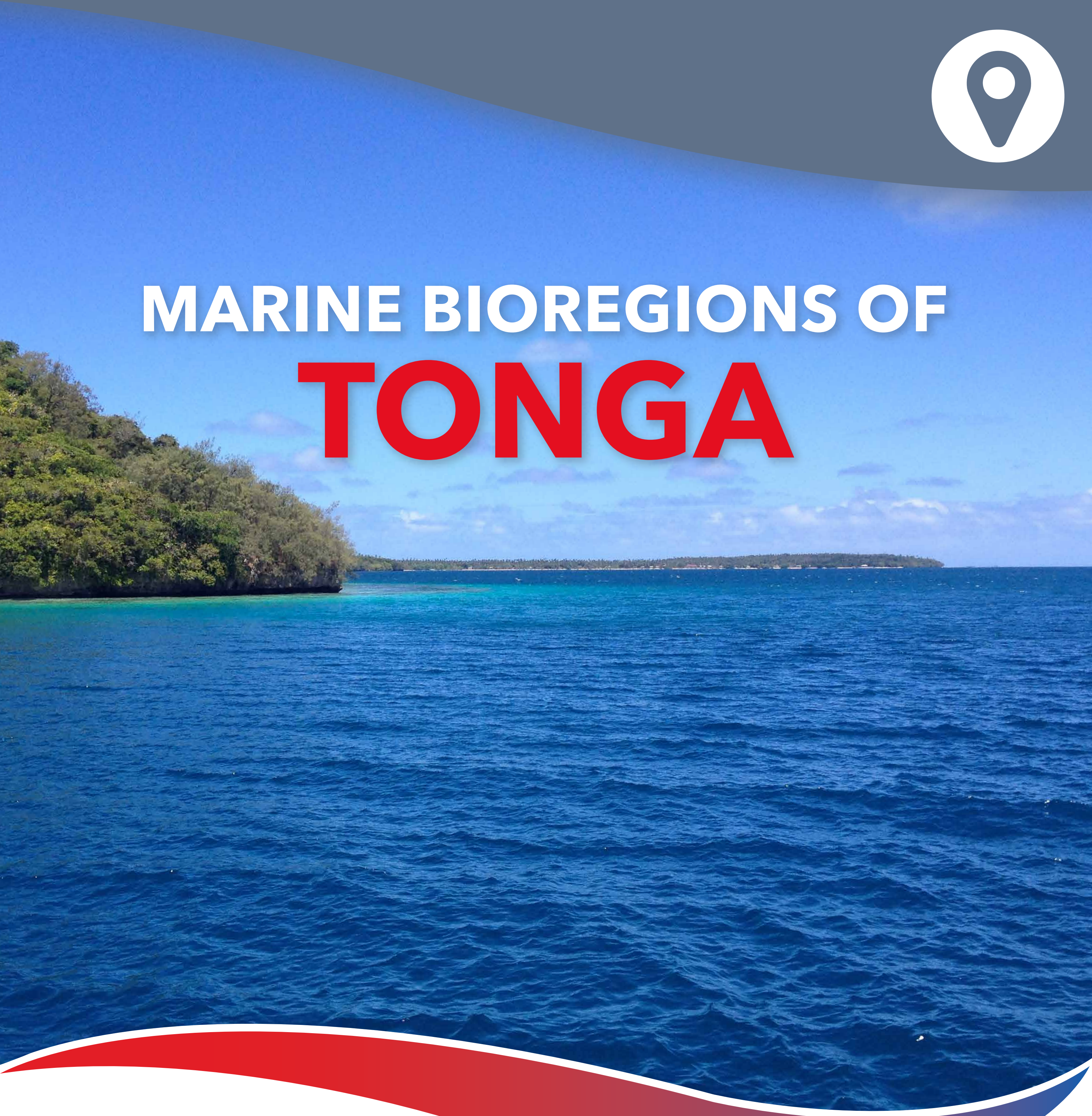
MARINE BIOREGIONS OF TONGA



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 Tonga. 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

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On behalf of:
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Marine and Coastal Biodiversity Management in Pacific Island Countries

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EXECUTIVE SUMMARY

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

However, means for countries 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 Tonga in particular, at a scale that can be used nationally, as a basis for the systematic identification of an ecologically representative system of marine protected areas.

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

To take account of differing types and resolution of data, two separate bioregionalisations were developed; firstly, for the deepwater environments and secondly for reef-associated environments. For the deepwater, thirty, mainly physical, environmental variables were assessed to be adequately comprehensive and reliable to be included in the analysis. These data were allocated to over 140 000 grid cells of 20x20 km across the Southwest Pacific. K-means and then hierarchical cluster analyses were then conducted to identify groups of analytical units that contained similar environmental conditions. The number of clusters was determined by examining the dendrogram and 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 6500 sites. We combined these datasets, which were quality-checked for taxonomic consistency and normalised, resulting in more than 800 species that could be used in further analysis. All these species data and seven independent environmental datasets were then allocated to over 45 000 grid cells of 9x9 km across the SW Pacific. Next, the probability of observing these species was predicted, using the environmental variables, for grid cells within the unsurveyed reef-associated habitats. Hierarchical cluster analysis was then applied to the reef-associated datasets to deliver clusters of grid cells with high similarity.

The final analytical steps, applied to all the outputs, were to refine the resulting clusters using manual spatial processing and to describe each cluster to deliver the draft bioregions. This work resulted in 262 draft deepwater marine bioregions and 102 draft reef-associated bioregions across the SW Pacific and 33 deepwater and four reef-assocated bioregions for Tonga.

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 Tonga 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 21 deepwater and four reef-associated marine bioregions being finalised for use in national planning in Tonga.

By ensuring that each bioregion is represented adequately within Tonga's network of Marine Protected Areas (MPAs, which will be part of Tonga's Marine Spatial Plan), Tonga will fulfil its commitments to a network that is ecologically representative. This will enable these MPAs. In turn, to deliver on Tonga's social, economic and cultural aspirations for her ocean.

1 INTRODUCTION

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

Pacific Island countries who are signatory to the CBD have committed to an ecologically representative system of Marine Protected Areas (MPAs) (see box below)[2]. In addition, several leaders from the region have made commitments to better protect large parts or all of their EEZs. Many of these commitments were declared internationally and are being implemented nationally. For example, Tonga, Fiji and Micronesian countries who have signed onto the Micronesia Challenge[3] have committed to protect 30% of their marine environment in marine protected areas.

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

Kiribati and the Cook Islands have already put in place significant measures to protect their marine environment, creating the Phoenix Islands Protected Area and the Marae Moana Marine Park respectively[4]. Many are also committed to integrating their national networks of MPAs into wider seascapes through national Marine Spatial Plans (e.g. Vanuatu, Tonga and the Solomon Islands[5]).

There are a number of initiatives from international, regional, national and local organisations that are assisting Pacific Island countries in achieving their national goals in marine and coastal resource management (e.g. see projects being run by the Secretariat of the Pacific Regional Environment Program, the Pacific Community, the Forum Fisheries Agency, the Office of the Pacific Ocean Commissioner, the International Union for the Conservation of Nature – Oceania Regional Office, the CBD Secretariat[6]). Many Civil Society Organisations and Non-Government Organisations are also well established in the region and have, over the years, supported Pacific Island Countries in the management and protection of their environment both at the local community scale and at national and regional levels (e.g. see projects by the Wildlife Conservation Society, the Locally Managed Marine Area Network, WWF-Pacific, the Coral Triangle, Conservation International[7]).

However, for those countries where marine planning is underway to achieve Aichi targets, there is a lack of an effective way to systematically represent biodiversity. None of the previous work has provided an ocean-wide description of the marine environment at the scales needed for national marine spatial planning, and decisions about locations of ecologically representative MPAs within and across countries.

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, Building and Nuclear Safety (BMUB) through its International Climate Initiative (IKI). The Project is helping the countries to improve management of marine and coastal

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

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

3 https://themicronesiachallenge.blogspot.com.au/p/about.html

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

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

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

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

biodiversity at the national level including to meet their commitments under the CBD Strategic Plan for Biodiversity 2011–2020 such as relevant Aichi Biodiversity Targets. MACBIO is implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) with the countries of Fiji, Kiribati, Solomon Islands, Tonga and Vanuatu. It has technical support from the Oceania Regional Office of the International Union for the Conservation of Nature (IUCN-ORO) and is working closely with the South 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 managing MPAs, including payments for environmental services, are demonstrated at selected sites.

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

The MACBIO project has built draft marine bioregions across the Southwest Pacific for use by Pacific Island countries, including Tonga, in their national marine spatial and marine protected area planning processes. By ensuring that each bioregion is represented adequately within Tonga's network of Marine Protected Areas (MPAs, which will be part of Tonga's Marine Spatial Plan), Tonga will fulfil its commitments to a network that is ecologically representative. This will enable these MPAs. In turn, to deliver on Tonga's social, economic and cultural aspirations for her ocean.

1.1 AIMS OF THE BIOREGIONALISATION

Our marine bioregionalisation aims to support national planning efforts in the Pacific. This report describes the technical methods used by the MACBIO project to classify the entire marine environment within the MACBIO participating countries to inform, in particular, their national marine spatial and marine protected area planning efforts. The draft outputs are marine bioregions that include reef-associated and deepwater biodiversity assemblages with complete spatial coverage at a scale useful for national planning. Results for Tonga have been presented to the marine experts and government of Tonga for review. The resulting Tongan marine bioregions will provide a biological and environmental basis for the nation's MSP process. Specifically, it allows for the identification of candidate sites for a 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[8]. This includes at least 130 Pacific-specific targets. In order to achieve these targets, many nations are currently in the process of zoning their marine and coastal areas for better management and greater protection. The placement and effective designation of sites as MPAs within each country requires the full representation of marine biodiversity in conservation and management areas, whilst considering socio-economic and cultural needs.

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

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

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).

8 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 in the carbon, nitrogen and phosphorus (C/N/P) ratio (Martiny et al. 2013), and this corresponds to using the N/P ratio (or C/N/P ratio) as a surrogate for plankton diversity. Similarly, harmful algal bloom 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 var CHLa), 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.

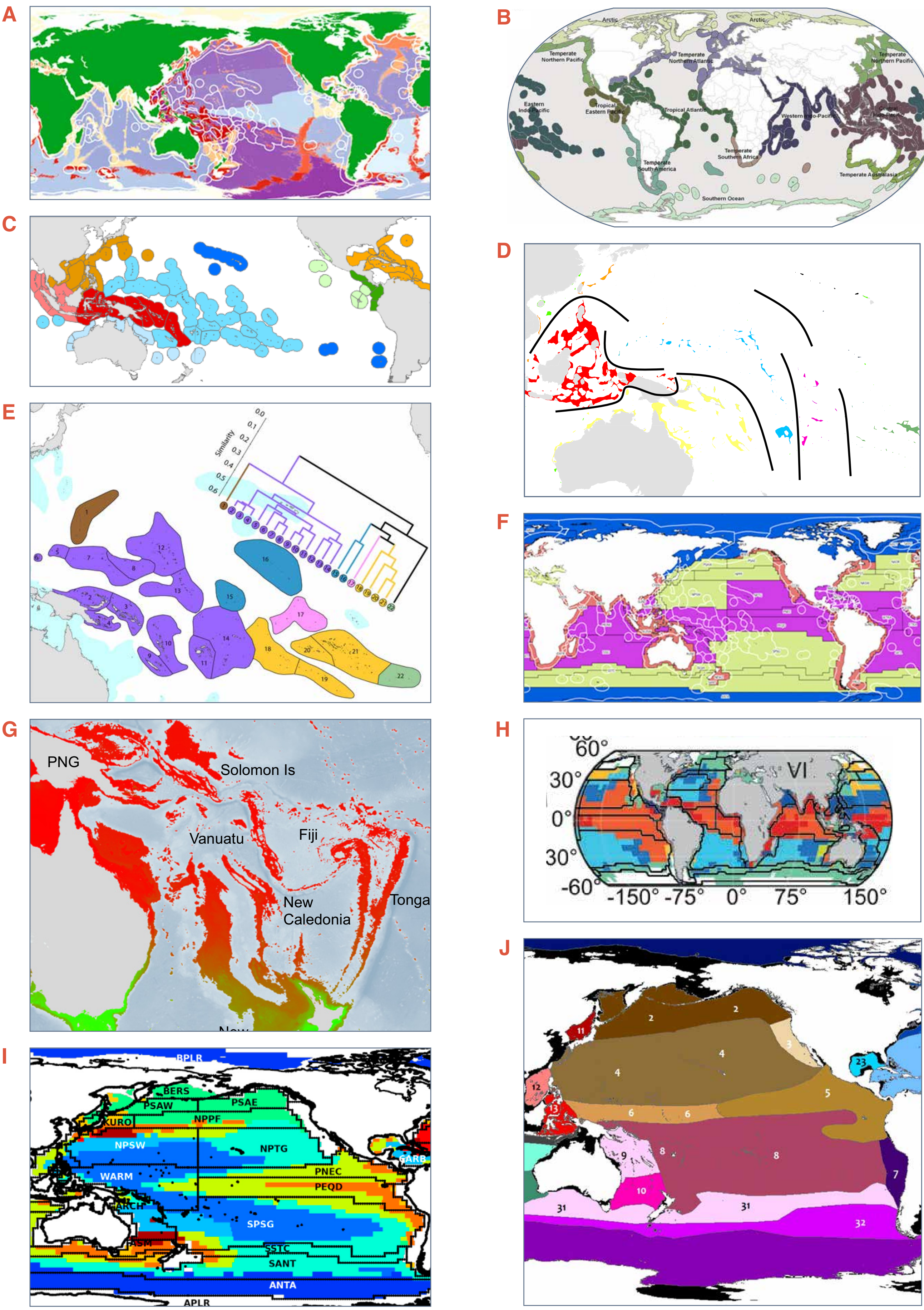


FIGURE 1: Map of selected existing classification schemes. a) GOODS (UNESCO 2009); b) MEOW (Spalding et al. 2007); c) coral reef fishes (Kulbicki et al. 2013); d) Scleractinian corals (Keith et al. 2013); e) Veron et al (2015); f) Biogeochemical provinces (Longhurst 2006); g) Deepwater ophiurods (O'Hara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

2.1.1 Coastal classifications

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

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 52 sub-provinces (9 in Oceania) (Longhurst 2006).

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

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

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

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

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

3 TECHNICAL METHODS

Scale-appropriate, comprehensive descriptions of the marine environment of Pacific Island countries and territories remain missing. Existing higher-level marine bioregionalisations, as described above, are not sufficiently refined to effectively inform within-country planning. This impedes the implementation of ecologically representative networks of MPAs nationally, including in Tonga. 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.

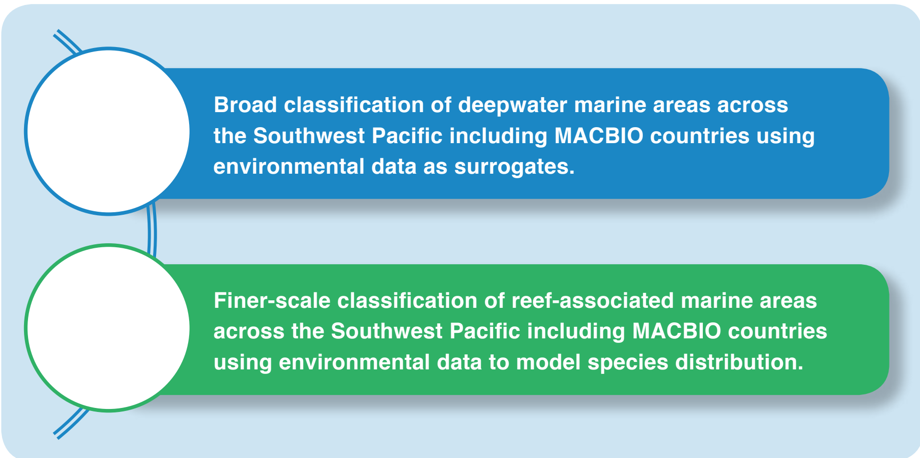


FIGURE 2: MACBIO's two-pronged integrated marine classification approach.

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.

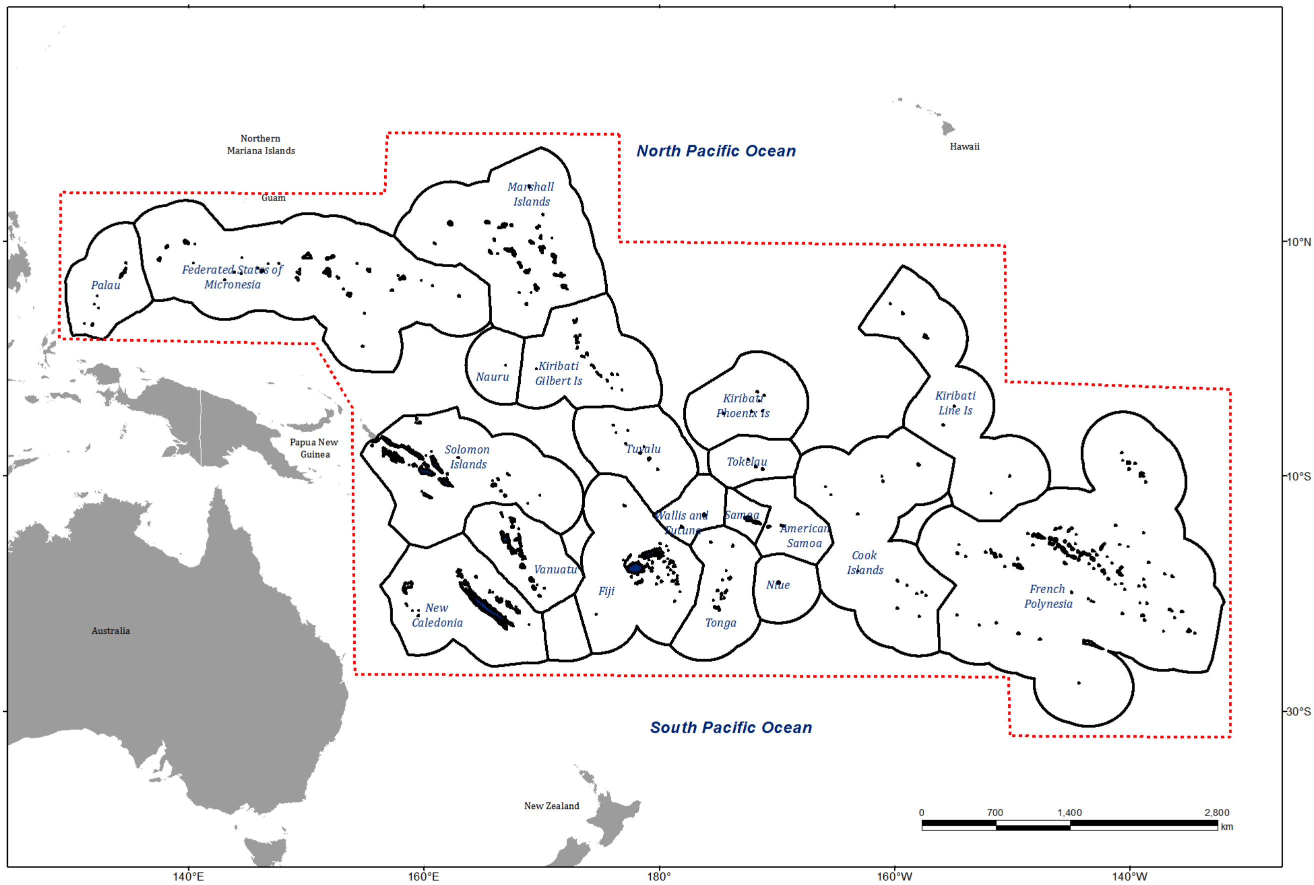


FIGURE 3: Map displaying the Area of Interest (red dotted line) and indicative provisional Exclusive Economic Zones (black solid lines).

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 3.2 and 3.3).

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

3.2 DEEPWATER BIOREGIONS METHODS

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

3.2.1 Data used in analysis

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

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

	DATASET NAME (SOURCE)	PARAMETER
1	Satellite gravimetry & multibeam data (GEBCO)	Depth (m)
2	Aqua-MODIS (BioOracle)	Calcite Concentration (mol/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)
18	Aqua-MODIS (NASA)	Sea Surface Temperature (°C) (minimum)

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

	DATASET NAME (SOURCE)	PARAMETER
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 (164,430 cells). The 20x20 km cells represented the smallest unit of the deepwater 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 3.3 below) leaving 140,598 cells of 20x20 km resolution in the deepwater area. The datasets were then assigned to these 20x20 km grid using the QGIS "zonal statistics plugin" algorithm to calculate the mean value of each dataset within each cell. The mean value of each input dataset for each cell were then exported 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 deepwater environmental parameter dataset would require 80GB of RAM, which was not available).

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

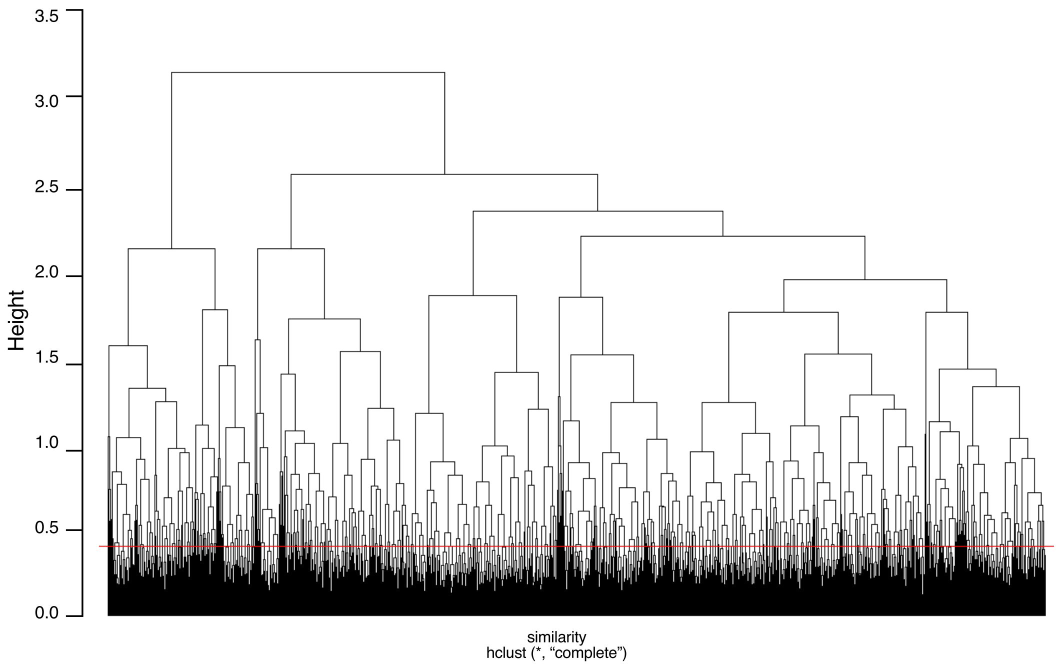


FIGURE 4: Dendrogram for offshore bioregional classification, where the red line shows the cut-off.

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

3.2.3.2 SMOOTHING AND QUALITY CONTROL

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

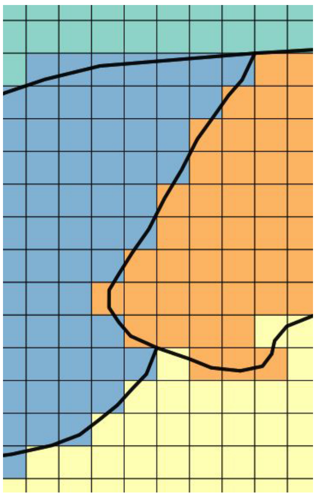


FIGURE 5: Graphic showing the 20km resolution analysis units (coloured) along with the smoothed boundaries (heavy black line).

10 www.gdal.org/gdal_sieve

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

Where the analysis identified a non-contiguous bioregion with parts that were separated by up to 1000 km, these multi-part bioregions were manually inspected to determine if their geographic locations could be explained by biological connectivity or environmental homogeneity. For example, the environmental conditions described by region 69 occurred in two locations east and west of Fiji. If the geographic locations could be explained by biological connectivity or environmental homogeneity, then the bioregion was retained as a non-contiguous bioregion; if not they were separated into distinct bioregions as was the case for Bioregion 69 (Figure 6).

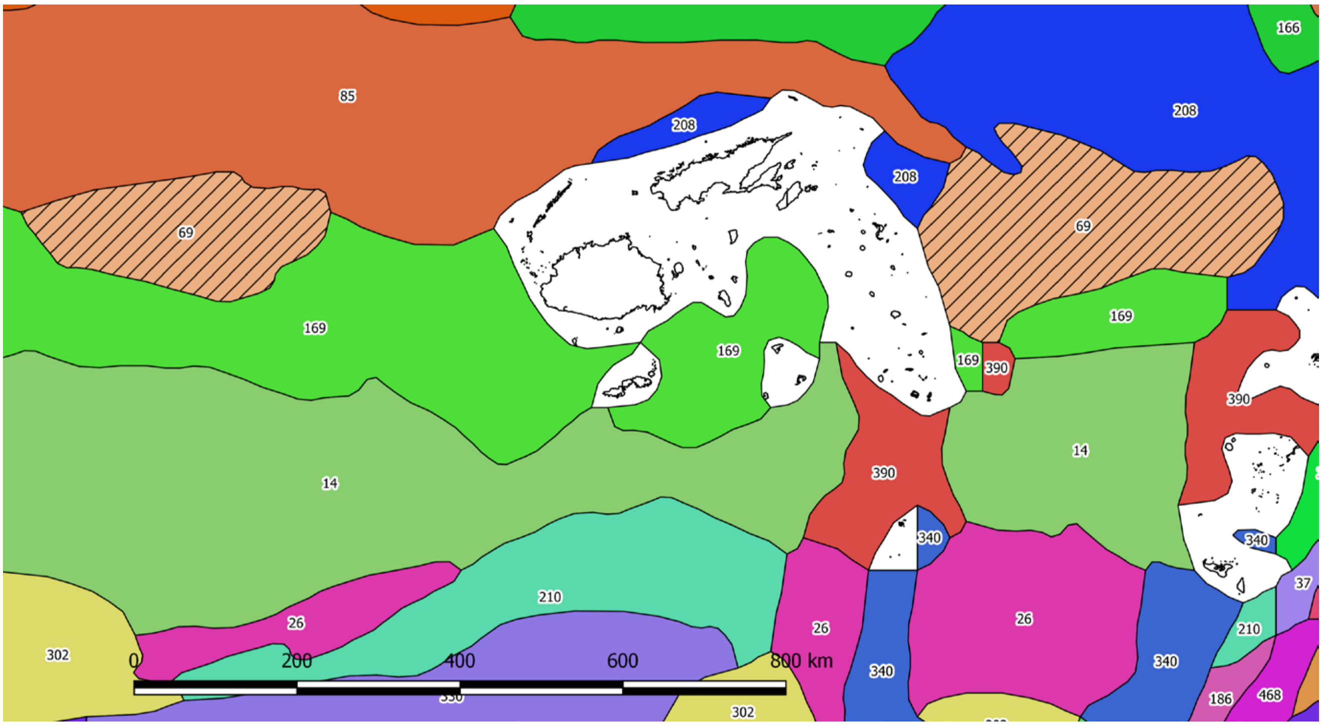


FIGURE 6: Example of post-processing decision making for non-contiguous bioregions.

3.3 REEF-ASSOCIATED BIOREGIONS METHODS

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

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

3.3.1 Biological data collation and standardisation

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

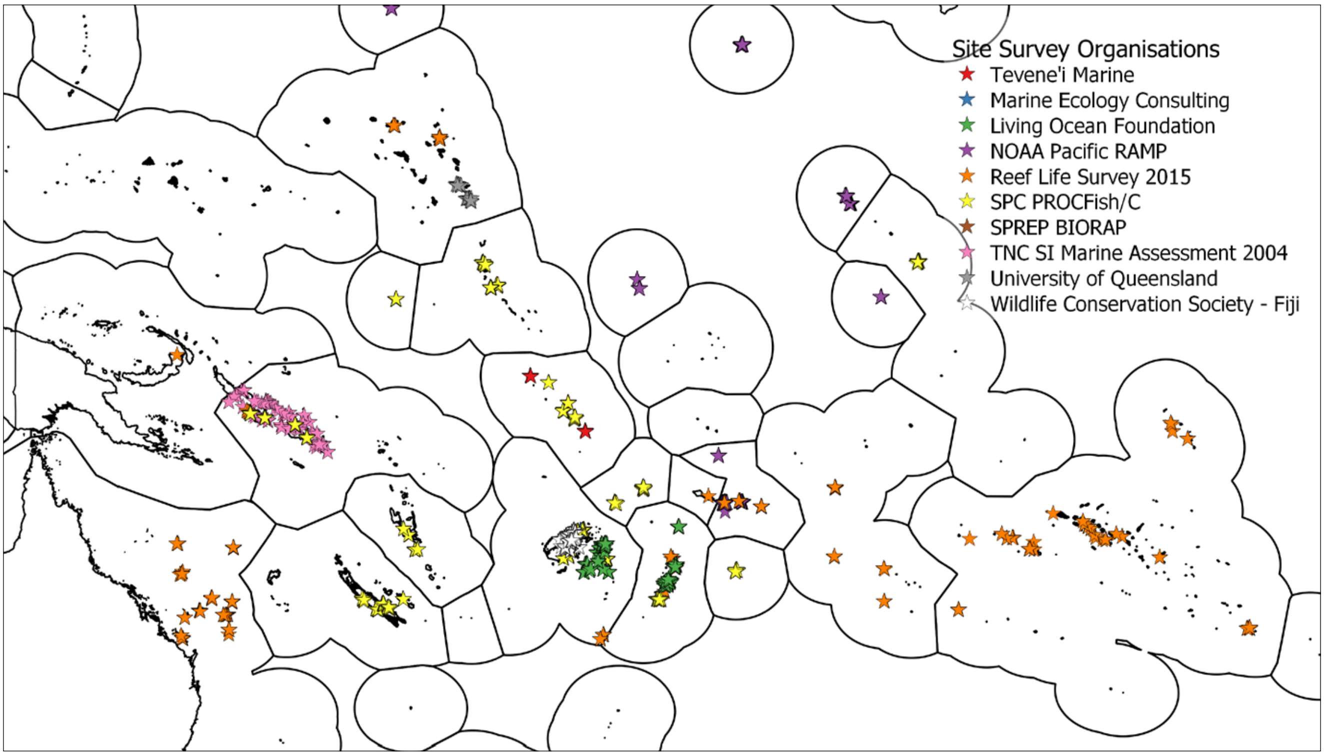


FIGURE 7: Map showing locations of fish, coral and other invertebrate surveys used.

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

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

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

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

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

3.3.2 Treatment of rare species

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

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

TABLE 2: Datasets used to derive reef-associated bioregions

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

3.3.3 Predicting probabilities of observation for each species

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

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

3.3.4 Clustering to create reef-associated bioregions

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

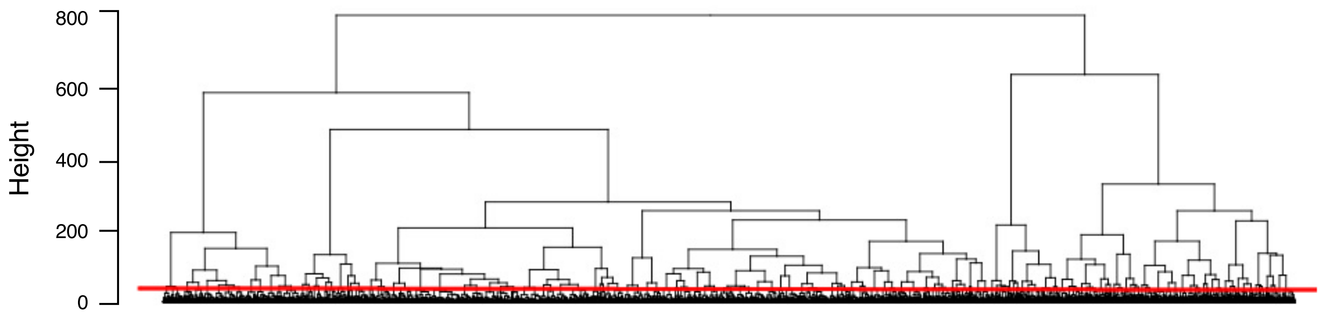


FIGURE 9: Dendrogram for reef-associated bioregional classification

3.3.5 Smoothing and categorising reef-associated bioregions

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

12 www.oracle.ugent.be

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

3.4 BIOREGION NAMES AND DESCRIPTIONS

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

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

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

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

4 TECHNICAL RESULTS

4.1 DRAFT MARINE BIOREGIONS ACROSS THE SOUTHWEST PACIFIC

The technical bioregionalisation analysis resulted in the division of the entire AOI into draft deepwater and reef-associated bioregions across the Southwest Pacific including Tonga. 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

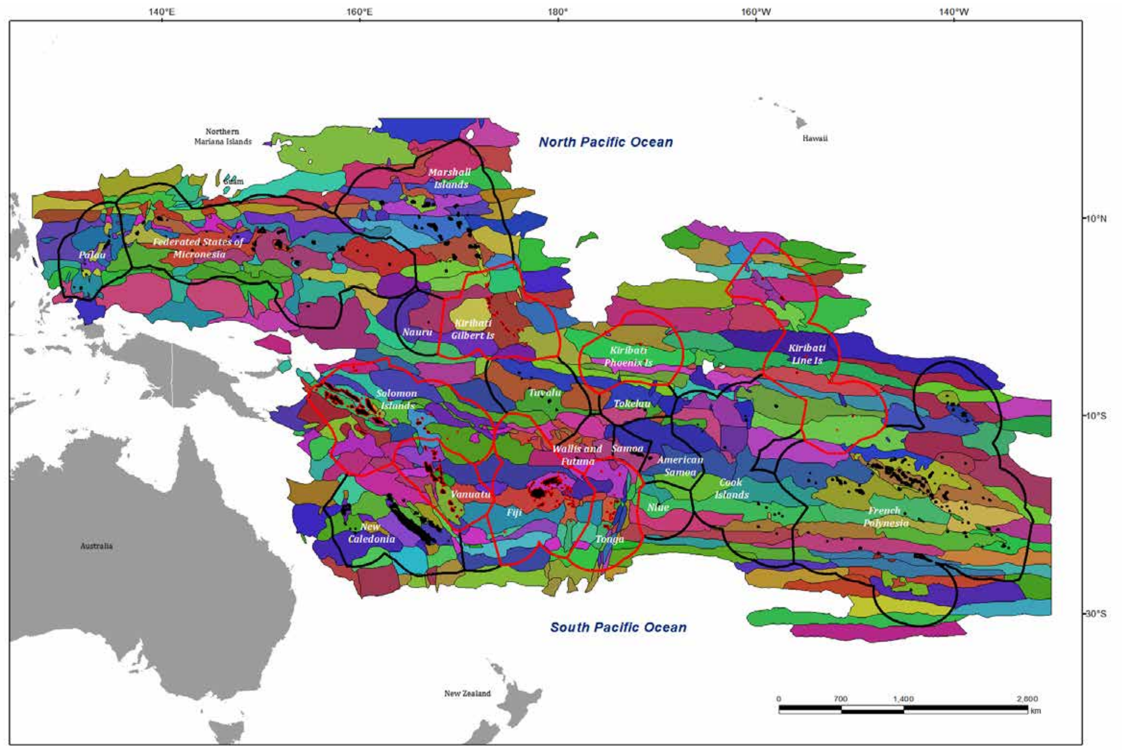


FIGURE 10: Draft deepwater bioregions for the Southwest Pacific including MACBIO countries (red solid line).

The different coloured areas represent different bioregions. Because the colour palette available to us was not sufficient, some different bioregions may appear to be the same colour. Bioregions specific to Tonga are presented in Appendix 6.

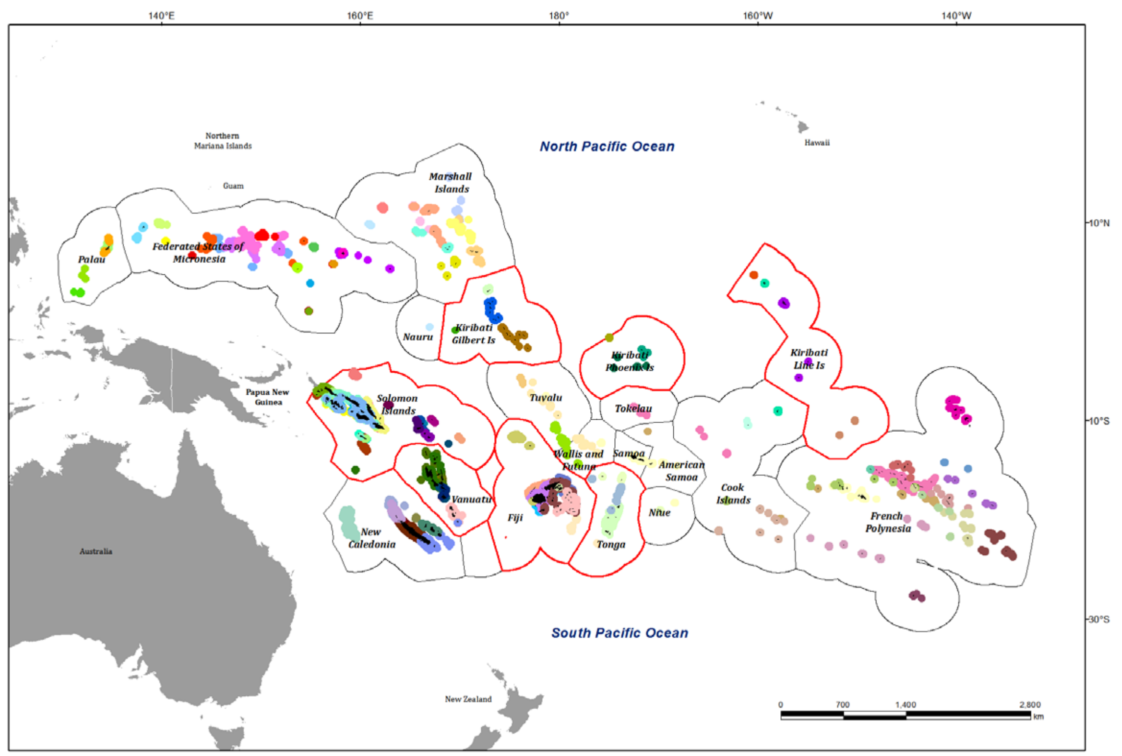


FIGURE 11: Draft reef-associated bioregions for the Southwest Pacific including MACBIO countries (red solid line).

Reef areas are exaggerated in this Figure for ease of viewing. The different coloured areas represent different bioregions. Because the colour palette available to us was not sufficient, some different bioregions may appear to be the same colour. Bioregions specific to Tonga are presented in Appendix 6.

5 DISCUSSION

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

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

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

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

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

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

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

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

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

In national planning, of course, many other considerations and data should inform decisions about where to locate marine protected areas – both biophysical and socio-economic. For example, at the finer scale, habitat and species distribution information within bioregions, where available, should be used to complement bioregions to ensure networks of MPAs that represent the entire range of biodiversity within countries (see Ceccarelli et al. 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).

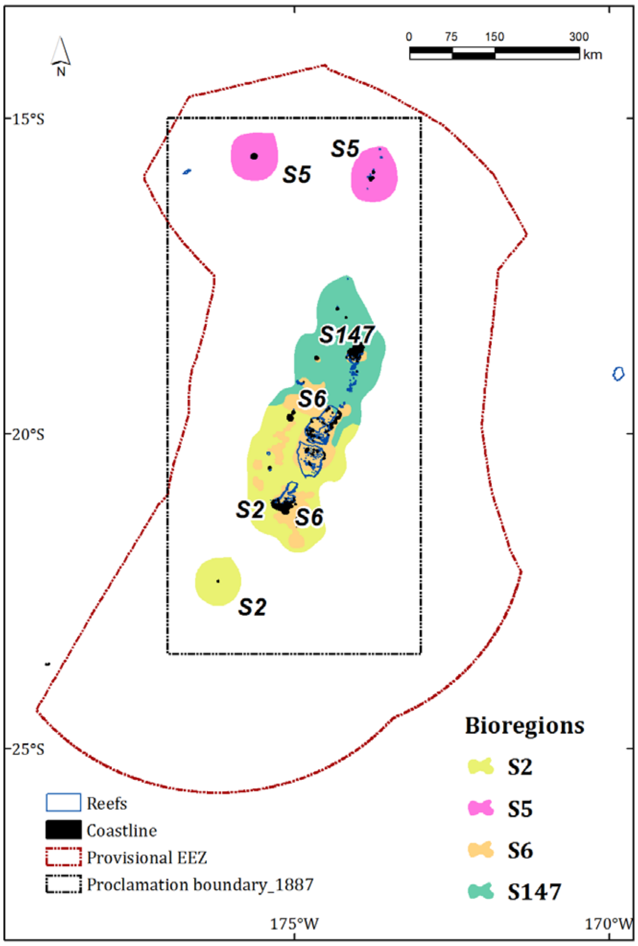
The marine environment and the organisms that live in the ocean do not respect national boundaries. As such, the data used in these analyses and the resulting draft marine bioregions extend beyond national boundaries (ABNJ) and can contribute, also, to management of the high seas should an ecologically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

6.1 INTRODUCTION

As discussed, (Section 1.1), marine conservation work in a number of Pacific Island nations has begun outlining bioregions at a scale appropriate for national marine spatial planning. The previous sections of this report present preliminary marine bioregions across the Southwest Pacific and the technical methods used to derive them. This work resulted in 33 deepwater marine bioregions and four reef-associated draft preliminary bioregions in Tonga's EEZ (see Section 4.1, Figure 12, Figure 13).



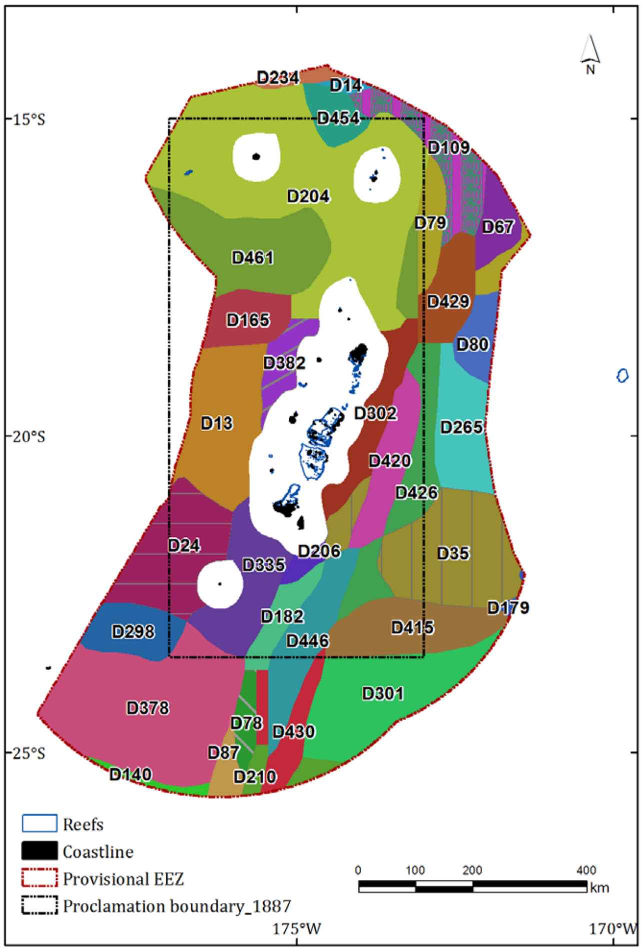


FIGURE 12. Draft reef-associated bioregions for Tonga.

FIGURE 13. Draft offshore bioregions for Tonga. Each colour and code represent a different marine bioregion.

However, this process would be incomplete without input from Tongan experts. An important, subsequent, non-analytical step, presented here, was to refine the resultant draft bioregions with marine experts in Tonga 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 in Tonga occurred on April 19 2017, in Moulton Hall, Nuku'alofa, Tonga. This workshop was hosted by the Government of Tonga and the welcoming remarks were given by Mr Paula Pouvalu Ma'u, CEO of the Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communication. The aim of the workshop was specifically to gather Tongan marine expertise to review the draft bioregions identified by the technical process described above. The workshop agenda (Appendix 1) was circulated to all participants (Appendix 2), and the technical analysis used and workshop process was described (Appendix 3) with a Powerpoint presentation at the start of the workshop.

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

- Location
- Boundaries
- Name
- Description

The format in which the information was gathered from participants can be seen in Appendix 4. The 19 participants were divided into three working groups (Table 4, Figure 14). Each working group had a rapporteur, facilitator and GIS technician.

TABLE 4. Participants assigned to each group

GROUP	AREA	NAME	MINISTRY/AFFILIATION
Green	Tongatapu and southern waters	Vailala Matoto	CRSP-ADB Project
		Siola'a Malimali	Ministry of Fisheries
		Sam Tatafu	Deep Blue
		Sione Talanoa	Ports
		Sione Sunia	MLNR
Blue	Ha'apai and central waters	Samuela Pohiva	MIA
		Teisina Fuko	Fishing Industries
		Maka Matekitonga	NSPAO (Puma)
		Yumi Nafe	MLNR
		Silia Leger	NSPAO (Puma)
		Iliesa Tora	R2R Project/MEIDECC
		Taniela Fe'ao	TONGA NFS
Red	Vava'u and northern waters	Lesieli Tu'ivai	MEIDECC
		'Ofa Kaisamy	MEIDECC
		Karen Stone	VEPA
		Dorothy Foliaki	MEIDECC
		Taaniela Kula	MLNR
		Sulieti Hufanga	DOE
		Siua Latu	MEIDECC (Env)

FIGURE 14. Participants of the workshop to review draft marine bioregions in Tonga.

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

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

Careful colour coding was used to allocate notations and information to the group from which the data were gathered. This enabled easy follow-up, by the authors of this report, with each group regarding any queries or further information that was required.

6.3 RESULTS

6.3.1 Bioregions with changes

6.3.1.1 REEF-ASSOCIATED

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

Vava'u S6: A number of specific changes were suggested to the draft S6 boundaries in Vava'u and the Niuas. S6 was determined to be situated only in shallow waters, and an extension was suggested to include all adjacent reef areas. The Red Group also requested the removal of one S6 site to the south, and its inclusion into in S147, the moving of the Metis Reef boundaries to around the reef area. Toku Island is surrounded by a shallow ridge coral reef area, and the S6 boundary should reflect this. Fonualei and Late Islands also have a shallow ridge area close to the island, which needs to be included within the S6 bioregion. Shallow patches on reef ridges surrounding Hakaufasi Islands should also be included within S6, as the species assemblages are similar. The shallow area around Uta Vava'u should be S6, as it has similar coral reef and ridge areas with similar habitats and assemblages.

Northern S147: It was suggested that the area surrounding Metis Shoal, beyond the shallow reef area, be changed from S6 to S147.

Ha'apai S6 (Tokelau lafalafa): Blue group participants suggest that this bioregion be extend to include all similar areas. The habitats suggested for inclusion are known to support small limo (seaweed), small fish and invertebrates such as small shellfish, manini, orea, gomana and kuku. The two areas (or "circles") of S6 to the west of the main island group were highlighted for removal, as they are thought to support different reef habitats. It was also suggested that the S6 bioregion be extended north into S147, which includes much deeper areas of reef.

Tongatapu S6 (Hakau Ngoto): The green group noted that the S6 boundaries included both shallow reef and deepwater areas. They suggested that the boundaries be changed to include just shallow reef and reef-associated habitats, and that they be extended to include similar habitats adjacent to the existing boundaries.

Tongatapu S2 (Moana): In keeping with the suggestions pertaining to S6, the Green Group suggested that the deeper parts of S6 be merged with S2. The group also noted that S2, being deeper, is also associated with whale movement corridors in the area.

6.3.1.2 DEEPWATER

The Red Group requested that bioregions D454 (Moana Vailili – Deep Hot Springs), D14 (Mui Tokelau – Northern Edge) and D109 (Maata'u Tokelau – Northern Hook) be merged, as they support similar assemblages and are, together, known as a productive area for albacore tuna. Additionally, the group suggested merging D204 (Hunga Tokelau – Northern Hunga), D79 (Liku Tafahi – Tafahi Cliff) and D461 (Ika Moana – Deep Fish), due to similar high nutrient (especially phosphorous) concentrations providing a popular fishing area. It was noted, however, that D204 appears to have abundant hydrothermal vents, and D461 is known as a deepwater fishing area, potentially setting these bioregions apart.

The Green Group, responsible for southern waters, suggested the merging of a number of bioregions. They suggested combining D24 (Mavae'ata – Diverted 'Ata), D298 (Tu'ateleki – Teleki Outbound) and D378 (Telekimoana – Passing the Deep), as all these areas share similar attributes that support high catches of tuna (albacore, bigeye and yellowfin), deepwater red snapper and blue nose snapper. Further combinations, on similar grounds, were suggested for D446 (Tele'a 'Ata – 'Ata Trench), D430 (Likukoloa – Minerals Cliff) and D210 (Hanga ki Pulotu – Pulotu Lookout); D206 (Likutonga mei Kalau – Southern Cliff from Kalau), D182 (Liku 'o 'Ata – 'Ata Cliff), D335 (Mo'ungatu'uua – Halved Ridge) and D78 (Tu'akoloa – Minerals Outbound); and D426 (Tele'a Moana – Deep Trench), D415 (Tu'a Tele'a – Trench Outbound) and D301 (Hangaihahake – Eastern Lookout).

It was noted by the Blue Group that D13 (Mavae'anga 'o Tonga – Tonga Spreading Centre) and D420 (Lala 'i Moana – Deep Breeding) host similar fish assemblages, therefore it was decided to merge these bioregions.

6.3.2 Accepted bioregions

6.3.2.1 REEF-ASSOCIATED

Northern S5: No changes were suggested to the S5 boundaries around the Niuas.

Ha'apai S2 (Vaha'a loto): No changes were suggested.

6.3.2.2 DEEPWATER

No changes were suggested for the northern deepwater bioregion D302 (Tafenga mei Tele'a – Passage from Trench), and for the southern D35 (Liku 'o 'Eua – 'Eua Cliff).

6.3.3 Bioregions without comment

6.3.3.1 REEF-ASSOCIATED

All reef-associated bioregions were subject to comments and suggested changes.

6.3.3.2 DEEPWATER

No comments were made about D382 (Taka'anga Motu'a – Old Hang Outs) and D302 (Tafenga mei Tele'a – Passage from Trench), therefore it was understood that these bioregions were accepted by the working groups and this was confirmed with follow-up discussions.

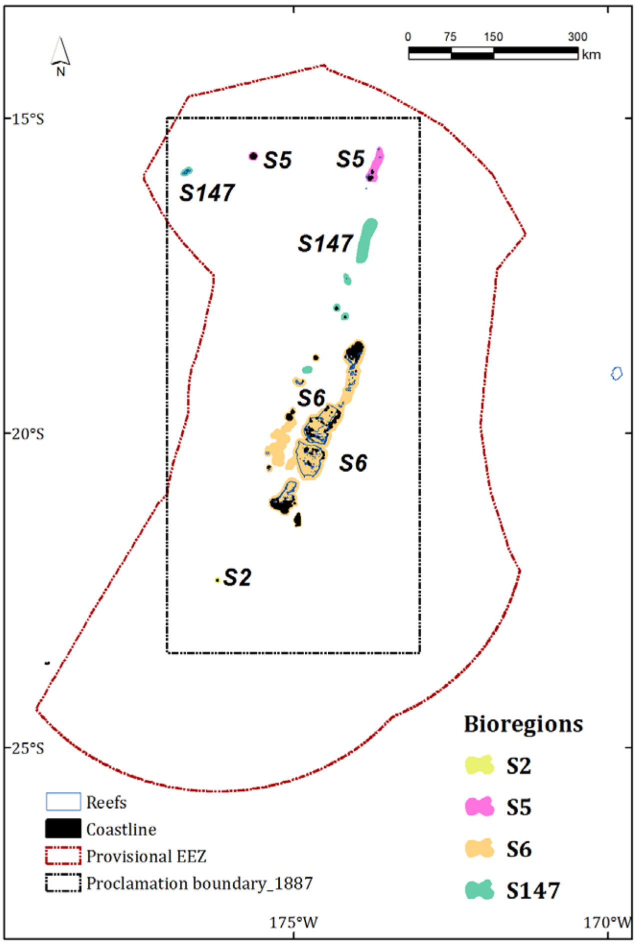


FIGURE 15. Revised reef-associated bioregions for Tonga

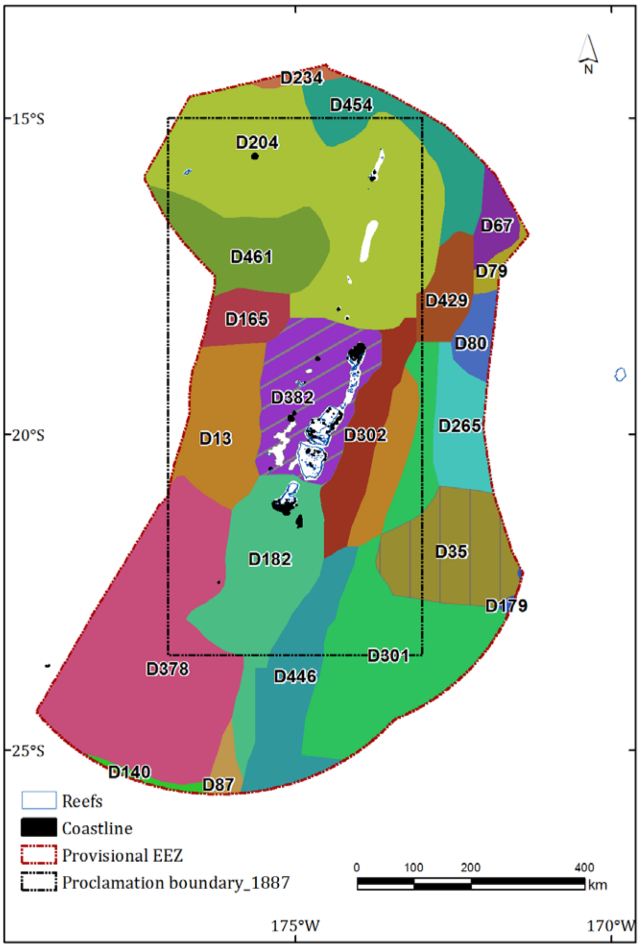


FIGURE 16. Revised deepwater bioregions for Tonga

6.4 CONCLUSIONS

All reef-associated bioregions were subject to comments and suggested changes, based on the workshop participants' knowledge about the coral reef ecosystems in their allocated areas. As a result, the four reef-associated bioregions were maintained, but the boundaries were tightened according to suggestions. In a number of cases, reef habitats types (e.g. patches versus ridges) and depth contours were used to redefine boundaries of reef-associated bioregions. 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).

A number of the deepwater bioregions were merged following review by the workshop participants, as they pointed out instances where different bioregions supported very similar fish assemblages (usually based on fisheries information), and were characterized by similar biophysical attributes. As a result, the 33 preliminary draft bioregions were recombined into 21 deepwater bioregions.

The final bioregion names and/or descriptions for Tonga 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/tonga.

These marine bioregions now form a robust and technically sound framework upon which, together with other data, to base marine spatial planning decisions in Tonga. By ensuring that each bioregion is represented adequately within

Tonga's network of Marine Protected Areas (MPAs, which will be part of Tonga's Marine Spatial Plan), Tonga will fulfil its commitments to a network that is ecologically representative. This will enable these MPAs. In turn, to deliver on Tonga's social, economic and cultural aspirations for her ocean.

Nonetheless, we acknowledge that marine data for Tonga remain imperfect, and the bioregions should be subject to further review as more data are made available.

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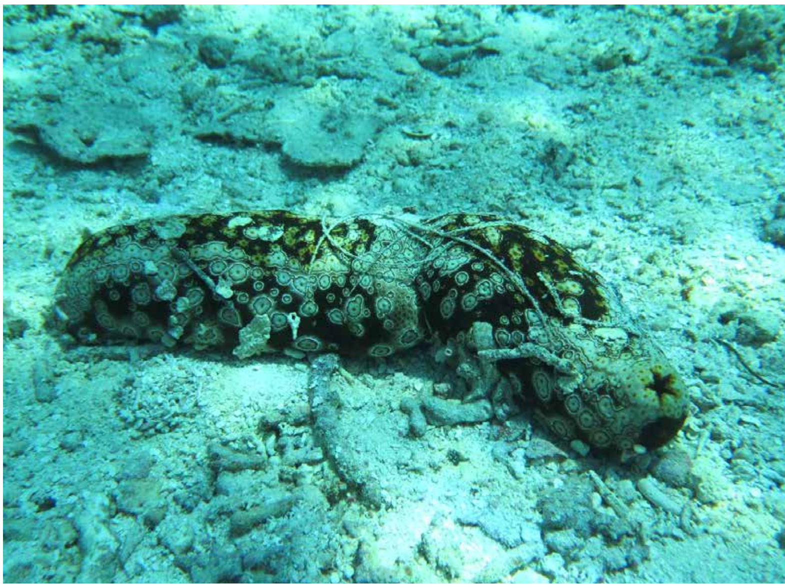

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9 APPENDICES

9.1 APPENDIX 1 WORKSHOP AGENDA

TIME	AGENDA ITEM	LEAD
8:30 – 9:00 9:00 – 9:05 9:05 – 9:15	Registration Prayer Welcome Remarks	 Mr Paula Pouvalu Ma'u
9:15 – 9:25	**Agenda item 1:** **Introductions** ▪ Overview of meeting & expectations ▪ Introductions of participants and resource walls	Ms Lupe Matoto
9:25 – 9:40	**Agenda Item 2:** **Objective:** *Reviewing Tonga's marine spatial planning process* **Presentation:** ▪ Review of the current process to achieve a national marine spatial plan	 Dr Siola'a Mali Mali
9:40 – 10:00	**Agenda item 3:** **Objective:** *Review status of report on Tonga's special and unique marine areas (SUMA)* **Presentation:** ▪ Key outcomes of the National Marine Prioritization workshop, which identified special, unique marine areas	 Dr Leanne Fernandes
10:00–10:30	Morning tea	
    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 Tonga's marine environment and results* **Presentations:** ▪ Introduction to the concept of different marine biological regions (bioregions) for Tonga, how a description of the entire marine environment of Tonga differs from special, unique marine areas ▪ Methods and data used to create draft preliminary marine biological regions (bioregions) for Tonga ▪ Introduction to Tonga's draft preliminary marine bioregions ▪ Seabed geomorphological features found in Tonga	 Dr Leanne Fernandes Mr Hans Wendt
11:20 – 13:00	**Agenda Item 5:** **Objective:** *Review the deep-water marine bioregion boundaries and descriptions* ▪ Description of group work and breakout into groups ▪ Expert review and revision of Tonga's <u>deep-water</u> marine biological region boundaries and descriptions ▪ Feedback from each group	 Dr Leanne Fernandes Break-out groups Group rapporteurs
13:00 – 14:00	Lunch	
14:00 – 15.15	**Agenda Item 6:** **Objective:** *Review the reef-associated bioregion boundaries and descriptions* ▪ Expert review and revision of Tonga's reef-associated marine biological region boundaries and descriptions	 Break-out groups
15:15 – 15:30	Afternoon tea	
15:30 – 16.30	**Agenda Item 6:** *cont.* ▪ Feedback from breakout groups	 Group rapporteurs
16.45 – 17.00	**Agenda Item 7:** ▪ Next steps	Ms Lupe Matoto

9.2 APPENDIX 2 WORKSHOP PARTICIPANTS

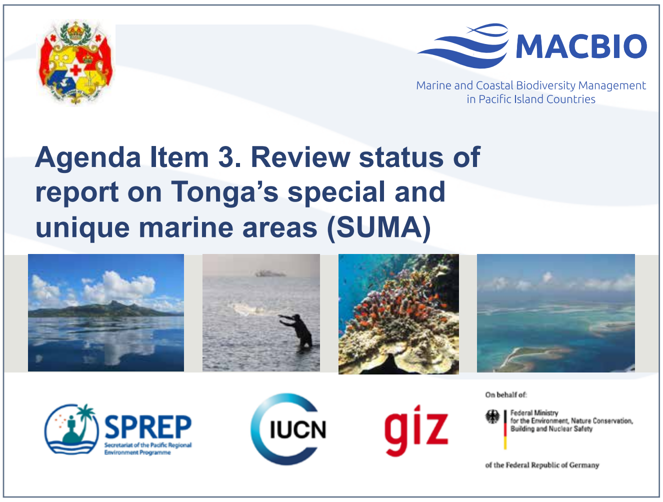
PARTICIPANTS LIST

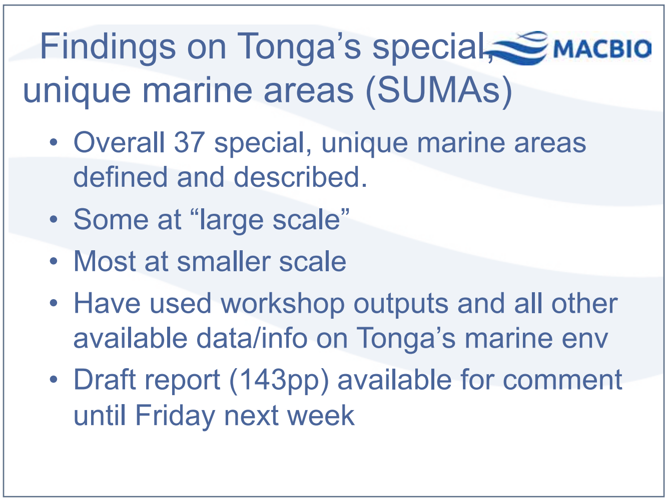
NATIONAL EXPERT WORKSHOP ON THE ESTABLISHMENT OF BIOLOGICAL REGIONS TO DESCRIBE TONGA'S MARINE ENVIRONMENT

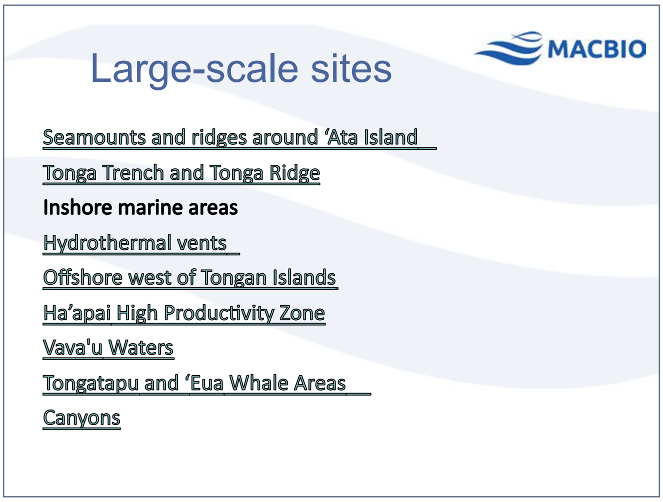
DATE: 19/4/2017 VENUE: MOULTON HALL

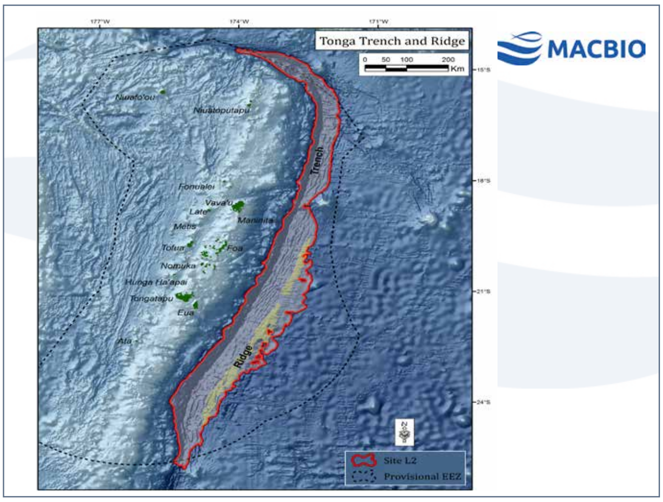
NO.	NAME	MINISTRY
1	Karen Stone	VEPA
2.	Siola'a Malimali	Ministry of Fisheries
3.	Yumi Nafe	MLNR
4.	Iliesa Tora	R2R Project/MEIDECC
5.	Lupe Matoto	MEIDECC (Env Dept)
6	Sam Tatafu	Deep Blue
7	Vailala Matoto	CRSP-ADB Project
8	Dorothy Foliaki	MEIDECC
9	Paula Ma'u	MEIDECC (Ceo)
10	Siua Latu	MEIDECC (Env)
11	Taaniela Kula	MLNR
12	Siale 'Ilolahia	Civil Society Forum of Tonga
13	Taniela Fe'ao	Tonga NFS
14	Samuela Pohiva	MIA
15	Lesieli Tu'ivai	MEIDECC
16	'Ofa Kaisamy	MEIDECC
17	Maka Matekitonga	NSPAO (Puma)
18	Silia Leger	NSPAO (Puma)
19	Teisina Fuko	Fishing Industries
20	Sione Sunia	MLNR
21	Rosamond Bing	MLNR
22	Sulieti Hufanga	DOE
23	Leanne Fernandes	IUCN
24	Hans Wendt	IUCN
25	Eileen Fonua	MEIDECC (Env)
26	Sione Talanoa	Ports

9.3 APPENDIX 3 WORKSHOP PRESENTATION





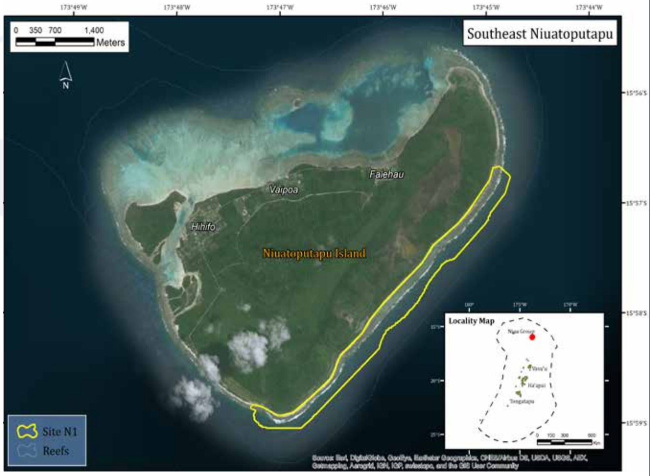




Smaller scales sites

- Niua's – five sites
- Vava'u – seven sites
- Ha'apai – seven sites
- Tongatapu – eleven sites

30 fine scale sites in all



Scoring of SUMAs

- Geographic explicitness – score out of 3
- Justification – score out of 3
- Number & type of sources – score out of 3
- Inter/national obligations – score out of 3

Larger scale sites scored from 10 to 6 (4 x 10)

Finer scale sites scored from 12 to 6 (2 x12; 1 x 11; 2 x 10.5; etc)

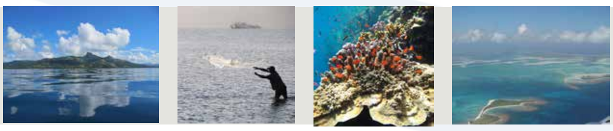
Use of SUMAs

Examples:

- Permit decisions
- Planning
- EIAs
- Licence conditions
- Spatial planning
- MPA siting

MACBIO
Marine and Coastal Biodiversity Management in Pacific Island Countries

Agenda item 4. Introduction of approach used to describe Tonga's marine environment and results



SPREP IUCN giz On behalf of: Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety of the Federal Republic of Germany

MSP process : 2015-2020

1. MSP network vision and objectives
2. Analysis of legal basis for MSP
3. Ocean management area typology
4. Prioritisation of marine areas
5. Ocean-wide description: marine environment (THIS WORKSHOP)
6. Placement guidelines for management areas
7. National consultation on all of the above
8. Draft map of ocean management areas
9. Consultations on draft map
10. Final map for gazettal

MPAs – part of MSP

MACBIO

- The Deputy Prime Minister has on several occasions (e.g. Pacific Ocean Summit, 2016, UNOC Prep Comm 2017) committed to 30% ecologically representative MPAs
- The NBSAP commits Tonga to ecologically representative MPAs
- As signatory to the CBD – commitment to ecologically representative MPAs

Old paradigm

MACBIO

– 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

MACBIO

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

MACBIO

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

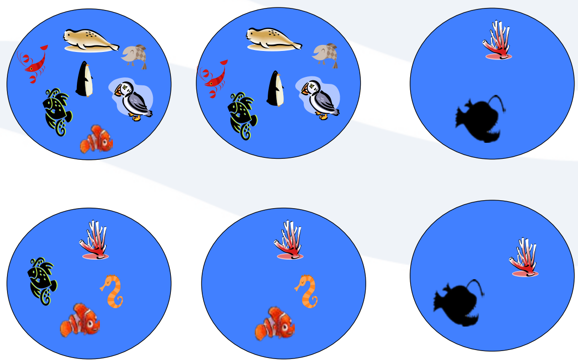
But what are bioregions and why do we care?

MACBIO

- Areas of relative similarity
  – Habitats, communities, and physical features within a bioregion are more similar to each other than those in a different bioregion.
- A way to represent the full range of biodiversity
- A classification of habitat and environmental types

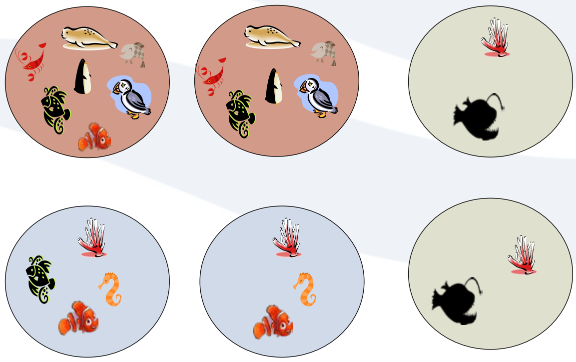
Example of Species Assemblages

MACBIO



“Bioregions” with Similar Species

MACBIO



Bioregions as a planning tool

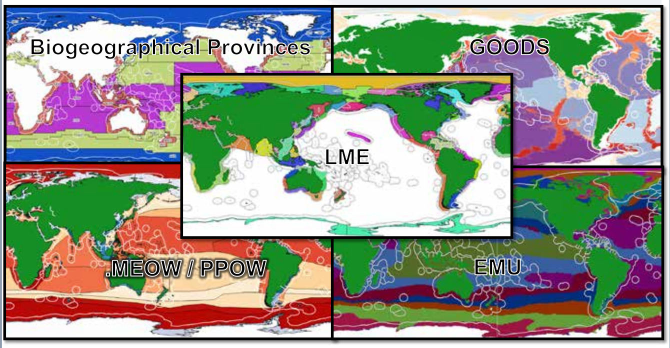
MACBIO

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

MACBIO



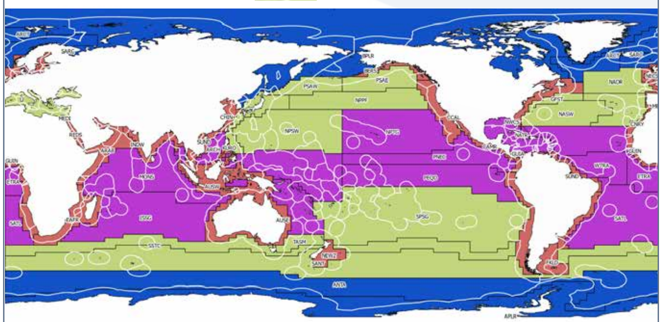
Longhurst, 2010. Biogeographical Provinces

MACBIO

4 global provinces: 3 in Oceania

52 sub-provinces: 9 in Oceania

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



3/18/18 MACBIO

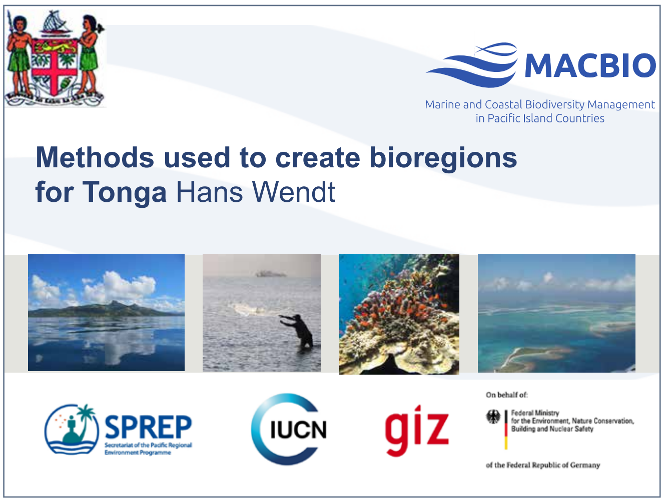
Bioregions as a planning tool

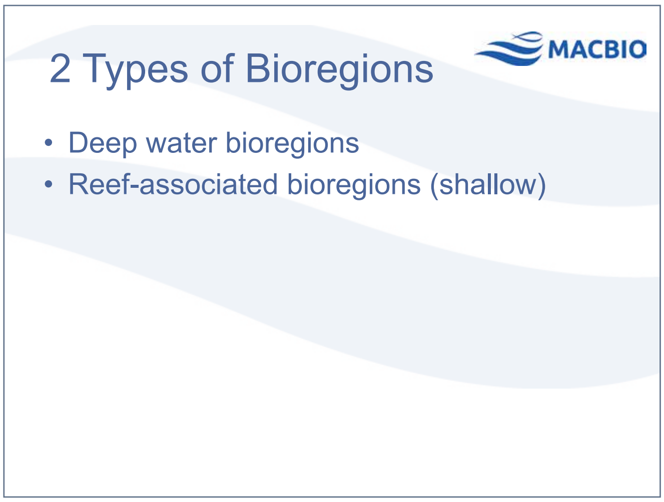
MACBIO

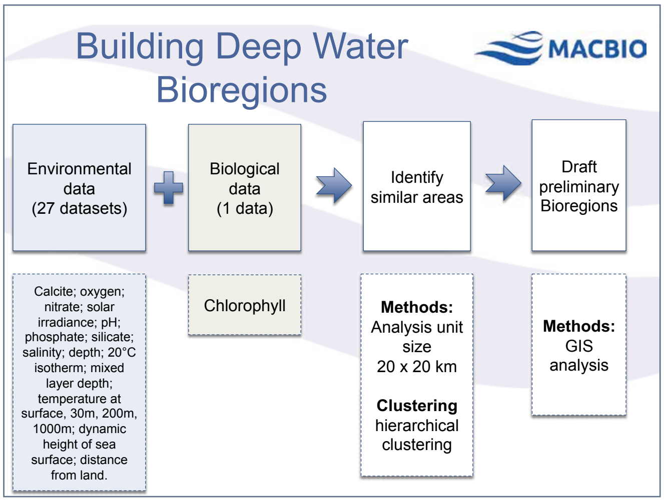
- The MACBIO project is working with 5 countries to support Marine Spatial Planning within their EEZs.
- Global-scale bioregions are not useful for national scale marine planning and management.
- Tonga needs finer scale descriptions of its entire marine environment

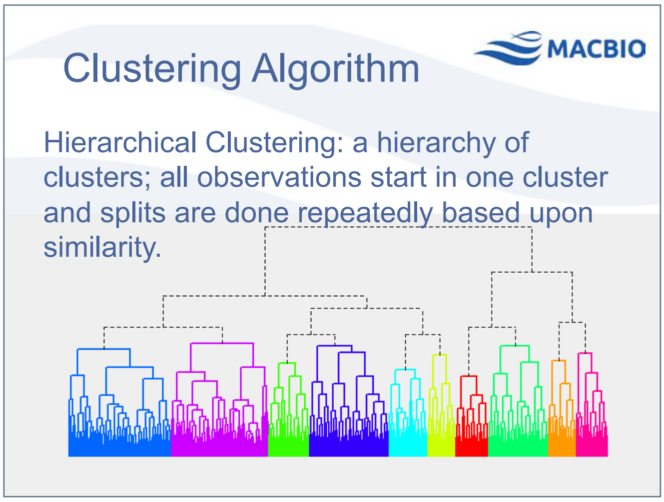
Questions?

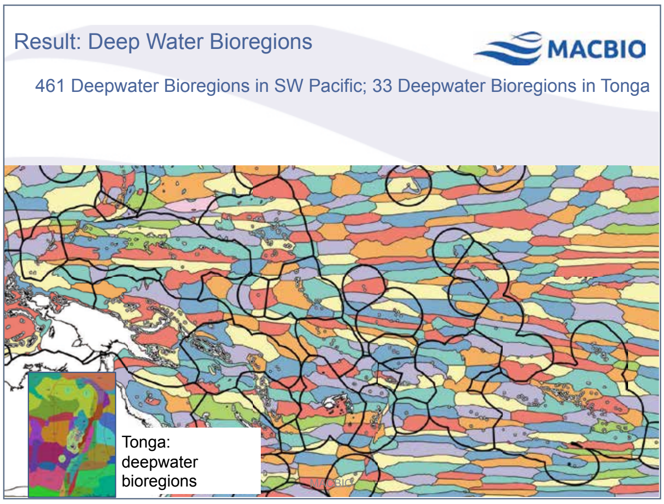
MACBIO

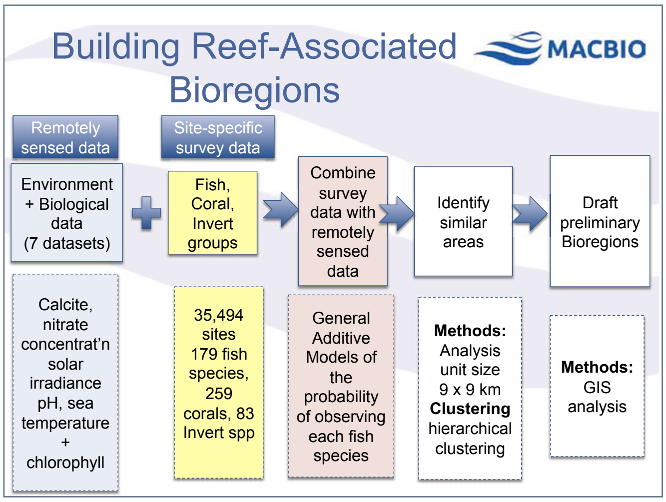

MACBIO
Marine and Coastal Biodiversity Management in Pacific Island Countries
Methods used to create bioregions for Tonga Hans Wendt
SPREP
IUCN
giz
On behalf of:
Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
of the Federal Republic of Germany

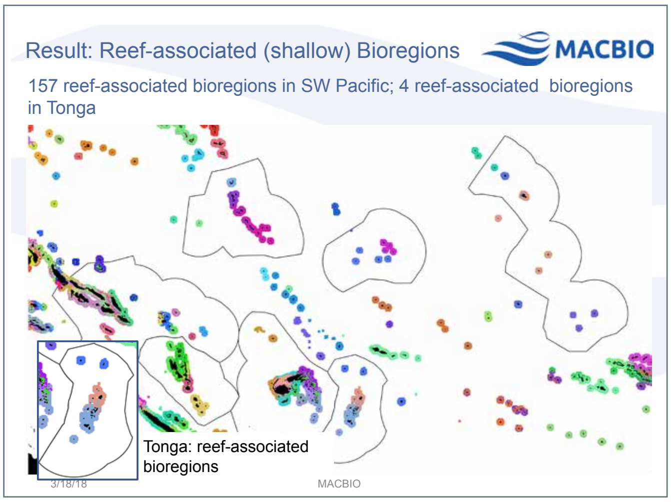

2 Types of Bioregions
MACBIO
• Deep water bioregions
• Reef-associated bioregions (shallow)

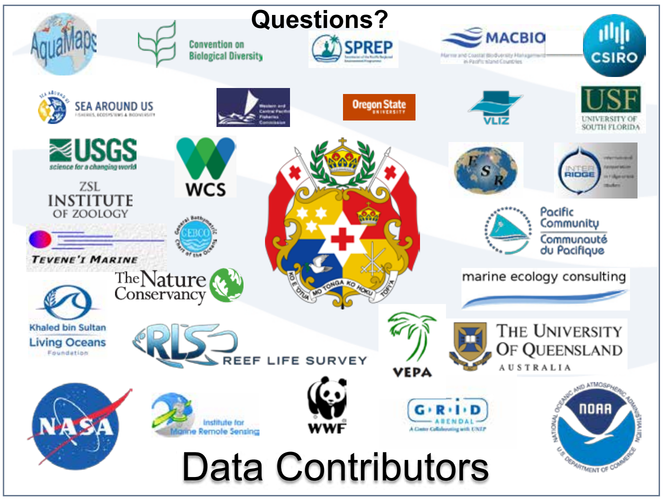

Building Deep Water Bioregions
MACBIO
Environmental data (27 datasets)
Biological data (1 data)
Identify similar areas
Draft preliminary Bioregions
Calcite; oxygen; nitrate; solar irradiance; pH; phosphate; silicate; salinity; depth; 20°C isotherm; mixed layer depth; temperature at surface, 30m, 200m, 1000m; dynamic height of sea surface; distance from land.
Chlorophyll
Methods: Analysis unit size 20 x 20 km
Clustering hierarchical clustering
Methods: GIS analysis

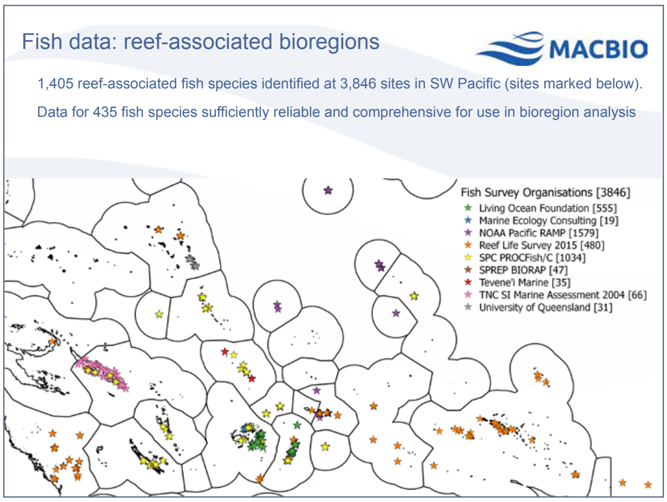

Clustering Algorithm
MACBIO
Hierarchical Clustering: a hierarchy of clusters; all observations start in one cluster and splits are done repeatedly based upon similarity.


Result: Deep Water Bioregions
MACBIO
461 Deepwater Bioregions in SW Pacific; 33 Deepwater Bioregions in Tonga
Tonga: deepwater bioregions

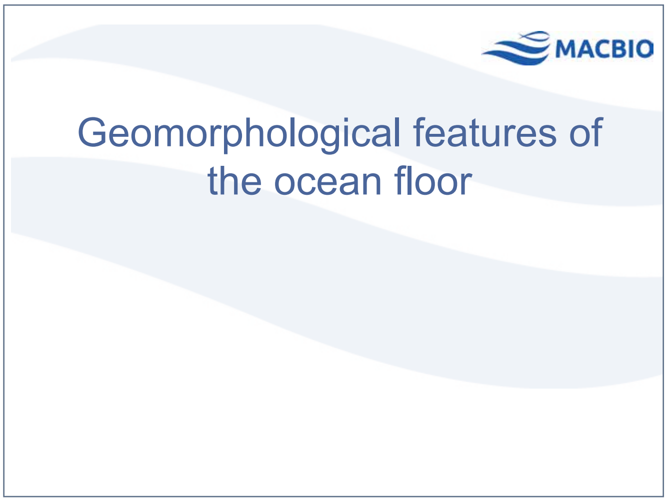

Building Reef-Associated Bioregions
MACBIO
Remotely sensed data
Site-specific survey data
Environment + Biological data (7 datasets)
Fish, Coral, Invert groups
Combine survey data with remotely sensed data
Identify similar areas
Draft preliminary Bioregions
Calcite, nitrate concentrat'n solar irradiance pH, sea temperature + chlorophyll
35,494 sites 179 fish species, 259 corals, 83 Invert spp
General Additive Models of the probability of observing each fish species
Methods: Analysis unit size 9 x 9 km Clustering hierarchical clustering
Methods: GIS analysis

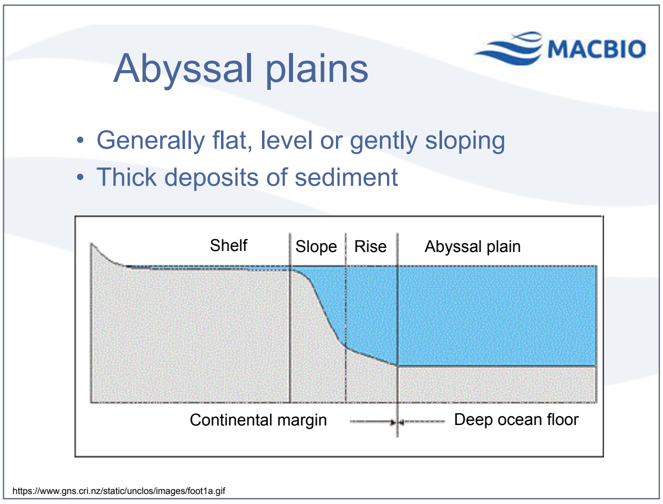

Result: Reef-associated (shallow) Bioregions
MACBIO
157 reef-associated bioregions in SW Pacific; 4 reef-associated bioregions in Tonga
Tonga: reef-associated bioregions
3/18/18
MACBIO


Questions?
Data Contributors
AquaMaps
Convention on Biological Diversity
SPREP
MACBIO
CSIRO
SEA AROUND US
Oregon State
VLIZ
USF
USGS
WCS
ZSL INSTITUTE OF ZOOLOGY
TEVENE'I MARINE
The Nature Conservancy
Pacific Community
Communauté du Pacifique
marine ecology consulting
Khaled bin Sultan Living Oceans Foundation
REEF LIFE SURVEY
VEPA
THE UNIVERSITY OF QUEENSLAND AUSTRALIA
NASA
WWF
GRID ARENDAL
NOAA


Fish data: reef-associated bioregions
MACBIO
1,405 reef-associated fish species identified at 3,846 sites in SW Pacific (sites marked below).
Data for 435 fish species sufficiently reliable and comprehensive for use in bioregion analysis
Fish Survey Organisations [3846]
Living Ocean Foundation [555]
Marine Ecology Consulting [19]
NOAA Pacific RAMP [1579]
Reef Life Survey 2015 [480]
SPC PROCFish/C [1034]
SPREP BIORAP [47]
Tevene'i Marine [35]
TNC SI Marine Assessment 2004 [66]
University of Queensland [31]

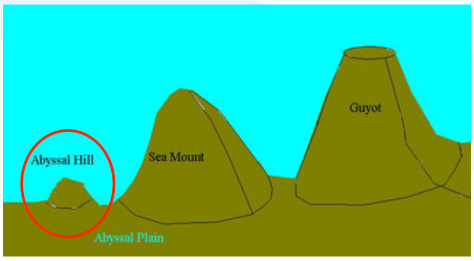

MACBIO
Marine and Coastal Biodiversity Management in Pacific Island Countries
Introduction to Tonga's seabed geomorphology and marine bioregions
SPREP
IUCN
giz
On behalf of
Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
of the Federal Republic of Germany


MACBIO
Geomorphological features of the ocean floor


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

Abyssal hills

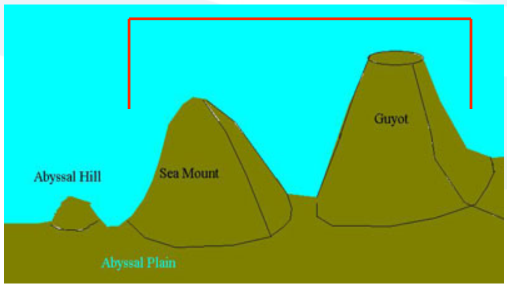
- Small elevations
- Peak height between 300 – 1000 m above seafloor



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

Abyssal mountains

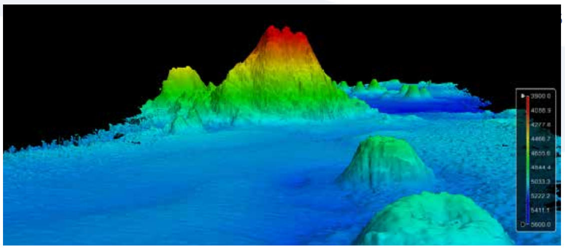
- Submarine mountains
- Peak height greater than 1000 m
- Includes seamounts and ridges



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

Seamounts

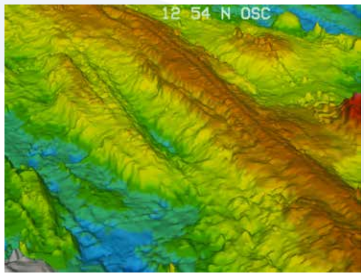
- Large conical shaped mountains
- Peak height greater than 1000 m from seafloor
- Isolated or in groups



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

Ridges

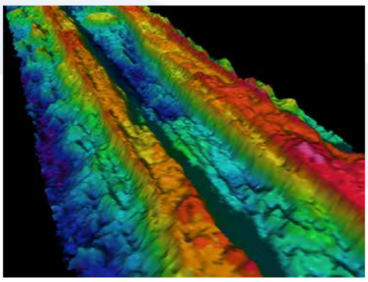
- Long, narrow elevations with steep sides
- Peak height greater than 1000 m from seabed



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

Rift valleys

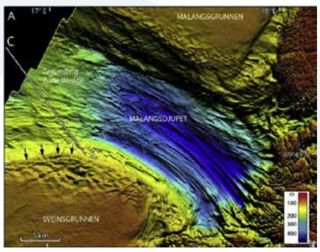
- Long valleys
- Found between spreading ridges



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

Troughs

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

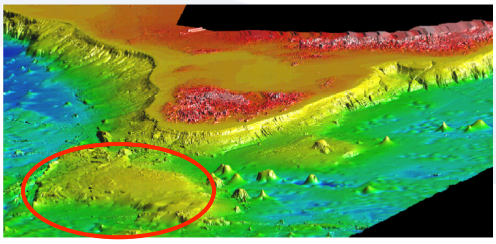


https://www.researchgate.net/profile/Martin_Jakobsson2/publication/282377233/figure/fig5/AS:281937424994341@1444230529290/Fig-6-a-Multi-beam-bathymetric-data-showing-a-submarine-palaeo-ice-stream-bed-ice-fl.png

Plateaus

MACBIO

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

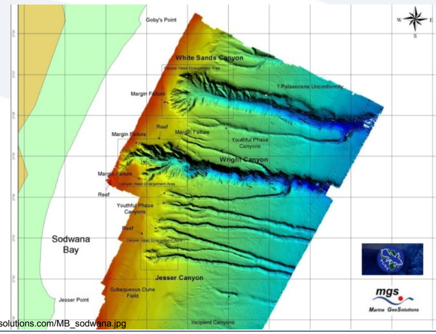


https://www.researchgate.net/profile/Peter_Harris14/publication/284032480/figure/fig5/AS:297399898656781@1447917069918/Figure-613-Bathymetric-image-from-Geoscience-Australia-showing-a-three-dimensional-view.png

Submarine canyons

MACBIO

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

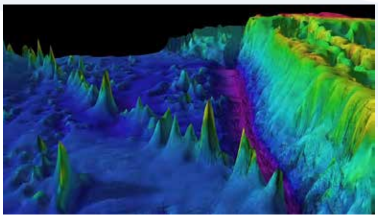


https://www.marinegeosolutions.com/MB_sodwana.jpg

Trenches

MACBIO

- 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

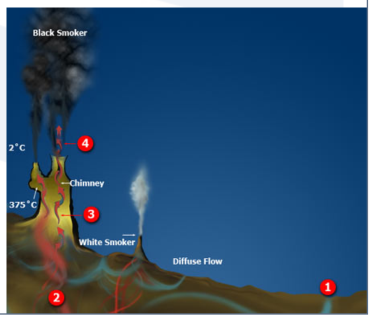


https://www.whoi.edu/cms/images/kermadec_trench_x_415673.jpg

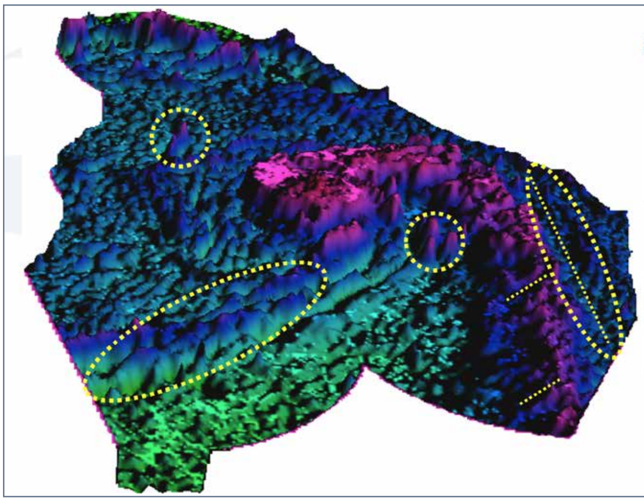
Hydrothermal vents

MACBIO

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



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



MACBIO

Agenda Items 5 & 6: Break-out groups

Resources:

a) Resource wall (hard copy maps posted on the wall of (i) some of the 40-odd datasets used in technical analysis and (ii) over 20 other datasets that might be useful
b) Hard copy maps and input forms on tables to guide discussions
c) GIS data (with GIS person to drive it) per table – can pull up any of 140 datasets relevant to Tonga including draft preliminary bioregions

MACBIO

Agenda Item 6. Review the draft preliminary reef-associated bioregion boundaries and descriptions

Breakout groups: nominate a rapporteur

All groups to consider:

1. Boundaries and location of the bioregions
2. Names for the bioregions
3. Description of the bioregions

Feedback from breakout groups

MACBIO

Agenda Item 5. Review the draft preliminary deep-water marine bioregion boundaries and descriptions

Breakout groups: nominate a rapporteur

All groups to consider:

1. Boundaries and location of the bioregions
2. Names for the bioregions
3. Description of the bioregions

Feedback from breakout groups

9.4 APPENDIX 4 WORKSHOP INFORMATION GATHERING

NATIONAL EXPERT WORKSHOP ON THE ESTABLISHMENT OF BIOLOGICAL REGIONS TO DESCRIBE TONGA'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 AVAILABLE TO WORKSHOP PARTICIPANTS

List of bioregions maps, resource wall and e-copy maps and GIS data

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

BIOREGIONS MAPS USED FOR FEEDBACK

1. Deepwater bioregions maps
   a. EEZ-scale
   b. Vava'u and northern area
   c. Ha'apai and central area
   d. Tongatapu and southern area

2. Shallow reef-associated bioregions map (4 zoomed-in island group maps)
   a. Niuas group
   b. Vava'u group
   c. Ha'apai Group
   d. Tongatapu Group + Ata

RESOURCE WALL (HARD COPY MAPS POSTED ON THE WALLS)

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

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 the GIS.

1. BASE LAYERS

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

2. ENVIRONMENTAL VARIABLES

a. Sea surface temperature
b. Temperature at 1000 meters depth
c. Temperature at 200 meters depth
d. Temperature at 30 meters depth
e. Depth of 20 degree isotherm
f. Mixed layer depth
g. Salinity
h. pH
i. Photosynthetically available radiation
j. Nitrate
k. Calcite
l. Silicate
m. Phosphate
n. Depth

3. BIO-PHYSICAL DATA

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

9.6 APPENDIX 6 FINAL LIST OF BIOREGIONS FOR TONGA

NOTE: Deepwater bioregions extend beyond Tonga's EEZ. The deepwater bioregion descriptions provided here apply to the entire bioregion, not just the part of the bioregion within Tonga.

HABITAT	CODE	TONGAN NAME	ENGLISH NAME	DESCRIPTION
Deepwater	D13	Mavae'anga 'o Tonga	Tonga Spreading Centre	Bioregion dominated by plateau and basins with spreading ridges and rift valleys. The southern end of the Bioregions consists of one seamount. The area includes large abyssal hills, large plateau towards the east and isolated pockets of seamounts and spreading ridges. SST is very unstable and low. CHL is 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 is quite low in the 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. Has high densities of yellowfin and bigeye tuna.
Deepwater	D140	'Olioni	Orion	Contains ridges, canyons, basins, troughs, plateaus and abyssal plains, hills and mountains. SST is low and stable; CHL, 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 low and variable. Dissolved oxygen concentration is moderate and stable. Moderate sea surface currents generally from the northwest. Contains no seamounts. Includes 5 blind canyon types. Contains 1 active, confirmed; 1 active, inferred hydrothermal vents. The upper depth is 1,000m and the lower depth is 2,500m.
Deepwater	D165	Paepae 'a Maui	Maui's Stone Place	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. SST is moderate, variable. CHL is high with a large bloom in the western region. MLD is 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	D179	Hiku'i Niue	Niue's Tail	Mostly dominated by abyssal plains and hills with basin. Other features include escarpment and ridges. SST is low and stable; CHL, 20°C Iiotherm 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. Intersects 1 seamount type 11 (intermediate size, largest basal area and deepest peak depth). The upper depth is 5,000m and the lower depth is 6,000m.
Deepwater	D182	Mo'ungatu'uua	Halved Ridge	Small bioregion with canyons, ridges, plateau and slope. SST is low and stable; CHL, 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. Contains 2 seamounts type 2 (small with deep peak, most common type); 2 seamounts type 3 (intermediate size, large tall and deep); 2 seamounts type 8 (small and short with very deep peaks, deepest type); 3 seamounts type 11 (intermediate size, largest basal area and deepest peak depth). Includes 7 blind canyon types and 1 shelf incising canyon type. The upper depth is 4,500m and the lower depth is 5,000m. Important area for yellowfin, bigeye and albacore tuna and for deepwater snappers.

HABITAT	CODE	TONGAN NAME	ENGLISH NAME	DESCRIPTION
Deepwater	D204	Hunga Tokelau	Northern Hunga	Bioregion exists in the two Niua islands, and sits on a plateau in the north of Tonga's EEZ with numerous large and intermediate seamounts. Non-contiguous bioregion which extends into Fiji's EEZ. SST is moderate and variable, CHL is high closer to land, and low towards the east, salinity is low and variable, dissolved oxygen is low and variable, deepwater temperature is deep, 20°C isotherm is deep, mixed layer depth is shallow, solar irradiance is moderate, pH level is moderate, silicate level is high, phosphate level is moderate, nitrate level is moderate, calcite is generally low but high close to land. Contains 7 seamounts type 1 (small with deep peak, short with moderately deep peak); 1 seamount type 3 (intermediate size, large tall and deep); 14 seamounts 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); Includes 9 blind canyon types and 11 shelf incising canyon types. Contains 9 active, confirmed; 17 active, inferred hydrothermal vents. The upper depth is 0m and the lower depth is 2,500m.
Deepwater	D234	Tokelau Momo	Northern Pieces	Includes medium size seamounts, northern parts of the Tonga Trench, and ridges that form the base of American Samoa with lots of canyons. SST is high, CHL low and variable, salinity is low, dissolved oxygen is low and stable, deepwater temp is deep, 20°C isotherm is deep, mixed layer depth is medium, solar irradiance is high, pH level is low, silicate level is moderate, phosphate level is moderate, nitrate level is moderate, calcite is low. Contains 1 seamount type 1 (small with deep peak, short with moderately deep peak); 7 seamounts type 2 (small with deep peak, most common type); 9 seamounts type 3 (intermediate size, large tall and deep); 1 seamount type 7 (small and short with very deep peaks, shortest); 1 seamount type 8 (small and short with very deep peaks, deepest type); 2 seamounts type 9 (Large and tall with shallow peak, larger); 10 seamounts type 10 (large and tall with shallow peak: shallow); 1 seamount type 11 (intermediate size, largest basal area and deepest peak depth). Includes 16 blind canyon types and 12 shelf incising canyon types. The upper depth is 2,000m and the lower depth is 5,000m.
Deepwater	D265	Lalo Kepilikoni	South Capricorn	Deep bioregion with mostly abyssal hills and plains extending towards the Tonga Trench and ridges. SST is moderate; CHL, 20°C isotherm and the deepwater temperature are low. Salinity, pH levels, nitrate and solar irradiance are moderate. Mixed layer depth is moderate. Calcite is low and variable and dissolved oxygen concentrations are low and stable. Strong sea surface currents generally from the north. Contains 1 seamount type 2 (small with deep peak, most common type); 4 seamounts type 3 (intermediate size, large tall and deep); 1 seamount type 6 (very large and tall with low escarpment); 4 seamounts type 7 (small and short with very deep peaks, shortest); 2 seamounts type 8 (small and short with very deep peaks, deepest type); 2 seamounts type 10 (large and tall with shallow peak: shallow); 1 seamount type 11 (intermediate size, largest basal area and deepest peak depth). The upper depth is 5,000m and the lower depth is 5,500m.
Deepwater	D301	Hangaihahake	Eastern Lookout	Contains the deep Tonga Ridge, abyssal hills and seamounts on abyssal mountains. SST is low and stable; CHL, 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. Contains 2 seamounts type 2 (small with deep peak, most common type); 1 seamount type 7 (small and short with very deep peaks, shortest); 3 seamounts type 8 (small and short with very deep peaks, deepest type); 11 seamounts type 11 (intermediate size, largest basal area and deepest peak depth). The upper depth is 5,000m and the lower depth is 6,000m. Important area for yellowfin, bigeye and albacore tuna and for deepwater snappers.

HABITAT	CODE	TONGAN NAME	ENGLISH NAME	DESCRIPTION
Deepwater	D302	Tafenga mei Tele'a	Passage from Trench	Dominated by a chain of canyons formed on ridges and plateau, dominated by Kaurai Ridge. SST is moderate; CHL, 20°C isotherm and the deepwater temperature are deep. Salinity, pH levels, nitrate and solar irradiance are moderate. Mixed layer depth is moderate. Calcite is low and variable and dissolved oxygen concentrations are low and stable. Strong sea surface currents generally from the north. Contain no seamounts. Includes 9 blind canyon types and 5 shelf incising canyon types. The upper depth is 1,500m and the lower depth is 4,500m. important habitat for bluenose snapper (deepwater fish species).
Deepwater	D35	Liku 'o 'Eua	‘Eua Cliff	Dominated by slope from ridges, and plateaus that slope towards the trench. SST is moderate. CHL, 20°C isotherm and the deepwater temperature are low. Salinity, pH levels, nitrate and solar irradiance are moderate. Mixed layer depth is moderate. Calcite is low and variable and dissolved oxygen concentrations are low and stable. Strong sea surface currents generally from the north. Contains 1 seamount type 3 (intermediate size, large tall and deep); 1 seamount type 6 (very large and tall with low escarpment); 2 seamounts type 7 (small and short with very deep peaks, shortest); 1 seamount type 8 (small and short with very deep peaks, deepest type); 1 seamount type 11 (intermediate size, largest basal area and deepest peak depth). Includes 3 blind canyon types. The upper depth is 4,500m and the lower depth is 5,500m. Important area for yellowfin, bigeye and albacore tuna and for deepwater snappers.
Deepwater	D378	Telekimoana	Passing to the Deep	Contains 2 seamounts. Contains trough and plateau with rift valleys forming on spreading ridges and basins. Towards the east is a chain of ridges which forms the Tonga Ridge with canyons in between the ridges. SST is low and stable, CHL is low and variable, salinity is high, dissolved oxygen is moderate and stable, deepwater temperature is moderate, 20°C isotherm is moderate, mixed layer depth is shallow, solar irradiance is low, pH level is moderate, silicate level is moderate, phosphate level is low, nitrate level is moderate, calcite is low. 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). Includes 5 blind canyon types. Contain 2 active, confirmed; 3 active, inferred hydrothermal vents. The upper depth is 500m and the lower depth is 2,500m. Important area for yellowfin, bigeye and albacore tuna and for deepwater snappers.
Deepwater	D382	Taka'anga Motu’a	Old Hang Outs	Three non-contiguous bioregions split between Fiji and Tonga. The boundary within Tonga is dominated by plateau with ridges and canyons around the Ha’apai region. The western region contains plateau and ridges on slopes. SST is moderate and variable, CHL is generally moderate but high close to land (Ha’apai group), salinity is moderate, dissolved oxygen is moderate and variable, deepwater temperature is medium, 20°C isotherm is medium, mixed layer depth is medium, solar irradiance is moderate, pH level is moderate, silicate level is moderate, phosphate level is low, nitrate level is moderate, calcite is generally low but high closer to land (Ha’apai group). Contains 3 seamounts type 1 (small with deep peak, short with moderately deep peak); 2 seamounts type 5 (intermediate size, small, moderately tall and shallowest peak depths of this group). Includes 3 blind canyon types and 7 shelf incising canyon types. Contains 2 active, inferred hydrothermal vents. The upper depth is 500m and the lower depth is 2,000m. Feeding ground for skipjack tuna.
Deepwater	D429	Falakoni	Falcon	Deep bioregion on trench, abyssal hills and mountains. Also includes 2 canyons and a small ridge on basin. SST is high; CHL, 20°C isotherm and the deepwater temperature are low. Salinity is variable and pH levels, nitrate and solar irradiance are moderate. Mixed layer depth is low. Calcite is low and variable and dissolved oxygen concentrations are low and stable. Moderate sea surface currents generally from the north-northeast. Contains no seamounts. Includes 2 blind canyon types. The upper depth is 4,000m and the lower depth is 8,500m.

HABITAT	CODE	TONGAN NAME	ENGLISH NAME	DESCRIPTION
Deepwater	D446	Tele’a 'Ata	‘Ata Trench	Deep bioregion which contains ridges, basins that slopes into the Tonga Trench. SST is low and stable; CHL, 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. Contains no seamounts. The upper depth is 5,000m and the lower depth is 9,500m. Important area for yellowfin, bigeye and albacore tuna and for deepwater snappers.
Deepwater	D454	Maata'u Tokelau	Northern Hook	Bioregion north of the Niua Islands, includes two seamounts forming on ridges and escarpments. Other dominant features include plateau and spreading ridges. SST is high and stable, CHL low and stable, salinity is low and variable, dissolved oxygen is low and stable, deepwater temperature is deep, 20°C isotherm is deep, mixed layer depth is medium, solar irradiance is moderate, pH level is moderate, silicate level is moderate, phosphate level is moderate, nitrate level is moderate, calcite is low. Contains 2 seamounts type 3 (intermediate size, large tall and deep); 4 seamounts type 5 (intermediate size, small, moderately tall and shallowest peak depths of this group); 7 seamounts type 10 (large and tall with shallow peak: shallow); contains 1 active, confirmed; 2 active, inferred hydrothermal vents. The upper depth is 2,000m and the lower depth is 5,500m. Important area for albacore tuna.
Deepwater	D461	Ika Moana	Deep Fish	Non-contiguous bioregion. Western part of bioregion is big and dominated by spreading ridges formed on plateaus. Also includes rift valleys formed on basins. The eastern part of the bioregion is mainly dominated by plateau. SST moderate and stable, CHL is low and stable, salinity is low and variable, dissolved oxygen is low and stable, deepwater temperature is deep, 20°C isotherm is deep, mixed layer depth is medium, solar irradiance is medium, pH level is low, silicate level is moderate, phosphate level is low, nitrate level is moderate, calcite is low but high closer to land. Contains 4 seamounts 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); Includes 3 blind canyon types and 4 shelf incising canyon types. Contains 2 active, inferred hydrothermal vents. The upper depth is 1,000m and the lower depth is 2,500m. Important area for yellowfin tuna and deepwater snappers.
Deepwater	D67	Liku Mama'o	Far Cliff	Contains Tonga Trench and abyssal hills. SST is high; CHL, 20°C isotherm and the deepwater temperature are low. Mixed layer depth, salinity and pH levels, nitrate and solar irradiance are moderate. Calcite is low and variable and dissolved oxygen concentrations are low and stable. Strong sea surface currents generally from the northeast. Contains 8 seamounts type 2 (small with deep peak, most common type); 2 seamounts type 3 (intermediate size, large tall and deep); 1 seamount type 7 (small and short with very deep peaks, shortest); 3 seamounts type 8 (small and short with very deep peaks, deepest type); 3 seamounts type 10 (large and tall with shallow peak: shallow); 2 seamounts type 11 (intermediate size, largest basal area and deepest peak depth). The upper depth is 5,000m and the lower depth is 5,500m.
Deepwater	D79	Liku Tafahi	Tafahi Cliff	Non-contiguous bioregion; contains plateau, ridges and abyssal mountains. SST is high; CHL, 20°C isotherm and the deepwater temperature are low. Mixed layer depth, salinity and pH levels, nitrate and solar irradiance are moderate. Calcite is low and variable and dissolved oxygen concentrations are low and stable. Strong sea surface currents generally from the northeast. Contains 1 seamount type 1 (small with deep peak, short with moderately deep peak); 3 seamounts type 2 (small with deep peak, most common type); 4 seamounts type 3 (intermediate size, large tall and deep); 1 seamount 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); 3 seamounts type 8 (small and short with very deep peaks, deepest type); 1 seamount type 9 (Large and tall with shallow peak, larger); 6 seamounts type 10 (large and tall with shallow peak: shallow); 1 seamount type 11 (intermediate size, largest basal area and deepest peak depth). Includes 1 blind canyon type. The upper depth is 4,500m and the lower depth is 5,000m.

HABITAT	CODE	TONGAN NAME	ENGLISH NAME	DESCRIPTION
Deepwater	D80	Kepilikoni	Capricorn	Contains the biggest seamount, the "Capricorn Seamount" on abyssal hill and trench. SST is high; CHL, 20°C isotherm and the deepwater temperature are low. Salinity is variable and pH levels, nitrate and solar irradiance are moderate. Mixed layer depth is low. Calcite is low and variable and dissolved oxygen concentrations are low and stable. Moderate sea surface currents generally from the north-northeast. Contains 1 seamount type 1 (small with deep peak, short with moderately deep peak); 2 seamounts type 2 (small with deep peak, most common type); 4 seamounts type 3 (intermediate size, large tall and deep); 7 seamounts type 7 (small and short with very deep peaks, shortest); 4 seamounts type 8 (small and short with very deep peaks, deepest type); 1 seamount type 9 (Large and tall with shallow peak, larger); 6 seamounts type 10 (large and tall with shallow peak: shallow); 2 seamounts type 11 (intermediate size, largest basal area and deepest peak depth). Includes 2 blind canyon types. The upper depth is 4,000m and the lower depth is 5,500m.
Deepwater	D87	Tu'atonga	Tonga Outbound	Contains ridges, abyssal mountains and plateau. SST is low and stable; CHL, 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 low and variable. Dissolved oxygen concentrations are moderate and stable. Moderate sea surface currents generally from the northwest. 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); 1 seamount type 9 (Large and tall with shallow peak, larger); Includes 9 blind canyon types. The upper depth is 2,000m and the lower depth is 4,000m.
Reef-associated	S2	Vaha'a Loto	Ata Reefs and Associated	Relatively deep (>50m) reefs with larger fish and larger invertebrates, such as *palu kula, palu mutumutu, valu*, tuna.
	S5	Tahi Ofato	Niue and Niuas Reefs	Isolated, oceanic reefs around the Niuas
Reef-associated	S6	Tokelau Lafalafa	Tongatapu, Ha'apai and Butaritari Associated Reefs	Relatively shallow water with higher levels of Chlorophyll, nitrate and calcite. High coral cover. Habitats for small fish including *manini, pose, kuku* etc. Organisms in this region will grow and eventually move into deeper S2 and S147.
Reef-associated	S147	Hakau Nimenima	Hakau Nimenima	Reefs typical of Vava'u.

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