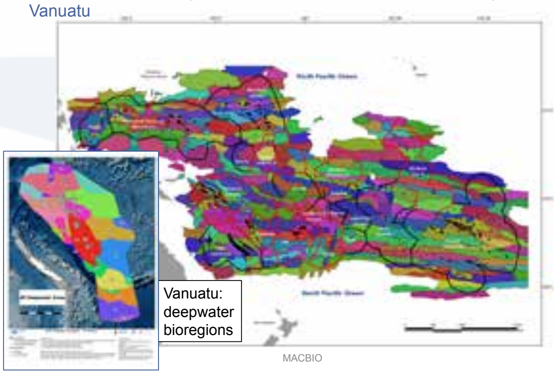
Agenda Item 4.4
Results - draft marine bioregions across the SW Pacific INCLUDING Vanuatu – Hans Wendt

MACBIO

Result: Deepwater Bioregions

MACBIO

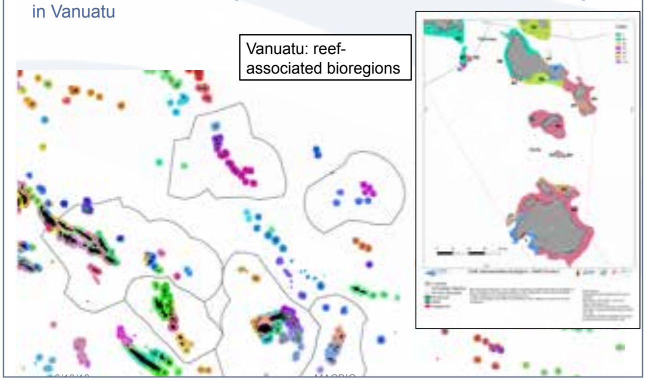
262 Deepwater Bioregions in SW Pacific; **25** Deepwater Bioregions in Vanuatu



Result: Reef-associated (shallow) bioregions

MACBIO

102 reef-associated bioregions in SW Pacific; **7** reef-associated bioregions in Vanuatu



Agenda Item 5

MACBIO

- Three Working Groups
- Allocate yourself to your geographic area of expertise
- If your knowledge is across Vanuatu, ROAM across the working groups
- Each group has a GIS expert, needs a rapporteur and facilitator (from within the group)
- All your notes and markings should be annotated with your "Group Colour"

Agenda Item 5

MACBIO

For each reef-associated and deepwater bioregion consider:

- The bioregion location and boundaries – do any boundaries need to change? Do any bioregions need to be merged or split?
- The bioregion name – provide your own
- The bioregions description – review & add to the deepwater bioregion descriptions; create descriptions for the reef-associated bioregions

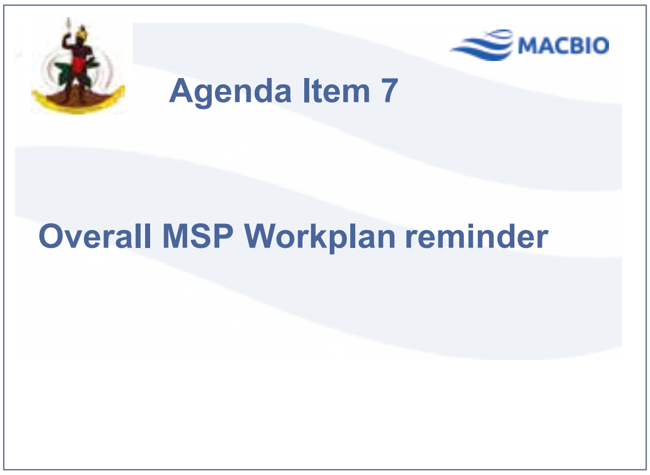
Agenda Item 6: Reflections upon expectations

MACBIO

Agenda Item 7 – Next steps

MACBIO

- Digitise and/or type up information from Bioregions Workshop
- Prepare minutes/notes from these on Bioregions workshop & distribute w map to participants for input
- Provide same to consultant to prepare report
- Distribute draft report back to participants for input


MACBIO
Agenda Item 7
Overall MSP Workplan reminder


MSP Workplan
MACBIO
Legal review - done 2015
Develop draft Ocean mgt objectives – done 2015
Finalise Ocean Policy - done 2016
Build consultation/communication plan - done mid-2017
Build draft zone typology - done mid - 2017
Identify biologically special or unique areas- done end-2017
Develop biophysical description of Vanuatu's ocean early - 2018
Design zone placement guidelines early - 2018
Public consultation – what kinds of uses/protection where? 2018
Draft marine spatial plan late 2018
Preparation for consultation late 2018
National/public consultation on draft spatial plan 2019
Revise and finalise draft spatial plan late 2019
Informal consultation within government/stakeholders late 2019
Formal Government Gazette 2020
Inform public of new Ocean Plan 2020

9.4 APPENDIX 4 WORKSHOP INFORMATION GATHERING

NATIONAL EXPERT WORKSHOP ON THE ESTABLISHMENT OF BIOLOGICAL REGIONS TO DESCRIBE VANUATU'S MARINE ENVIRONMENT

EXPERT INPUT FORM

GROUP: ____

Bioregion number: ____

Are there annotations on a hardcopy map associated with this input form? YES / NO

PLEASE CODE THE ASSOCIATED MAP WITH YOUR GROUP COLOUR

Suggestions (on bioregion location, name, boundary, descriptions)

____

____

____

____

____

____

____

9.5 APPENDIX 5 DATA AND MAPS AVAILABLE TO WORKSHOP PARTICIPANTS

LIST OF MAPS AVAILABLE FOR FEEDBACK AND ON THE RESOURCE WALL, E-COPY MAPS AND GIS DATA FOR VANUATU MARINE BIOREGIONS WORKSHOP 14.03.18

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 how species are distributed in the ocean.

DRAFT BIOREGIONS MAP USED FOR FEEDBACK

1. DRAFT REEF-ASSOCIATED BIOREGIONS MAPS

Malampa province

Matthew and Hunter

Penama province

Sanma province

Shefa province

Tafea province

Torba province

2. DRAFT DEEPWATER BIOREGIONS MAPS SCALE

All Sections – EEZ wide

Central Offshore Section

Northern Offshore Section

Southern Offshore Section

RESOURCE WALLS (HARDCOPY MAPS POSTED ON THE WALLS)

1. Vanuatu Overview Map
2. Vanuatu bathymetry (depth)
3. Vanuatu silicate concentration
4. Vanuatu sea surface temperature
5. Vanuatu chlorophyll a concentration
6. Vanuatu mixed layer depth
7. Vanuatu nitrate concentration in the ocean
8. Vanuatu dissolved oxygen
9. Vanuatu photosynthetically available radiation
10. Vanuatu phosphate concentration
11. Vanuatu marine species richness all species from aquamaps
12. Vanuatu benthic marine species richness from aquamaps
13. Vanuatu pelagic marine species richness from aquamaps
14. Vanuatu cold water corals
15. Vanuatu coral species richness
16. Vanuatu currents
17. Vanuatu cyclone tracks
18. Vanuatu upwelling
19. Vanuatu downwelling diffuse attenuation coefficient
20. Vanuatu downwelling eddy frequency
21. Vanuatu ecologically and biologically significant areas (EBSA)
22. Vanuatu important bird areas (IBAs)
23. Vanuatu front count
24. Vanuatu geomorphology
25. Vanuatu hydrothermal vents
26. Vanuatu mangroves, reefs
27. Vanuatu particulate organic carbon flux
28. Vanuatu reefs at risk
29. Vanuatu seamounts and seamount morphology classification
30. Vanuatu historic tsunami location
31. Vanuatu ocean productivity
32. Vanuatu Seamounts pelagic classification
33. Vanuatu depth classification GEBCO

DATA AVAILABLE TO PARTICIPANTS IN GIS

All of the hardcopy maps listed above were also available on the GIS. In addition, the following data were available on Q-GIS

1. BASE LAYERS

a. Vanuatu Provisional EEZ
b. Vanuatu Coastlines
c. Bathymetry data
d. Underwater feature names

2. ENVIRONMENTAL VARIABLES

a. Temperature at 1000 meters depth
b. Temperature at 200 meters depth
c. Temperature at 30 meters depth
d. Depth of 20 degree isotherm
e. Salinity
f. pH
g. Calcite

3. BIOPHYSICAL DATA

a. Mangroves, reefs and seagrasses

b. Geomorphological features

i. Escarpment
ii. Basin
iii. Bridge
iv. Guyot
v. Seamount
vi. Rift valley
vii. Trough
viii. Ridge
ix. Spreading ridge
x. Terrace
xi. Trench
xii. Plateau
xiii. Slope
xiv. Hadal
xv. Shelf classification (high, medium, low)
xvi. Abyssal classification (mountain, hill, plain)

9.6 APPENDIX 6 DESCRIPTION OF REVISED BIOREGIONS OF VANUATU

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

HABITAT	CODE	VANUATU NAME	SUMMARY DESCRIPTION
Deepwater	13	Vanuatu Plateau and Basins	Bioregion dominated by plateau and basins with spreading ridges and rift valleys. Southern end of bioregion consists of one seamount. Area includes large abyssal hills, large plateau towards the east and isolated pockets of seamounts, spreading ridges. Sea surface temperature very unstable, low. Chlorophyll-a concentrations are high with a large bloom in the northwestern corner, extending into bioregion 165. Salinity and dissolved oxygen are high. Temperature at 200m is low. Deepwater temperatures are high. MLD (Mixed Layer Depth) quite low in northwestern part. Silicate and phosphorous levels are high. Contains 2 seamounts type 1 (small with deep peak, short with moderately deep peak); 4 seamounts type 4 (small with deep peak, most isolated type); 3 seamounts type 5 (intermediate size, small, moderately tall and shallowest peak depths of this group); 1 seamount type 7 (small and short with very deep peaks, shortest); contains 11 blind canyon types. Contains 4 active, confirmed and 10 active, inferred hydrothermal vents. The upper depth is 2,000m and the lower depth is 3,500m.
	82	Penama Torba East	Contains trough and abyssal features. Also includes spreading ridge and ridge with escarpments. Sea surface temperature moderate, mildly variable. Chlorophyll-a concentrations are low, with scattered blooms around Maewo Island. Mid-depth temperatures very high while temperature at 1,000m is low. 20 degree isotherm is exceptionally shallow. Silicate and phosphorous levels are high. pH is high. Contains 1 seamount type 1 (small with deep peak, short with moderately deep peak); 1 seamount type 3 (intermediate size, large tall and deep); 3 seamounts type 5 (intermediate size, small, moderately tall and shallowest peak depths of this group); 1 seamount type 7 (small and short with very deep peaks, shortest); 2 seamounts type 10 (large and tall with shallow peak: shallow); includes 10 blind canyon types and 1 shelf incising canyon type. Contains 3 active, inferred and 1 inactive, hydrothermal vents. The upper depth is 2,500m and the lower depth is 3,500m.
	106	Torba Rise	Contains plateaus, ridges and canyons and the north Vanuatu (New Hebrides) Trench. Other features include trough, escarpment and basin. Sea surface temperature is stable and relatively high for Vanuatu. Chlorophyll-a concentrations are moderate, stable. Salinity and dissolved oxygen are low but higher in the east of the region. Mid-depth temperatures are very high while temperature at 1,000m is low. 20 degree isotherm is exceptionally shallow. Solar irradiance is quite high. Contains no seamounts. Includes 20 blind canyon types and 11 shelf incising canyon types. The upper depth is 500m and the lower depth is 3,500m. Contains underwater topographic features that allow for high catches of tuna, poulet, snapper, and other deep-sea fish, particularly between Ravenga and Mota Lava, and Mota and Mota Lava. Frequent whale sightings north of Vanua Lava. Rich fishing grounds for tuna, marlin, sailfish, and other pelagic fishes, particularly off the northwestern coast of Santo, and extending off its tip of Cape Cumberland.
	165	Shefa Central	Contains 1 intermediate and 2 small seamounts, formed on spreading ridges and basins. Rift valleys also form the base of the seamounts, with plateau also featured. Sea surface temperature is moderate, variable. Chlorophyll-a concentrations are high with a large bloom in the western region. MLD quite low in the southwestern part. Silicate, pH, and phosphorous levels are high. Contains 2 seamounts type 1 (small with deep peak, short with moderately deep peak); 1 seamount type 2 (small with deep peak, most common type); 8 seamounts type 5 (intermediate size, small, moderately tall and shallowest peak depths of this group); includes 24 blind canyon types and 9 shelf incising canyon types. Contains 2 active, confirmed; 5 active, inferred hydrothermal vents. The upper depth is 500m and the lower depth is 3,000m.

Deepwater	216	Malampa, Penama, Sanma Central Eastern	Mostly deep abyssal hills and mountains with overlying basins, and cuts across few seamounts, ridges and trench. Sea surface temperature is moderate, variable. Chlorophyll-a concentrations are high to moderate, variable. Salinity and dissolved oxygen are low. Temperature at 200m is low. Solar irradiance is quite high in the north. Contains 1 seamount type 2 (small with deep peak, most common type); 3 seamounts type 11 (intermediate size, largest basal area and deepest peak depth). Includes 2 blind canyon types and 3 shelf incising canyon types. The upper depth is 3,500m and the lower depth is 5,000m. Rich poulet fishing grounds near the southwestern coast of Santo.
	238	Tafea Central Eastern	Shallow region on Vanuatu plateau and ridges with canyons featured comprehensively. Also includes a trough in the east and seamounts in the western part. Sea surface temperature reduces significantly moving south, relatively stable. Chlorophyll-a concentrations are high, variable, with very high concentrations around the islands. Calcite concentration is high in this area as well. Salinity and dissolved oxygen are high, lower in the north. Deepwater temperatures are high. MLD is low. Solar irradiance is low, especially around islands. Contains 2 seamounts type 5 (intermediate size, small, moderately tall and shallowest peak depths of this group); 1 seamount type 9 (Large and tall with shallow peak, larger); 1 seamount type 11 (intermediate size, largest basal area and deepest peak depth). Includes 31 blind canyon types and 4 shelf incising canyon types. Contains 2 active, confirmed; 1 active, inferred hydrothermal vents. The upper depth is 500m and the lower depth is 3,000m. This area is rich in pelagic (tuna) and deep-water species, particularly near and around Aneityum due to a “warm pool” of water associated with underwater volcanoes.
	298	Matthew and Hunter	Contains trough and plateau with rift valleys forming on spreading ridges and basins. Western side of bioregion contain part of the Vanuatu (New Hebrides) Trench and ridges. Sea surface temperature is low and stable, Chlorophyll-a concentrations 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. Contains 1 seamount type 1 (small with deep peak, short with moderately deep peak); 1 seamount type 5 (intermediate size, small, moderately tall and shallowest peak depths of this group); 2 seamounts type 10 (large and tall with shallow peak: shallow); 3 seamounts type 11 (intermediate size, largest basal area and deepest peak depth). Includes 9 blind canyon types. Contain 1 active, inferred hydrothermal vent. The upper depth is 2,000m and the lower depth is 4,000m.
	325	South of New Hebrides Trench	Includes part of the Vanuatu (New Hebrides) Trench, few seamounts, spreading ridges and rift valleys and deep abyssal features. Sea surface temperature is low and stable, chlorophyll-a concentrations low and variable, salinity is moderate and variable, dissolved oxygen is low and variable, deepwater temperature is moderate, 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. Contains 2 seamounts type 1 (small with deep peak, short with moderately deep peak); 2 seamounts type 2 (small with deep peak, most common type); 1 seamount type 7 (small and short with very deep peaks, shortest); 1 seamount type 10 (large and tall with shallow peak: shallow); 4 seamounts type 11 (intermediate size, largest basal area and deepest peak depth). Includes 1 blind canyon type. The upper depth is 4,000m and the lower depth is 4,500m.
	415	New Hebrides Trench	Contains deep trench, ridge, abyssal hills and abyssal mountains. Sea surface temperature is low and stable; chlorophyll-a concentrations, 20°C isotherm and the deepwater temperature are moderate. Salinity and pH levels are high. Nitrate and solar irradiance are moderate to low. Mixed layer depth and calcite are moderate and variable. Dissolved oxygen concentrations are moderate and stable. Strong sea surface currents generally from the northwest. Contain no seamounts. The upper depth is 5,500m and the lower depth is 6,500m.

Reef-associated	1	Tafea	This bioregion covers the Tafea Province reef-associated areas with the exception of Aneityum. Pelagic fishes likely to be found within this bioregion include tuna-like species and deep bottom fish. Reef fishes include parrotfishes, surgeonfishes, mullet, mangru (scat fish), giant trevally and rabbitfishes. Invertebrates include green snail, Trochus, giant clams, lobsters, turtles. Cephalopods include octopus and squids.
	89	Lagoon and mangrove influenced	This bioregion includes mangroves, including in coastal lagoons, and estuaries both with a leeward and windward aspect. This bioregion has been identified as nesting ground for turtles. There are coastal lagoons (mangroves) and estuaries with seagrass, shellfish, crab, fishes and grazers. Particular lagoons and mangrove areas identified on Efate were: Eratap mangroves and lagoons, Erakor 1st and 2nd Lagoon, Undine Bay, Moso, Paunganisu and areas of North Efate that have mangroves. Malekula was also identified for its mangroves and lagoons, with areas of particular interest including Port Stanley, Bushmans Bay, Crab Bay, down the south east coast to Port Sandwich, Maskyenes area to South West Bay. This ecosystem is expected to be rich in fish, shellfish and crabs.
	90	Santo West and Torba Cluster	This bioregion refers to the western side of Santo Island; there is deep water close to the coast, and as a result benthic and pelagic fishing grounds are close to the coast. Rocky coastline, cliffs, boulder bank areas and long stretches of black sand beaches that drop off into deep are found all along the coast. Coral reefs are mainly fringing, and not as extensive as on the eastern side of Santo, similarly seagrass areas are very sparse. This is similar for most islands of the Torba Province, with rocky coastlines and fringing reefs. Some barrier reefs are found off some isand cliffs and boulder bank areas. On the larger Torba Islands, such as Gaua, stretches of black sand and white sand beaches are found. The main indicator species are Trochus, coconut crabs and manta rays.
	92	Santo East and Torba Cluster	This bioregion occurs on the eastern side of Santo from Wairua to the Sarakata river mouth to Saint Michel, from Nadui to Tariboi, from Palekula to Port Orly. There are seagrass beds, mangroves, turtle feeding areas, extended reefs and river mouth estuaries. Rich in reef habitats and species biodiversity, Trochus, green snail, coconut crab and lobsters. Mangroves are also found from Tangis island to Matantas. The Torba part of this bioregion's diversity includes mangroves, coral reefs, seagrass, turtles, crocodiles, endemic species of fish that have aquatic and marine life cycles, and seamounts rich in red snappers.
	94	Vanuatu Central seaward	Massive corals on the seaward side, good coral reefs, parrotfishes, unicornfishes, "strong skin fish" (sand paper fish), squid, green snail, Trochus, natural barrier to fishing activities on exposed (windward) side. Shepherd Islands: Strong tides from southeast trade winds, tuna and poulet fishing around area. Malampa: Ambrym: Sandy beaches found on the southwestern side of the island. Lalinda to Port Vato to Matnarara to Tabiak: Black beaches, most significant leatherback turtle nesting areas in Vanuatu. Penama: Maewo: There are natural barriers to fishing, particularly on the windward side of the island, which faces the strong southeasterly, it makes the sea quite rough most times of the year. Coral reefs surround the island with a few stands of mangroves on the windward side.
	97	Vanuatu Central Leeward	Seaward / windward differs from the leeward side; this applies to all islands in this central group. On Efate on the leeward side (from the south to the west), the majority of lagoons, bays, inslets and islands can be found, with barrier and fringing reefs. These physical feature attributes extend to some extent to the other islands located in the central region. Similar biophysical characteristics apply to Epi and Ambrym. Malekula Island is an exception in having a lagoon, offshore islands, bays and inslets on both sides of the island. However, Malekula's leeward side has extensive beaches fringing and barrier reefs. Sea conditions are somewhat similar to the western side of Santo. However, Malekua has different topography from Santo Island, whereby the mountain range on Santo also influences bathymetry and ocean characteristics.
	119	Keamu	This bioregion has abundant pelagic fishes (e.g. tuna) and deep bottom fish. Reef fishes include parrotfishes, surgeonfishes, mullet, mangru (scat fish), giant trevally and rabbitfishes. This bioregion includes the Mystery Island Marine Protected Area, and the southwestern coast of Aneityum, where most of Anetyum's prominent bays and barrier reefs are found.

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