Seabed Minerals Authority
Runanga Takere Moana

Strategic Environmental Assessment – Marine Spatial Assessment Sub-programme

Cook Islands Seabed Habitat Management Zones

John Parianos, Rima Browne, Tanga Morris

August 2023

Rev 1.1b

1 Abstract

Seabed habitat management zones (HMZ) are derived, presented, and tested as part of Cook Islands Seabed Minerals Authority's contribution to Marae Moana spatial management planning. These also serve as a key sub-programme for a forthcoming Strategic Environmental Assessment.

Dataset review supports level 1 (hierarchal) classification only at this stage, resulting in habitat management zones (likely groups of similar habitats) rather than discrete habitats themselves. Two semi-independent factors, each of three classes, are used: seabed geomorphology (abyssal plains, seamounts and ridges, plateau) and a model of net primary export for particulate organic carbon (based on levels used in a similar Clarion Clipperton Zone oriented study). The limited testing possible to date broadly supports the classification.

The HMZs have been subdivided by types of seas (e.g. territorial seas versus EEZ (exclusive economic zone)) and areas (EL (exploration licences)) to answer management questions. For example, abyssal plain type HMZs comprise slightly over 55% of the Cook Islands EEZ+ECS (extended continental shelf application), with Els over polymetallic nodules almost entirely confined to the very low and low net export types, with around 1/3rd and 1/10th of each of those areas currently under exploration licence. Data is limited but seabed mineral types (types of nodules, crusts and rare-earth rich muds) show associations with some of the HMZs.

Drafts of the HMZ system were presented to some eighteen different stakeholder groups with constructive feedback incorporated, especially in early versions of the exercise. This classification system can likely work alongside some of the other spatial plans for the region, e.g. for the overlying water column.

Test questions and a specific test program scope are also proposed for any future updates of the HMZs.

2 Contents

3 Introduction

This marine spatial assessment for the deep Cook Islands Seabed:

- Relies on mapping and classification of the seabed environment (i.e. habitat management zones);
- Is a contribution to the national Marae Moana spatial plan per the Marae Moana Act;
- Is a sub-programme for a Strategic Environmental Assessment (SPREP, 2020; Figure 3-1) for seabed minerals for the Cook Islands.

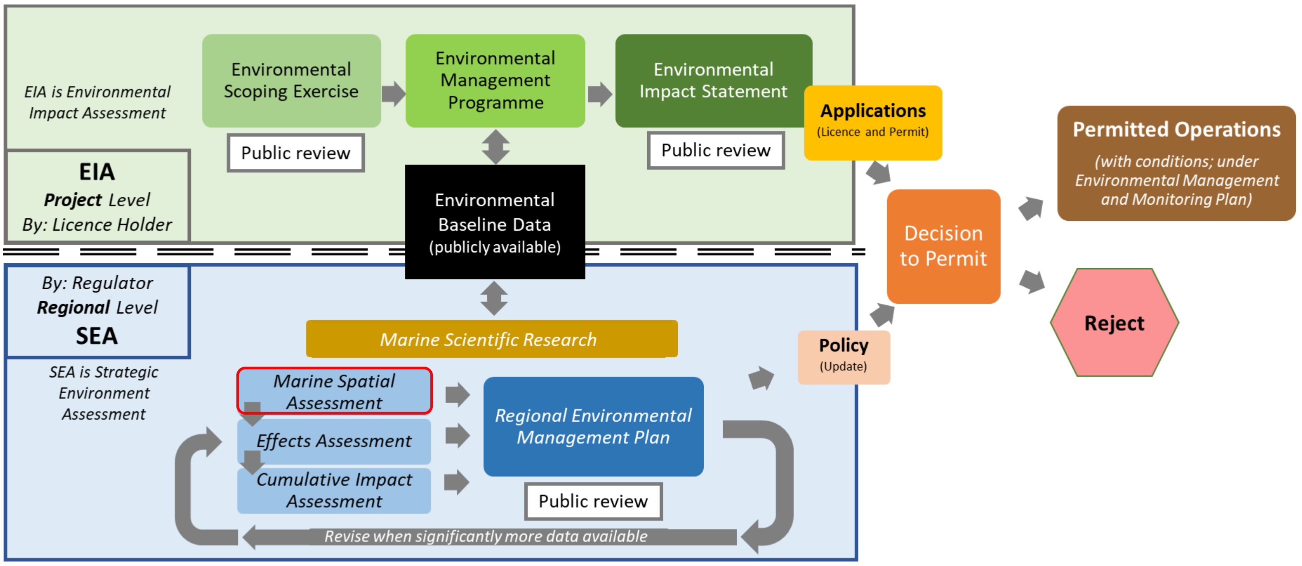


Figure 3-1: Marine Spatial Assessment in the context of the SEA and other Environmental assessments

In the context of the SEA at least the habitat management zones are fundamental. They form the basis for understanding the extent of the natural environment that might be impacted should minerals harvesting or mining be permitted to proceed.

The Cook Islands seabed hosts a large mineral resource of polymetallic nodules, part of which is being explored with the intent of eventual economic extraction. There are other mineralisation types present (RSC, 2023) but their distribution is currently very poorly understood.

4 Methods

4.1 Direction and datasets

Direction on production of a seabed spatial layer was taken from recent studies in the Clarion Clipperton Zone, i.e.:

1. Regional habitat classification per (McQuaid *et al.*, 2020)
2. Regional and local geoform (hierarchical) classifications in (Fejer, Cecino and Flynn, 2021)

Datasets available were:

- GEBCO 2021 grid (GEBCO Compilation Group, 2021) at a resolution of 15 arc seconds (~460, 445 and 416 m at 6,16 and 26°S respectively, noting much of the satellite input data is only accurate to a horizontal precision of 6 km or more (Li *et al.*, 2023));

- Geomorphological interpretation of the seabed based largely on the GEBCO 2021 grid, subsequently published by (Browne, Parianos and Murphy, 2023), at a scale of 1:3,000,000 scale
- Global model of particulate organic carbon flux (POC model; Lutz et al., 2007) at a resolution of 10 km.
- Existing proposed boundaries of the EEZ[1], ECS[2] and Marae Moana 50 nm island centred set-aside zones (termed MPAs but actually restricted multiuse zones; e.g. per https://navigatormap.org/).
- Locally restricted historical sampling, image transects and echosounder surveys at varying scales between 100 km and 100 m e.g. (JICA-MMAJ, 1986, 2001) and ultimately not used in the classification.

The datasets were compiled into GIS and evaluated in terms of precision against the three hierarchical levels of geoform of (Fejer, Cecino and Flynn, 2021). A key dataset was the GEBCO grid type identifier dataset as shown below in Figure 4-1. This indicates the vast majority of the bathymetry is indirect measurements from sea-level as measured by satellite. While often relatively accurate, the satellite data is of an order of magnitude lower precision than what the grid itself is reported to, as referenced above.

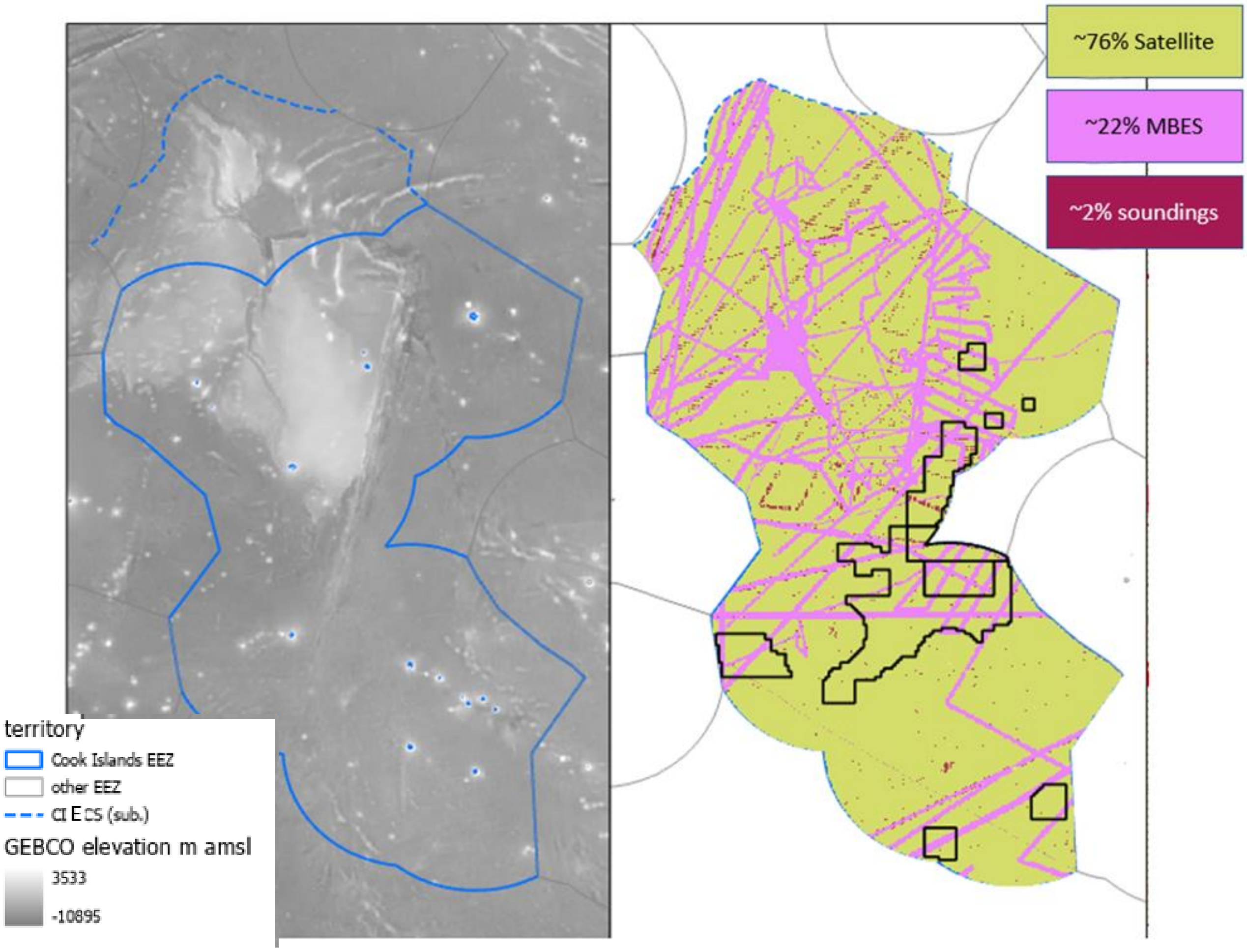


Figure 4-1: Gebco 2021 elevation and type identified for the Cook Islands

For accurate definition of mappable units, it is important that the datasets:

1. span the entire area being mapped, and this is the case for POC model and GEBCO grid-based geomorphology map;

---

[1] EEZ is Cook Islands Exclusive Economic Zone

[2] ECS is extended continental shelf submission

2. are at more or less the same precision, and this is the case for POC model and GEBCO grid-based geomorphology map (higher resolution information within the GEBCO grid being declustered or de-resolved).

Otherwise, any analysis will likely bias towards, or from, areas with data coverage, and maybe towards more data rich areas (in cases of higher variance).

It is also best if the datasets are largely independent of each other, which is the case of the POC model and the GEBCO grid-based geomorphology map, except that both datasets include depth amongst other factors, as discussed in classification methods further below.

Analysis of the data led to the decision being made that there is only enough information for a regional "level 1" hierarchical classification per (Fejer, Cecino and Flynn, 2021).

Planned exploration work, including MBES and seabed measurements, over the next five years should allow more detailed project or local scale classifications within a hierarchy (so-called level 2 and 3).

More detailed level classifications should be possible once MBES programs are complete as well as seabed measurements made to characterize the difference types of seabed physicochemistry, biology and substrate details. These classifications may then use different criteria than applied at level 1.

One dataset not used at the regional level classification, was nodule abundance. Reasons for this are given in the discussion section further below.

Another important point is that it was not assumed that habitats *per se* could be discriminated at level 1 as explained in the section below.

Shape files of 'sea-type' were also used to assist in possible management questions, i.e. EEZ, ECS, Territorial Seas (a key boundary between the Marae Moana Island vs National spatial plans), Marae Moana island centered Marine Protected Areas (MPAs) and current exploration licences.

4.2 Habitat Management Zones

A key implication at level 1 scale (resolution of kilometers to tens of kilometers) is that, irrespective of the foundation data and discrimination criteria applicable between habitats, individual habitats can likely not be resolved at this scale. Thus, the mapped units are termed habitat management zones or HMZs. HMZs are thus units that will likely include a range of different habitat types. For example, in terms of just geoform, abyssal plains include deeper located abyssal hill-valley complexes and interspersed small volcanic knoll-seamount edifices (e.g., Figure 4-2).

There is thus a key assumption that any such collection of habitat types within a habitat management zone(s), would be protected through the appropriate use of spatial management measures at this scale. This could include application in block (area) release policy for development. The use of the abovementioned hierarchically based levels 2 and maybe 3 would be then appropriate for more project and local scale-based activities such as seabed minerals extraction.

Definition of HMZs involves much fewer assumptions than the classification of (McQuaid *et al.*, 2020), who state "Each habitat class represents a different set of environmental conditions, and is assumed to support a distinct biological community."

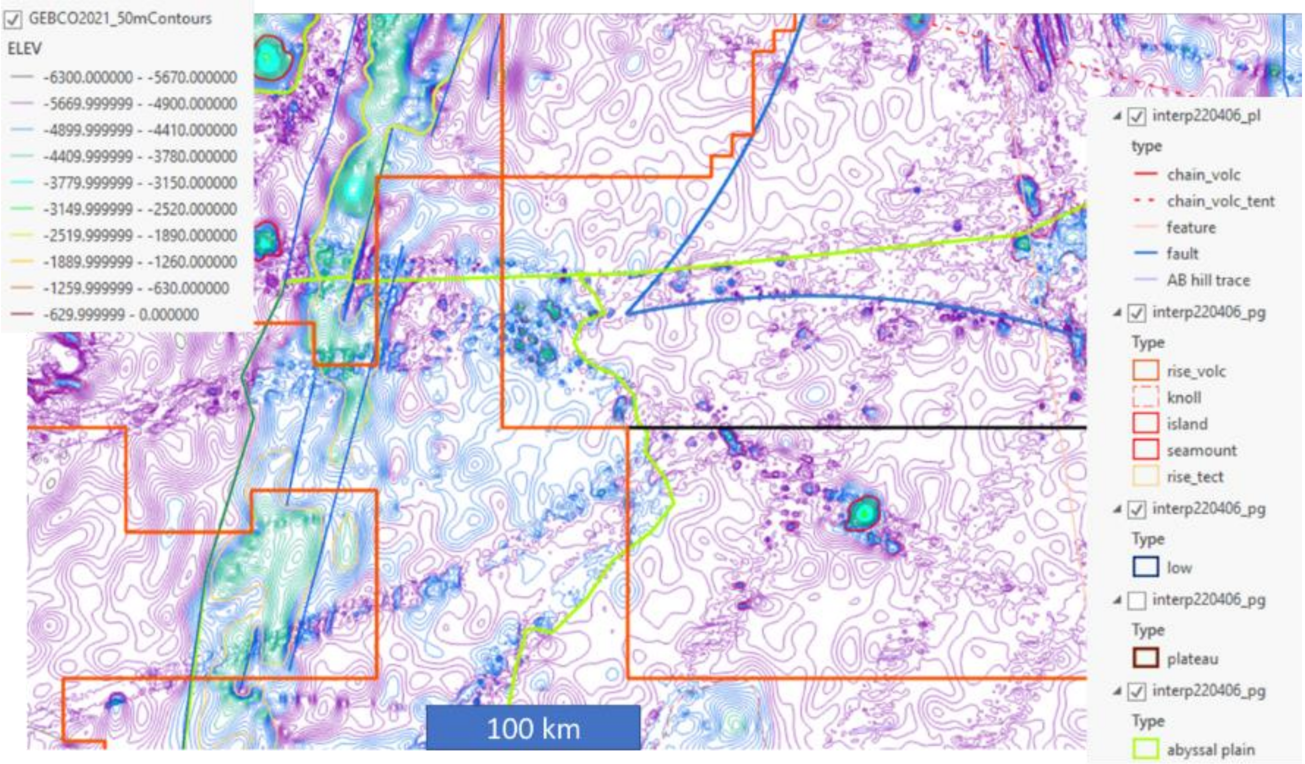


Figure 4-2: Example of MBES ship track data over abyssal plains (generally >4800 m).

Show areas composed of abyssal hills and knolls. This contrasts with the shallower tectonic rise towards the west that is associated with the Manihiki Plateau.

The level 1 HMZs can be thought to rest within an even larger scale spatial classification, i.e. that of global biogeographical zones e.g. per (Watling et al., 2013; Figure 4-3, see also Annex C), which is based on broadly similar criteria (seabed depth and surface primary productivity).

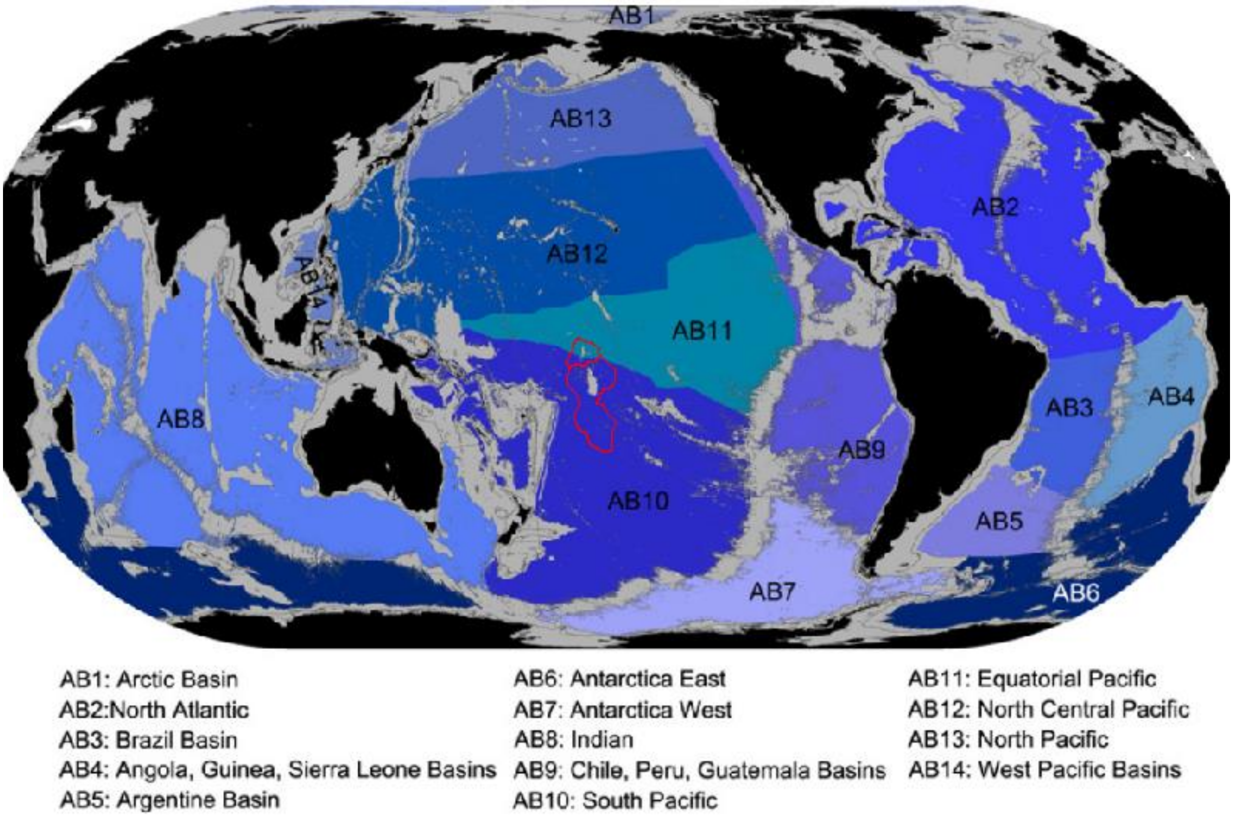


Figure 4-3: Cook Islands EEZ against one example of global biogeographic zones (Watling *et al.*, 2013)

4.3 Classification Methods

Key data used in the classification and delineation of the HMZs are:

1. seabed geomorphological interpretation and
2. net organic carbon export model

It is assumed that these two factors materially influence biodiversity and makeup at the scale of the management zones so can work as surrogates (e.g. per Harris, 2020). The results section below includes results of testing of these against alternative and complementary datasets.

4.3.1 Geomorphology

A 1:3,000,000 scale seabed geomorphology map of the Cook Islands (Browne, Parianos and Murphy, 2023), Figure 4-6, was consolidated to create three different geomorphological classes as described below.

The map is based largely on the GEBCO 2021 grid (GEBCO Compilation Group, 2021), which was contoured and carefully colour coded to emphasise key seabed features such as abyssal plain basins, troughs and knolls and seamounts (Figure 4-4). Reference was also made to magnetic data (Dyment, J., Lesur, V., Hamoudi, M., Choi, Y., Thebault, E., Catalan, M., the WDMAM Task Force*, the WDMAM Evaluators**, 2015). Interpretation of the geomorphology units was manually interpreted by one author, including ongoing review and re-review when contacts were less clear. The interpretation was then reviewed and checked by the other two co-authors, and the map went through associate and independent peer review prior to publication. While manual interpretation is labour intensive and not as easily reproduceable as techniques like autoclassification or cluster analysis, manual interpretation can be situationally focused, adaptable (i.e., can compensate for subtle difference in data density, depth changes and data artifacts) and can draw on the interpreter's >25 years of experience in geological and geomorphological mapping in both seabed and terrestrial settings. Formation of the Cook Islands seabed follows relatively well understood geological processes (Annex A). Manual interpretations are also done to a predetermined scale that reflects the overall quality and precision of the data, avoiding or reducing information effect issues and sometimes arbitrary or poorly justified data classification thresholds.

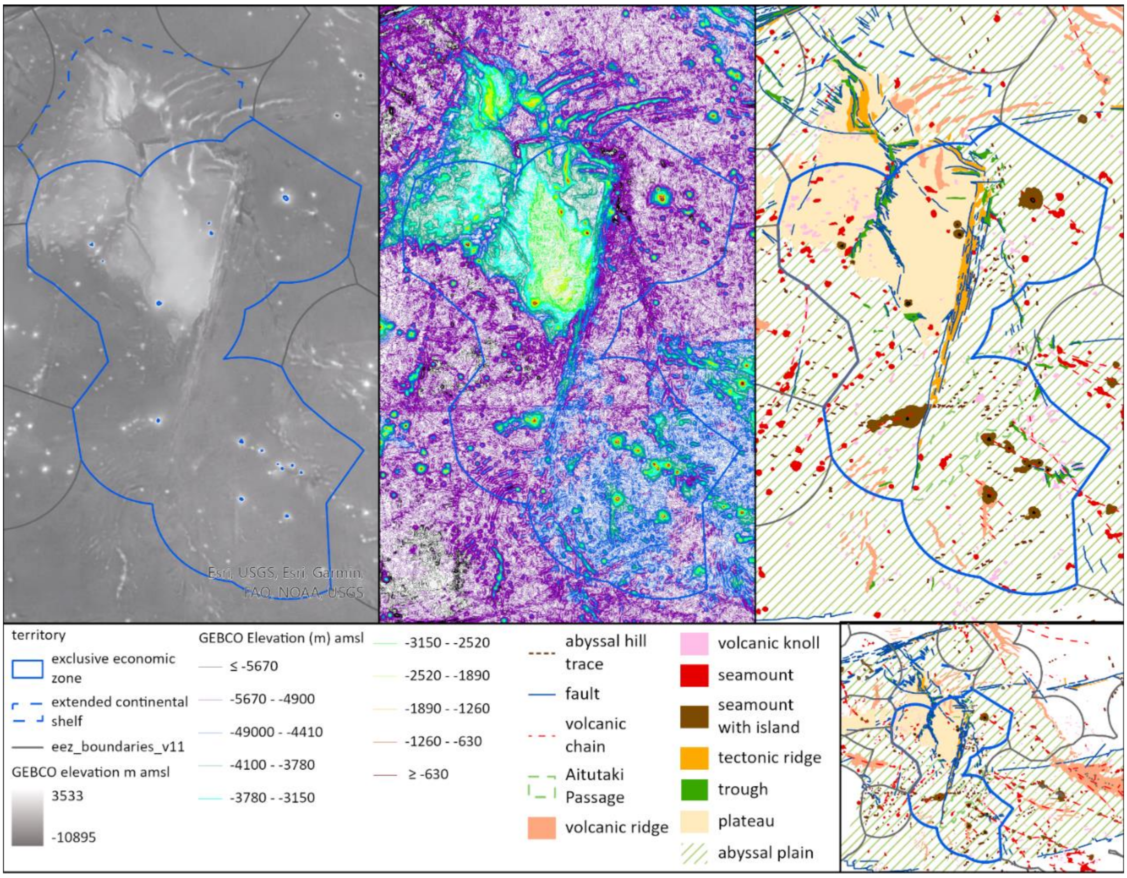


Figure 4-4: Process for the geomorphology interpretation

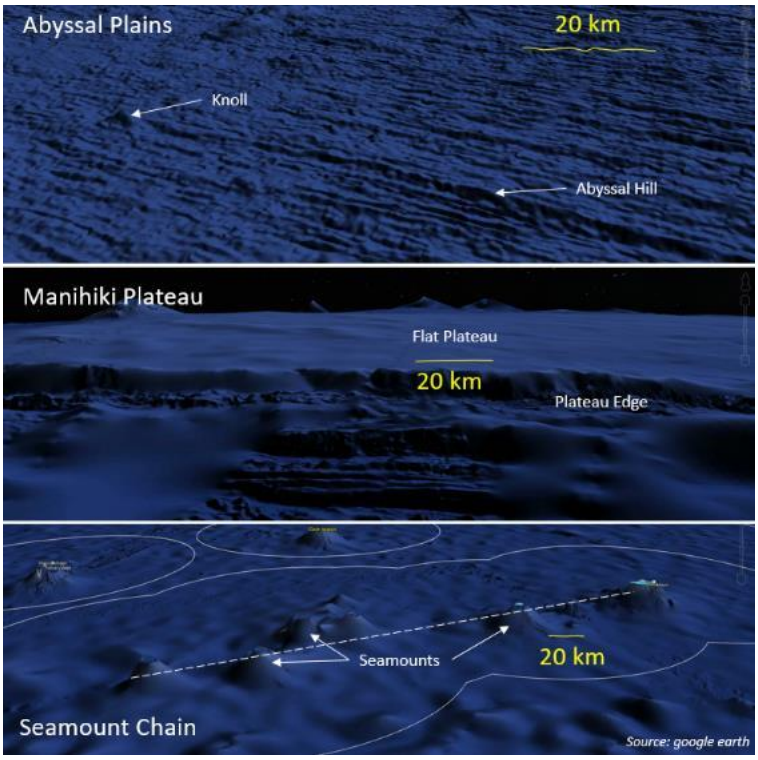
For the HMZs, the geomorphological classes are as detailed in Table 4-1 and Figure 4-5.

Table 4-1: HMZ geomorphology units

Class	**Key geoform**	**Other included geoforms**	**Key depths (Figure 5-4)**	**Other features**
A	Abyssal plains	Seabed “lows”, Aitutaki Passage, Rakahanga Rifts	Generally 5,500 to 5,000 mbsl	Mostly comprises red clay sediment at seabed transitional to clay-ooze at lower and higher latitudes cf POC model. Finer scales will include abyssal hill and isolated smaller knoll-seamounts. Nodules, crusts and REE muds known.
B	Seamounts	Larger knoll-seamount edifices extends to complexes and chains[3]	Highly variable	Sediment cover will vary with depth and slope with calcareous ooze at shallower depths. Extends further to 50 nm set-aside zones or marine protected areas under the Marae Moana Act Crusts and minor nodules expected.
C	Plateau	Danger Island troughs, marginal tectonic rises	Generally 3,000-4,000 mblsl	Comprises calcareous clay-ooze at seabed, some volcanic ridges and knolls at finer scales. Crusts and minor nodules known.

---

[3] A five km buffer (~one wide abyssal hill frequency) was included around seamounts and rises outside of the 50 nm Marae Moana set-aside areas.



Source: google earth

Figure 4-5: Examples of the main landforms

For context, the geomorphology map is compared with the HMZs in Figure 4-6.

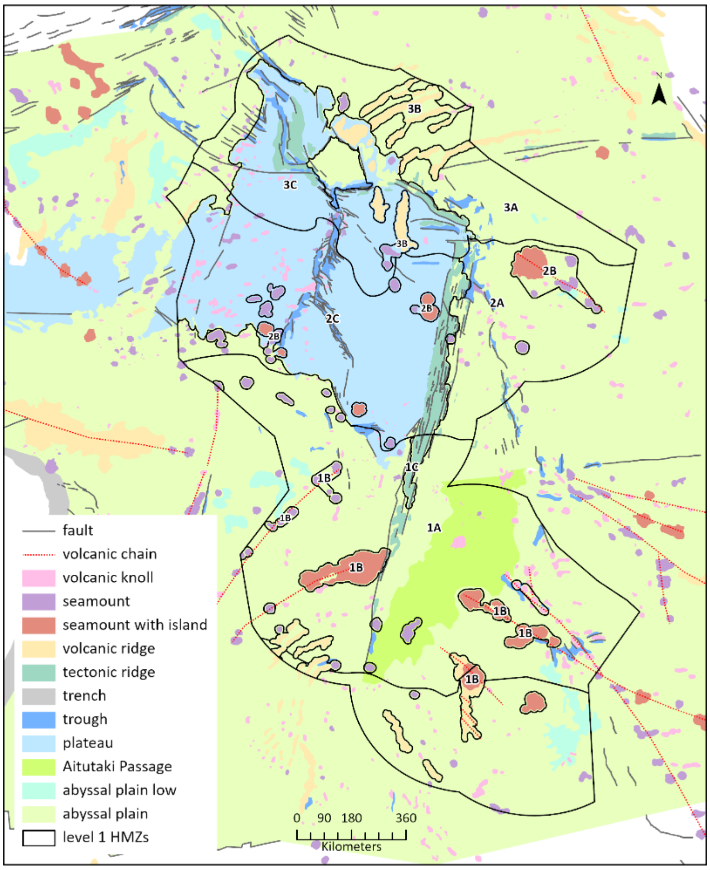


Figure 4-6: HMZs on 1:3,000,000 geomorphology map

The manual interpretation of the seabed geomorphology effectively takes into account the bathymetric position indices, slopes and depth criteria used by (McQuaid *et al.*, 2020), it also partly accounts for variations in substrate types (Table 4-1), but as will be discussed below seabed clay-ooze types are also more likely dependent on POC net export.

4.3.2 Net export model

Net particulate organic carbon flux is one of the key inputs of additional food to organisms at abyssal depths and thus very likely plays the greatest role in biological density and perhaps distribution of organisms. Like (McQuaid *et al.*, 2020), we used the net export model of (Lutz *et al.*, 2007).

This was for reasons of practicality (the Lutz model is publicly available), and to enable a ready comparison with the Clarion Clipperton Zone (the best studied nodule area to date).

The (Lutz *et al.*, 2007) model is a global model based on surface primary production of phytoplankton (between 1997 and 2004) and calculations on take-up by organisms in the water column. Surface production and flux models are adjusted for season variability (which broadly varies by ocean and latitude) and surface production/export amounts are empirically compared with flux collected in seabed sediment traps from around the world. The export model adjusts based on water depth (thus the dataset is semi-independent of the geomorphology), but there often seems to be little difference between 2,500 m and seabed in the region of the Cook Islands (Figure 4-7).

The south to north gradation in net export in the CCZ (per Figure 4-8), corresponds to a transitional change in seabed sediment type, that relates to changes in depth coupled with a south to north deepening lysocline in this region (Archer, 1999; Lipton, Nimmo and Parianos, 2016). Thus, deepsea water masses withstanding, at a certain (currently unknown) threshold the difference in export POC likely relates to changes in sediment composition at the depth of the abyssal plains.

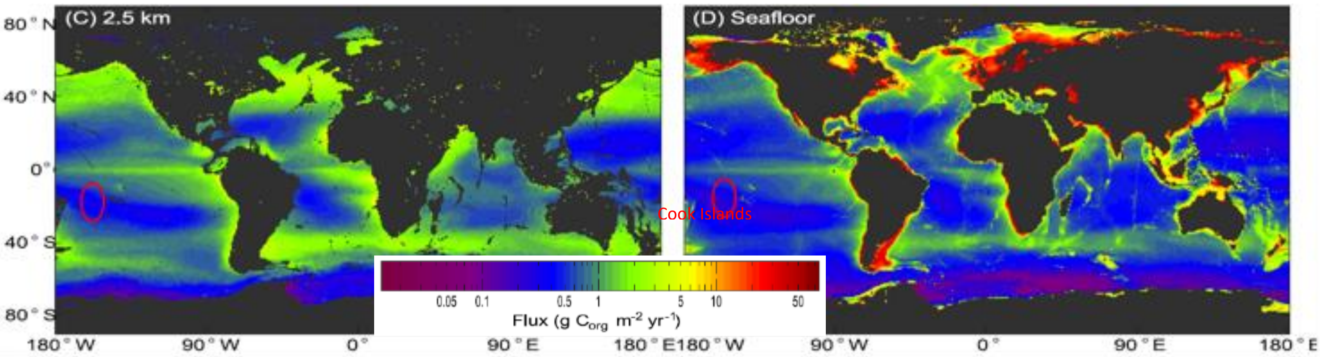
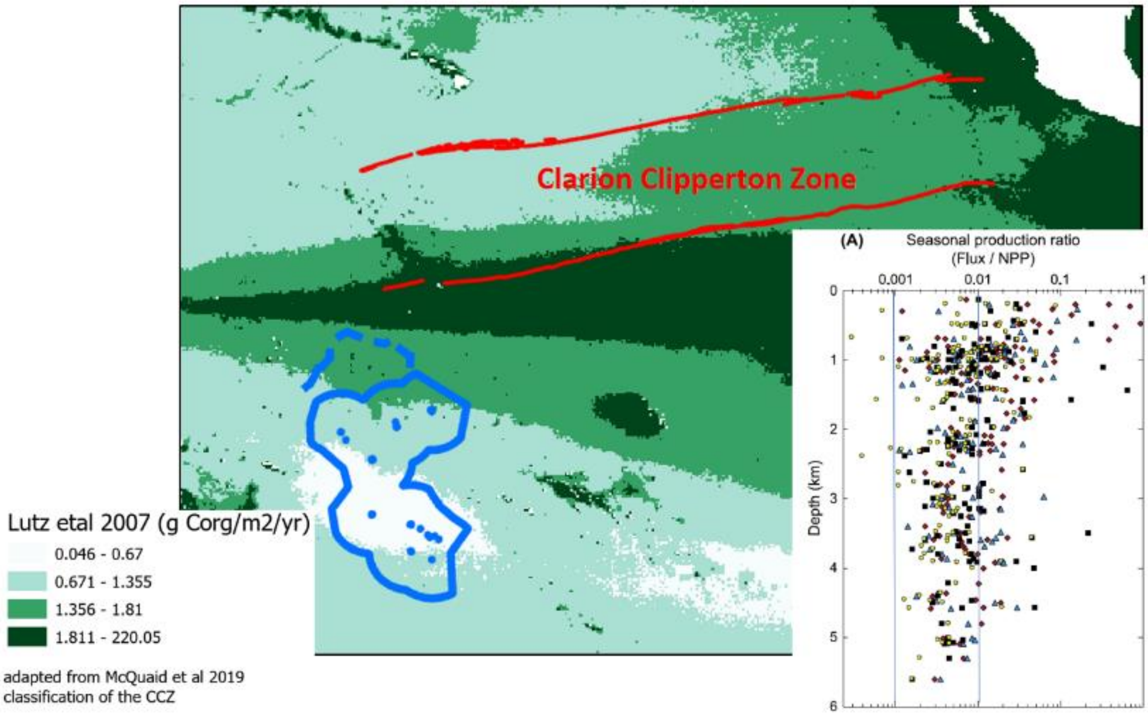


Figure 4-7: Net export model of (Lutz *et al.*, 2007) *at 2500 m depth and seafloor*

One key change was made to the classes of (McQuaid, Washburn and Howell, 2019; McQuaid *et al.*, 2020), that being addition of a very low class at approximately half the upper threshold of McQuaid's lowest class (Figure 4-8). The south Pacific and central Cook Islands includes the ultra-oligotrophic South-Pacific Gyre (e.g,. Pavia et al., 2020) due to distance from land and possibly Southern Ocean influences.

It is hoped that in due course the global net export model of (Lutz *et al.*, 2007) may be updated, perhaps in the region of the Cook Islands with a model including more complete local POC export data.



adapted from McQuaid et al 2019 classification of the CCZ

Figure 4-8: Seabed net export model for the central Pacific and example of measured flux rates

4.3.3 Spatial definition

After interpretation of the geomorphology and net organic carbon export, definition of the HMZs was a relatively simple process as illustrated in Figure 4-9:

1. Geomorphological units were combined in GIS per the three main classes discussed above;
2. These combined units were subdivided based on overlap with the net export classes.

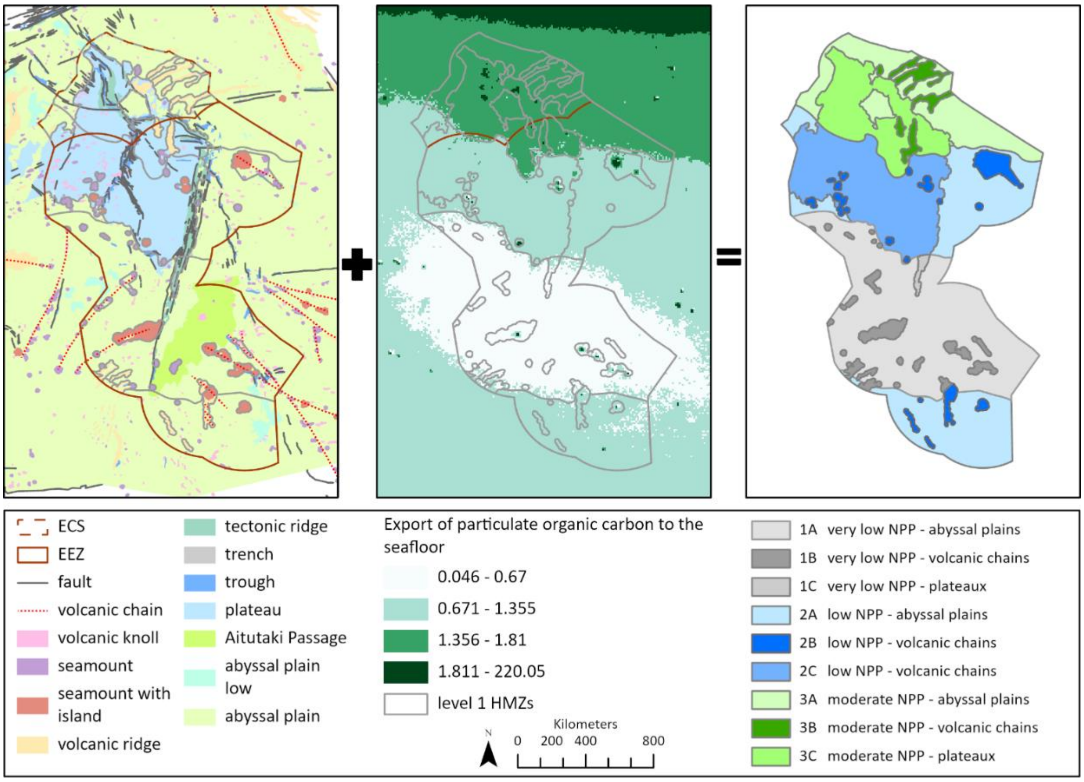
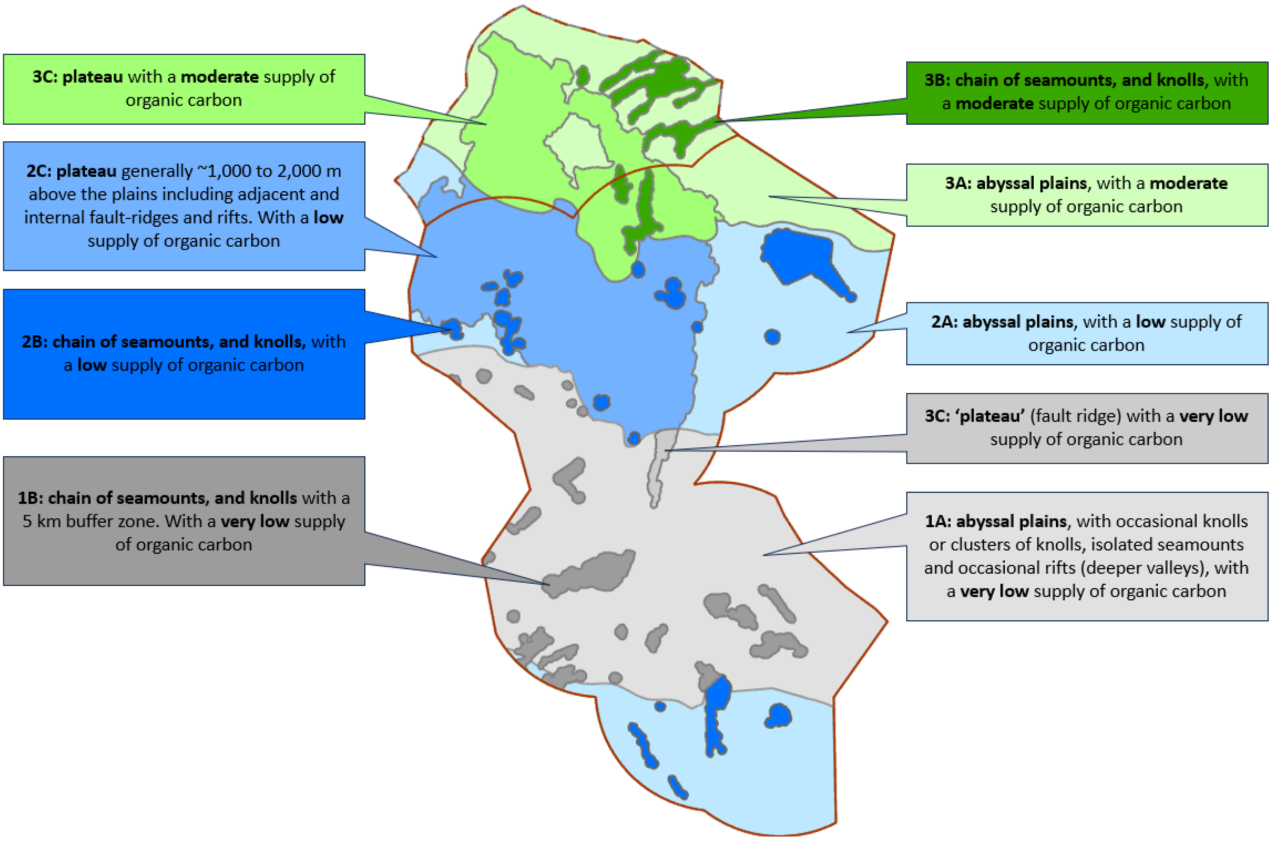


Figure 4-9: Essential process of defining the Level 1 HMZs

5 Results

5.1 Classification Results

The above methods classify the HMZs into a three-by-three matrix per Table 5-1 and Figure 5-1.



3C: plateau with a **moderate** supply of organic carbon

3B: chain of seamounts, and knolls, with a **moderate** supply of organic carbon

2C: plateau generally ~1,000 to 2,000 m above the plains including adjacent and internal fault-ridges and rifts. With a **low** supply of organic carbon

3A: abyssal plains, with a **moderate** supply of organic carbon

2B: chain of seamounts, and knolls, with a **low** supply of organic carbon

2A: abyssal plains, with a **low** supply of organic carbon

3C: 'plateau' (fault ridge) with a **very low** supply of organic carbon

1B: chain of seamounts, and knolls with a 5 km buffer zone. With a **very low** supply of organic carbon

1A: abyssal plains, with occasional knolls or clusters of knolls, isolated seamounts and occasional rifts (deeper valleys), with a **very low** supply of organic carbon

Figure 5-1: Summary of the HMZs

Table 5-1: HMZs Codes matrix and some key parameters

		Abyssal Plains etc.	Seamounts etc.	Plateaux etc.
Codes	Very low net POC	1A	1B	1C
	Low	2A	2B	2C
	Moderate	3A	3B	3C
	High	Not present in CI EEZ+ECS		
% of each HMZ in the EEZ+ECS	Very low	30%	3.6%	0.39%
	Low	22%	3.3%	17%
	Moderate	11%	2.4%	10%
% each HMZ under EL	Very low	27%	3.1%	17%
	Low	10%	0%	0.0047%
	Moderate	0%	0%	0%

Note colours in cells match legend in Figure 5-1.

Results of the classification include:

- Abyssal plain type (A) HMZs comprise slightly over 60% of the EEZ+ECS, with exploration licences for polymetallic nodules almost entirely confined to the very low (1) and low (2) net export types.
- A little under 1/3rd of the type 1A HMZs has been issued to exploration licence and about 1/10th of the 2A. These will clearly be key HMZs for future testing and will be supported by the exploration licence holders planned Environmental Management Programmes.
- High net export HMZs are not present in the Cook Islands, even marginally as found in the south-westernmost CCZ.
- Extents of Type 1C (Plateau, very low net export) are very limited and also of debatable definition, as this tectonic rise portion of the plateau is of relatively modest relief;
- Seamounts and volcanic chains are mapped from the bathymetric base of the chain and outside of the MPAs were assigned a 5 km buffer (in effect a single wide or several narrow abyssal hills).

5.2 Testing and Comparisons

Both surrogate components of the HMZs (geomorphology and net export model) were subject to some desktop testing. As noted further below, more testing is recommended (including focused seabed research) as material information comes to hand, and in due course the HMZs should be adapted according to then current understanding.

5.2.1 Geomorphology

The geomorphological interpretation was compared or tested against a:

- computer generated bathymetric position index (BPI) broad scale from the same grid per (Wright, D. J. *et al.*, 2005; Walbridge and Wright, 2012) Figure 5-2;
- global geomorphological map produced by (Harris *et al.*, 2014) Figure 5-3;
- summary of depth thresholds through the EEZ (Figure 5-4)

BPI (or TPI[4]) looks at relative position or depth based on scale factors that compare the position of a given position to its neighbours. Per (McQuaid, Washburn and Howell, 2019) for the broad scale BPI (bBPI) we used inner radius of 1 and outer radius 100 (scale factor 100 km) but we applied it to the GEBCO 2021 grid which has a resolution of 15 arc seconds (~463 m at the equator) or roughly 4 times the resolution of the GEBCO 2008 grid that was available to them. Processing for SBMA was carried out by consultants Kenex in Wellington New Zealand.

Visual comparison between the manual interpretation and the bBPI is very good. Textural differences between the different map units suggests that even the GEBCO grid is reflecting seabed form even if for example, individual abyssal hills cannot be seen. A comparison with the other benthic terrane modeler (BTM) products (depth, fine scale BPI and slope; Annex D) failed to find any meaningful correlation suggesting that such products should probably only be considered for areas with complete multibeam coverage (i.e. level 2 and/or level 3 HMZs).

---

[4] On land a very similar process is called Terrane Position Index

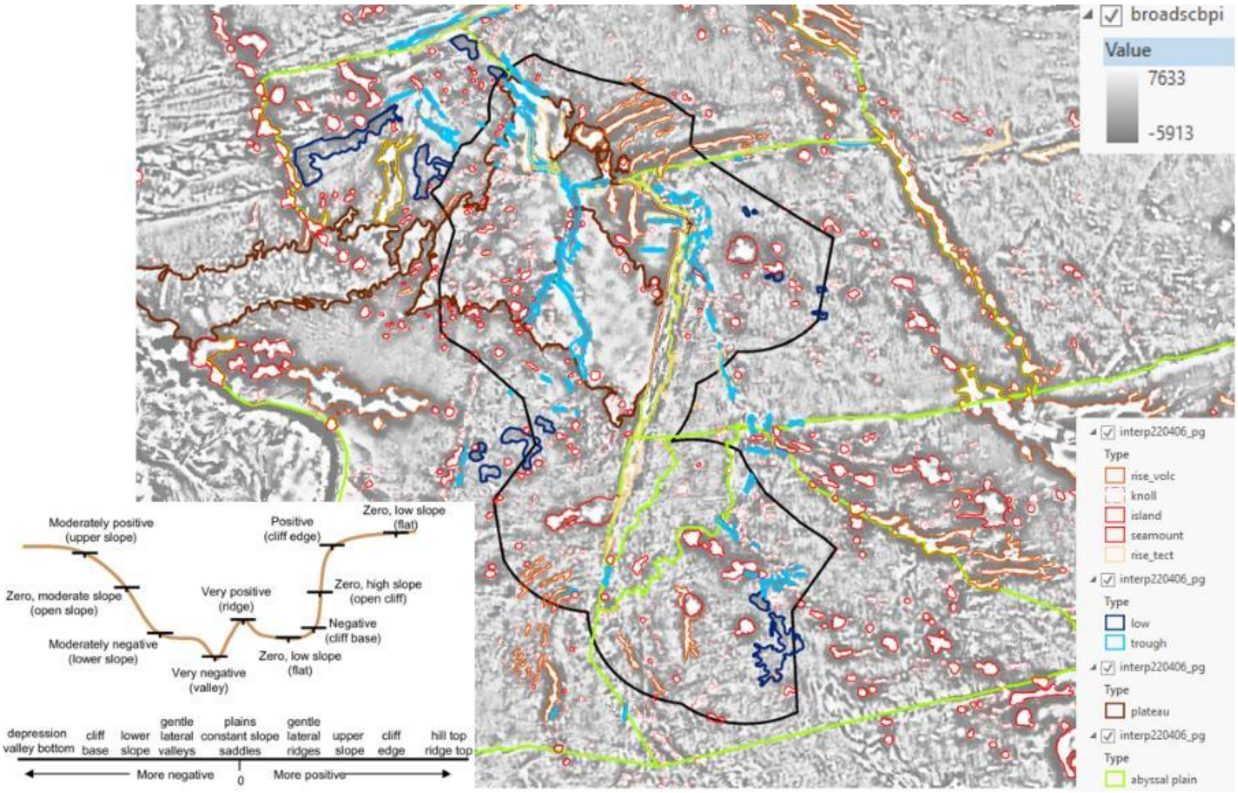


Figure 5-2: Comparison with bBPI (bathymetric position index broad scale)

The comparison with the global assessment by (Harris *et al.*, 2014) again shows good correlation, but the geomorphology by SBMA has better detail and resolution especially with regards to definition of some units such as the Manihiki Plateau. Differences in abyssal plain lows may relate to different generation GEBCO grids being used, with SBMA using a more modern higher resolution grid.

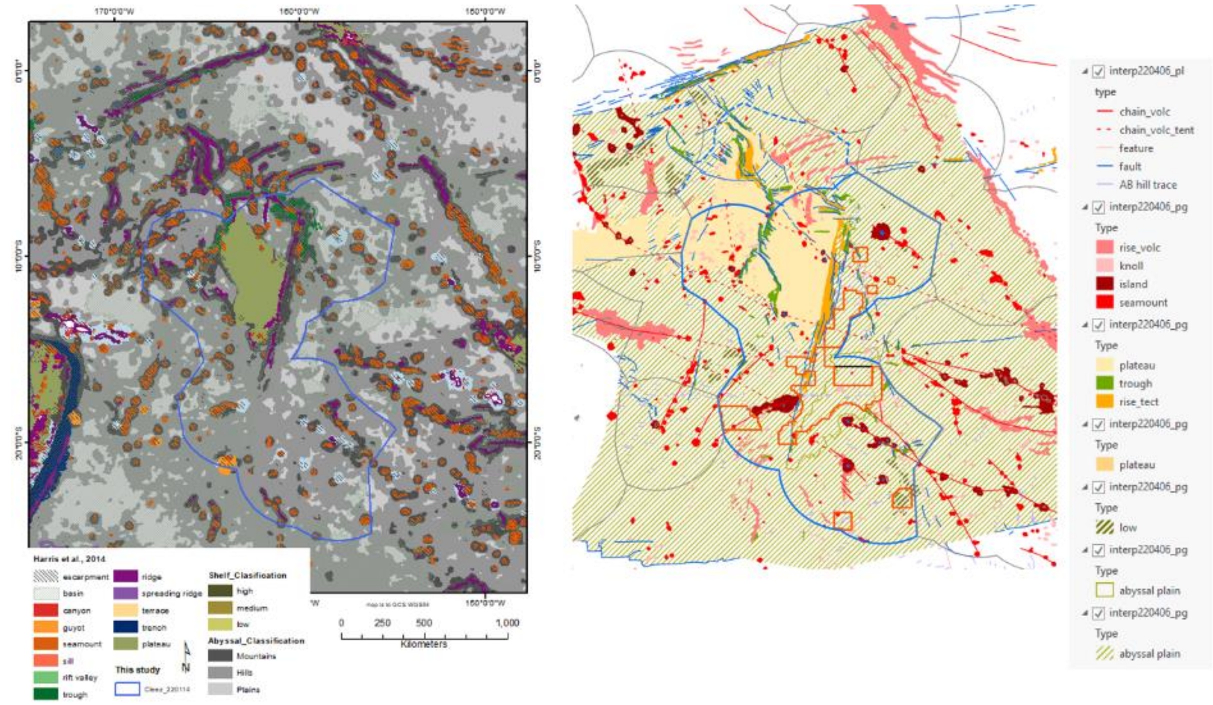


Figure 5-3: Comparison with global geomorphology of (Harris *et al.*, 2014)

When compared with depth thresholds (Figure 5-4) the abyssal plains mostly become apparent from the other units at the 4,000 m depth threshold. Variance within the Manihiki Plateau includes the Danger Island Troughs and the Manihiki Basin, while at 5,000 to 5,500 m the abyssal hills basins show some slightly distinctive areas that future testing may wish to focus on. Only some of the seamount chains (geomorphology class B) have any likelihood of crossing the oxygen minimum zone assuming the model in the world ocean atlas (Figure 5-4) proves to be accurate.

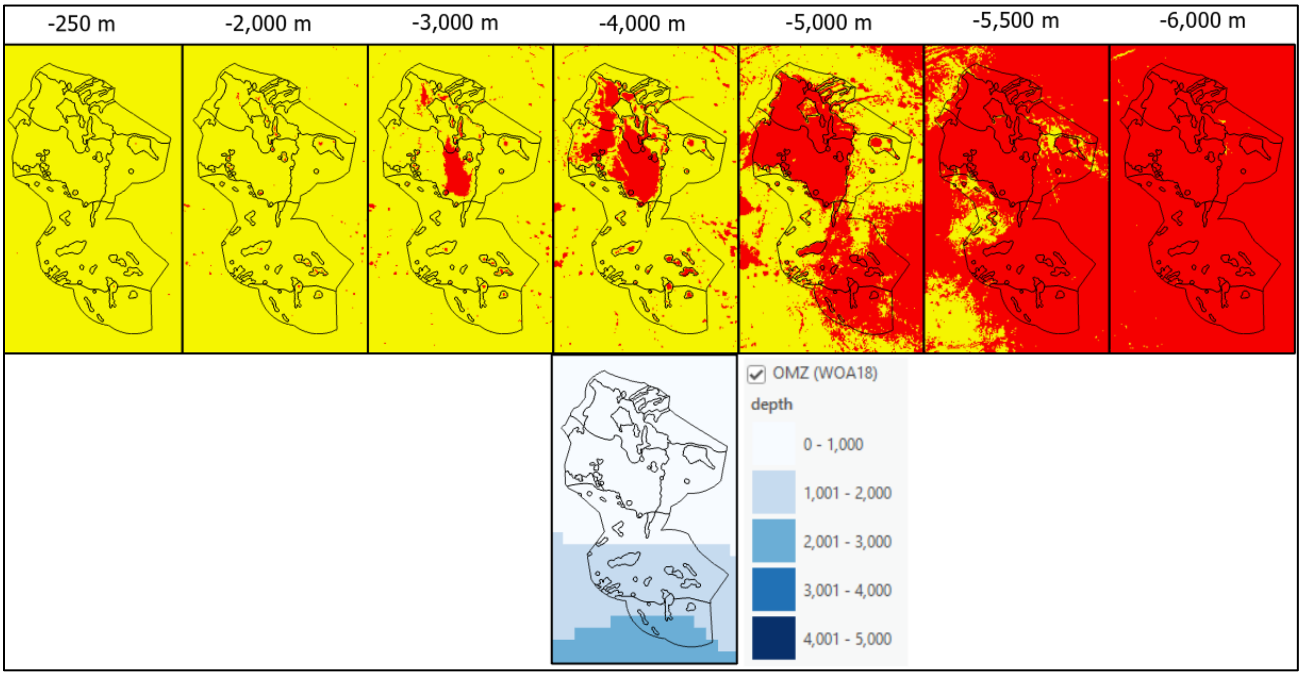


Figure 5-4: Comparison of HMZs with depth and model OMZ

5.2.2 Net export model

Testing or comparisons against the net export model was done in three ways, i.e. against:

1. Monthly and annual surface chlorophyll levels (e.g. Figure 5-5);
2. Regional scale ocean silicate levels (Figure 5-6);
3. Limited seabed photography (Figure 5-7).

Compilation of surface data chlorophyll data (e.g. Figure 5-5 was done courtesy of Fathom Pacific as the volume of raw data required was simply not able to be downloaded in the Cook Islands. Note there is a similar correlation with annual averages (Annex B).

As surface chlorophyll was a key dataset used in the modelling of (Lutz *et al.*, 2007), the test is not independent. However, monthly surface data was used mostly to try and evaluate the stability of the very low export and moderate export zones versus the low export zone as presence of a feasting season might influence habitats. From Figure 5-5 the various surface input into the zones is stable based on 10 years of averaged data.

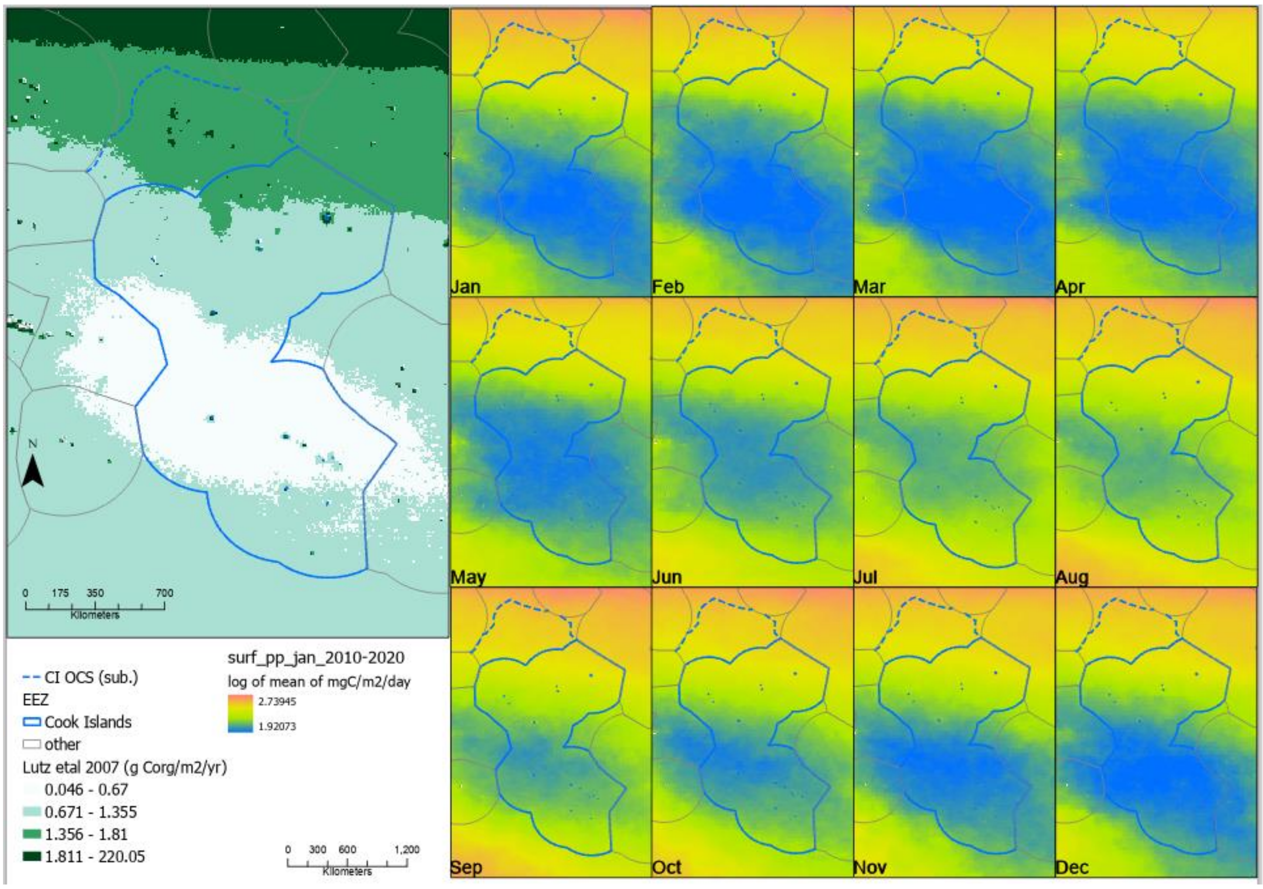


Figure 5-5: Comparison with surface chlorophyll – average of each month 2010-2020

Comparison with seawater silicate values (presumed to be largely derived from exported diatoms) was done per Figure 5-6 (Garcia *et al.*, 2019). As the dataset is dependent on the results of casting, seasonal or even annual data is not available. Samples are also relatively scarce, especially within the Cook Islands EEZ+ECS. Nonetheless it is apparent that while surface values are consistent with the surface chlorophyll, with greater depths a north-south trend dominates before there being no obvious trend. While silicate values do increase generally with depth (which is a characteristic of all of the major oceans). Future testing may well need to investigate the contributions from silicate-based organisms versus possible water mass contributions (e.g. Liu & Tanhua, 2021).

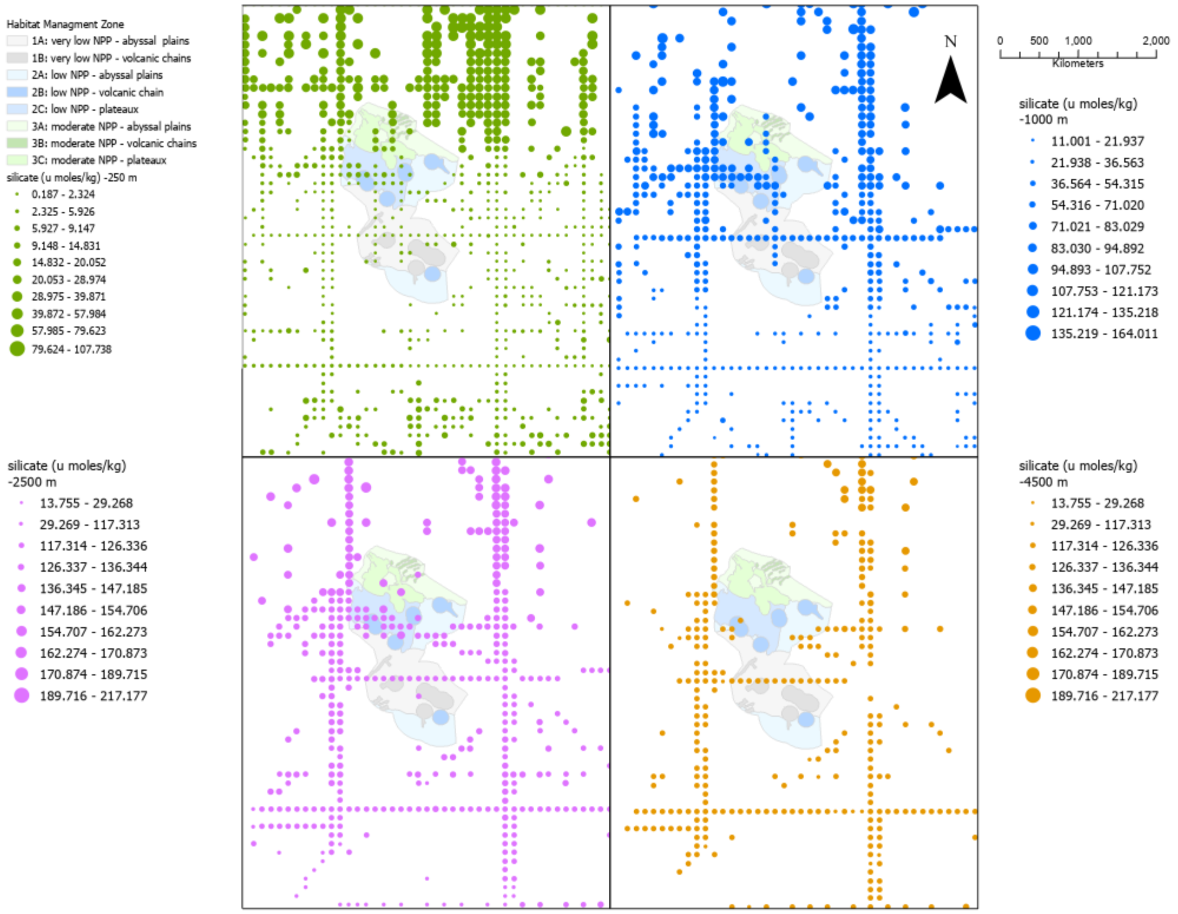
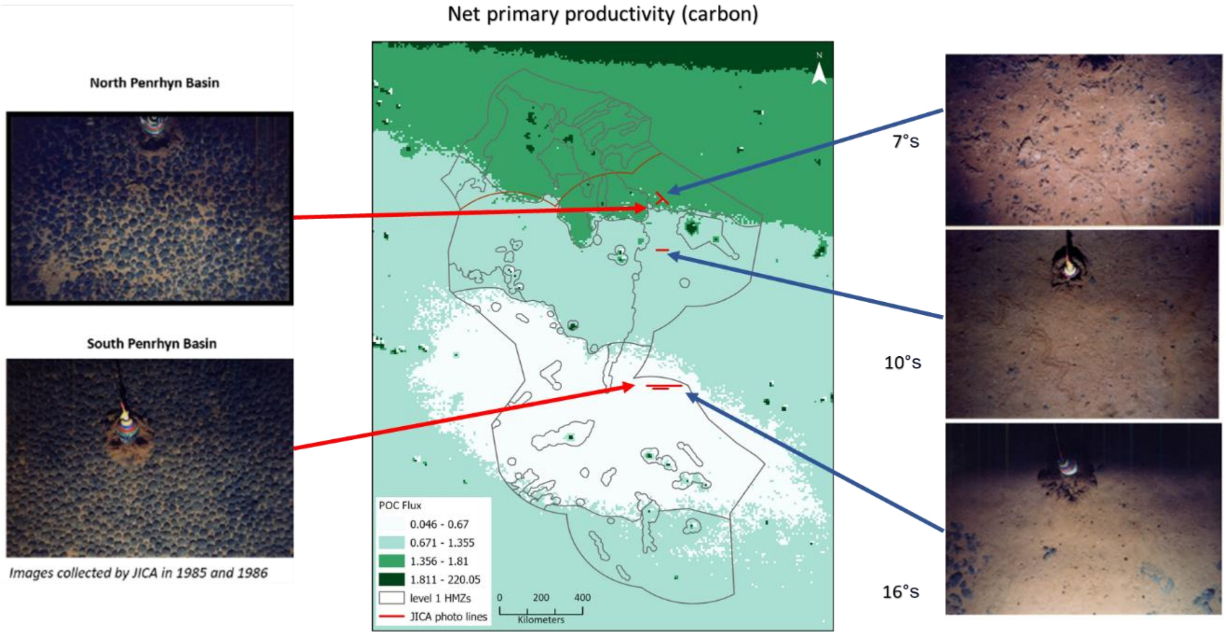


Figure 5-6: Regional silicate values and the HMZs



Images collected by JICA in 1985 and 1986

Figure 5-7: Seabed photos against net export zones

A direct comparison of the net export classes is possible by looking at seabed photographs from different latitudes (JICA-MMAJ, 1986, 1987). The photo examples in Figure 5-7 were collected using a towed camera and total about 200 in number. Most of the photos are of seabed covered in ferro-manganese deposits, but a few that are of exposed seabed clay ooze can provide an indication of the habitat and net export via the degree of observable bioturbation. There is a clear change from photos collected at 7° S against those further south, i.e., much higher rates of burrowing and scats as well as more ovoid and rougher surface nodules that suggest a possibly more diagenetic origin. There might be a slight decrease in bioturbation from 10 to 16° S, but the number of photos is nowhere near what might be considered statistically significant.

5.2.3 Future testing

Future testing may consider two key questions that the testing (Figure 5-8):

1. Between parts of a defined HMZ – are they truly the same? and
2. Between different HMZ – are they actually different?

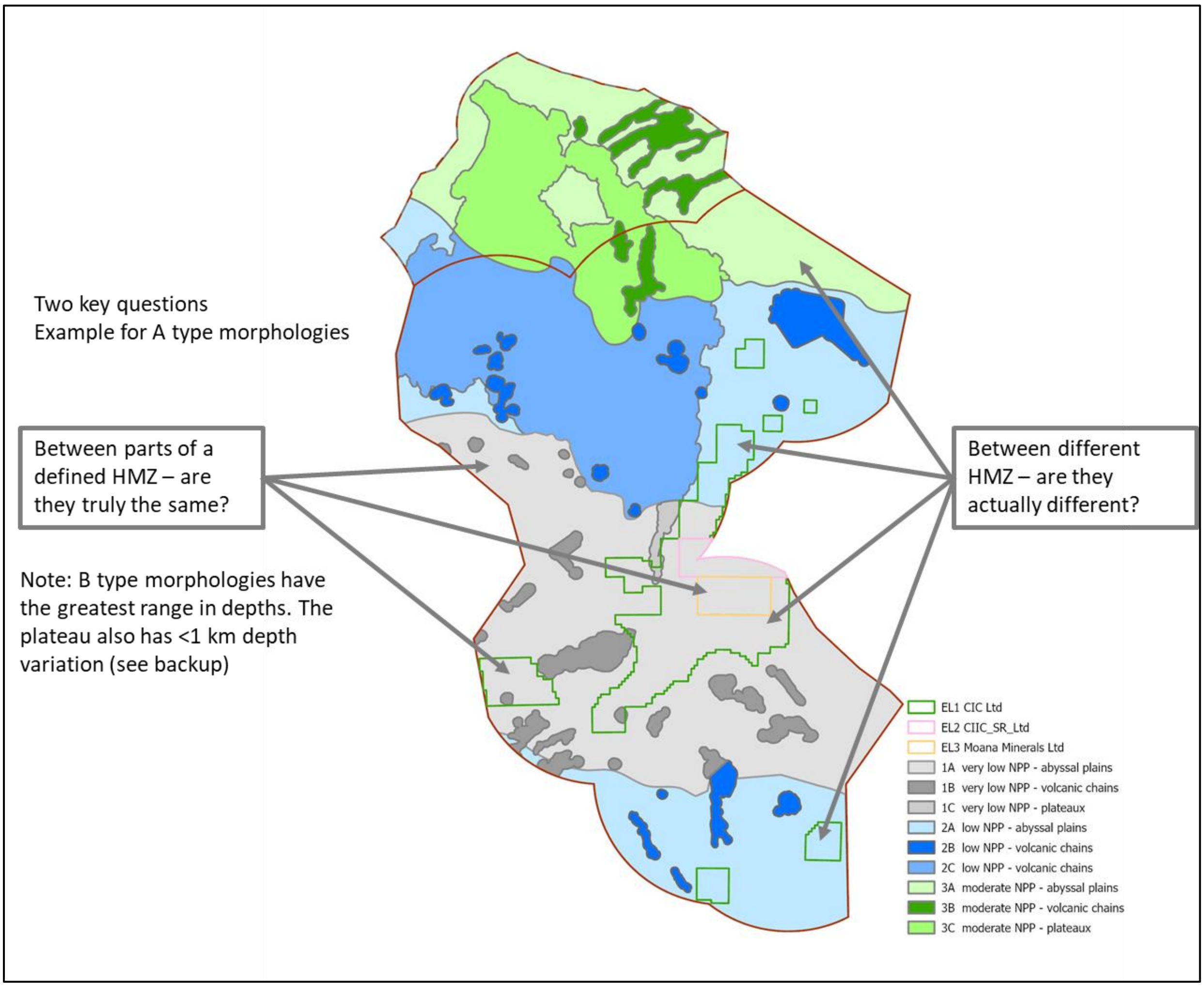


Figure 5-8: Questions for testing of HMZs

Clearly the type/nature of the HMZ would affect how the question/test would be detailed. Even before variance between differing latitudes or longitudes are considered, the seamount HMZs would be expected to get changes with depth, the question might be how these differ between different seamounts. Changes in depth between abyssal plain basins (~1,000 m within the Cook Islands) and the Plateau may or may not prove to be significant.

While detailed design of future testing of the HMZs is beyond the scope of this report, a preliminary concept is illustrated in Figure 5-9. The three times 30-day program envisages using Kiva Marine's Anuauna Moana with several passages collecting MBES, sub-bottom profiler data and incidental upper water column biomass estimates. A final transect would involve seabed sampling and imaging, likely through a combination of ROV, multicore and box core sampling (with water column profiles) as well as potential sediment chemical profiling.

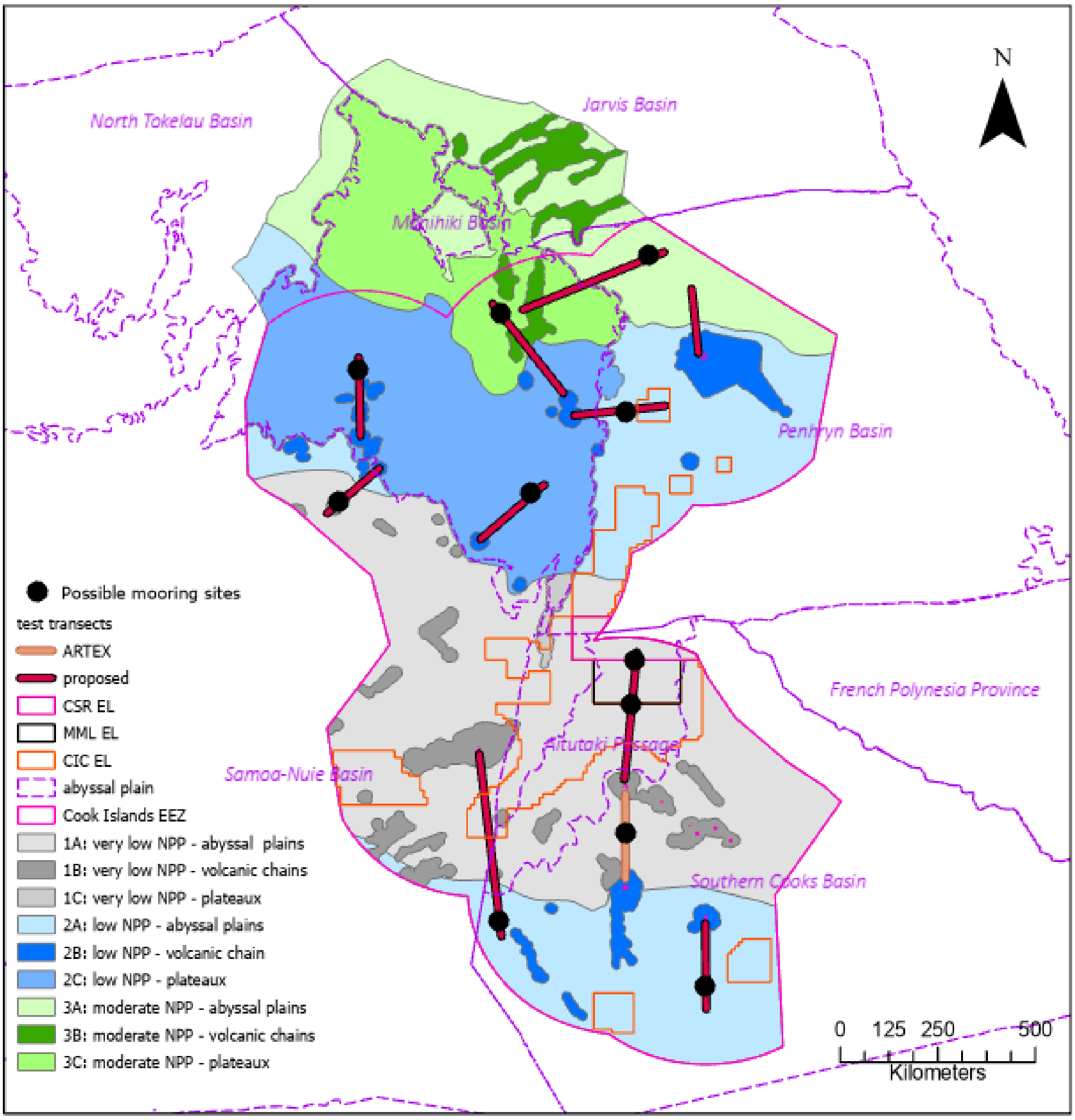
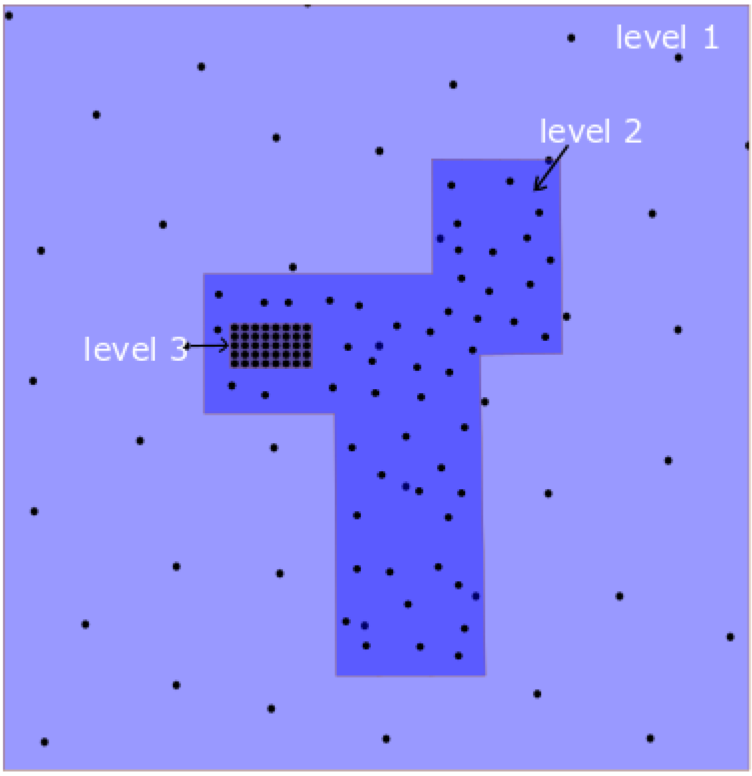


Figure 5-9: Draft test transects for testing of HMZs

6 Discussion

6.1 Levels of HMZs/Habitats

The difference between different levels of mapped HMZ/habitat is defined below in Figure 6-1, but it should be borne in mind that until a full derived example of Level 2 and 3 HMZ/habitats is complete the definition will be somewhat uncertain. Systems like the JNCC (Joint Nature Conservation Committee) Marine Habitat Classification for Britain and Ireland may prove to be useful at these levels (https://mhc.jncc.gov.uk/). Emerging automated processing techniques of the substrate component (e.g. Geomorphons) may also help (Di Stefano and Mayer, 2018).



Level 1	Level 2	Level 3
Substrate: geomorphology from mostly satellite bathymetry	**Substrate**: geology and geomorphology from multibeam echosounder bathymetry (MBES) and backscatter	**Substrate**: detailed geology and geomorphology from MBES bathymetry and backscatter supported by systematic photo surveys
Ecosystem function: from net export model	**Biogeochemical and Chemical** characterisation by HMZ	**Biogeochemical and Chemical** mapping
	Biological communities characterisation by Habitat/HMZ	**Biological communities** mapping and modelling
Application: entire EEZECS submission	**Application**: extents of MBES	**Application**: extents of planned development, anticipated impact and PRZs

Figure 6-1: Levels of habitat management zone or habitats

6.2 HMZs and types of seas and areas

Use of HMZs alongside other marine spatial planning layers can be as follows:

1. To answer specific questions e.g.
    - How much of each HMZ is present in the ECS+EEZ vs EEZ or ECS?
    - How much of each seabed HMZ has been permitted?
    - How might the objective of protecting 30% of the oceans by 2030 be best achieved?
2. To help inform the Marae Moana marine spatial plans for Islands (out to territorial seas excluding Suwarrow) and National area (remainder to the limits of the EEZ);
3. To inform the seabed minerals Strategic Environmental Assessment and thus government block release policy

To assist the HMZs are subclassified by “type” of sea i.e., extended continental shelf (ECS), exclusive economic zone (EEZ), Marae Moana marine protected area (MPA), territorial seas (TS) as well as seabed minerals exploration licence areas per Figure 6-2.

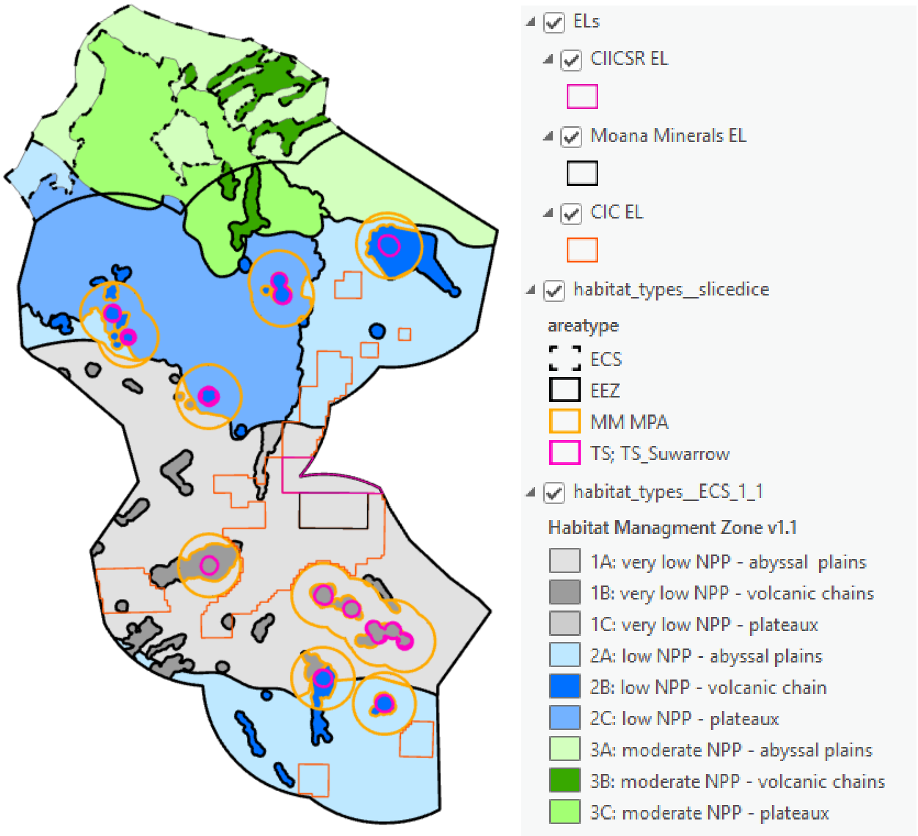


Figure 6-2: Types of seas and areas over the habitat management zones

6.3 Consultation and review

In addition to internal (SBMA) review, this HMZ schema has been presented to representatives from:

1. Marae Moana Technical Advisory Group;
2. National Environment Service;
3. Ministry of Marine Resources;
4. Ministry of Foreign Affairs & Immigration;
5. Ministry of Transport;
6. Marae Moana Coordination Office;
7. Infrastructure Cook Islands;
8. Climate Change;
9. several Te Aronga Mana;
10. Natural Heritage Trust;
11. Te Ipukarea Society;
12. Korero o te Orau;
13. the Pacific Community;
14. New Zealand National Institute of Water and Atmospheric Research;
15. International Union for Conservation of Nature;
16. CIC Limited
17. Cobalt Seabed Resources Limited;
18. Moana Minerals Limited.

Especially in earlier consultations, considerable feedback was received mostly around role and comparisons with other spatial datasets (e.g., Annex C), and was incorporated into the analysis.

6.4 Other seabed minerals

There is a clear association between seabed minerals types and the HMZs per Figure 6-3.

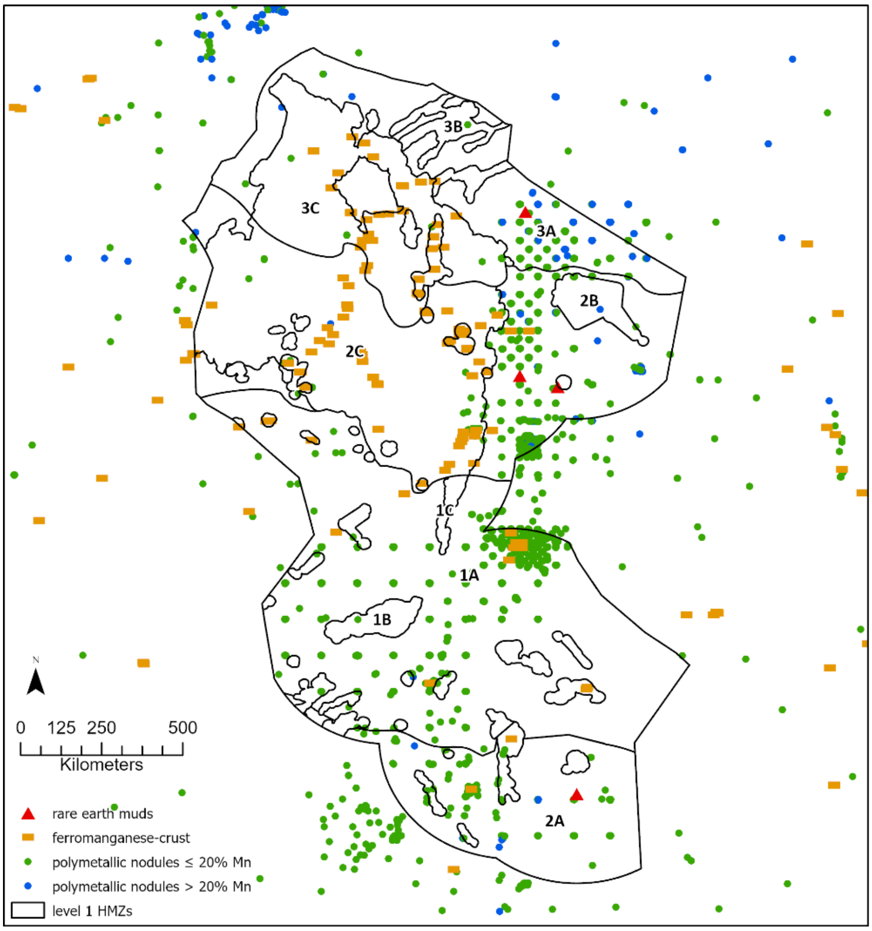


Figure 6-3: Different seabed mineral occurrences and the HMZs

Specifically:

- most nodules are found on abyssal plains (type A), with:
    - type 1A plains hosting low manganese type nodules; and
    - type 2A and more commonly 3A hosting a mix of low and high manganese type nodules (likely reflecting long periods of higher next export to these areas);
- most crust occurrences are:
    - on the sides of the Manihiki Plateau (2C and 3C); as well as on
    - some seamounts; and in some cases
    - on abyssal plains
- REE muds have so far only been found on type 2A and 3A, but these have not been well explored.

6.5 Use of nodule abundances in HMZ or habitat classification

Nodule abundances were not used as a discriminant for the level 1 HMZs, but they were used by (McQuaid *et al.*, 2020) in the classification of their 24 habitat types, who considered nodule abundances as a proxy for substrate. For completeness, maps of the key nodule domain and mineral resource estimate, scaled per the classes of (McQuaid *et al.*, 2020), comprise Figure 6-4.

There are three main reasons why nodule abundance was not used in the definition of the HMZs:

1. Data extent: Nodule abundance samples do not span the entire EEZ or even the abyssal plains (that were used as the bounding domain in the mineral resource estimate model[5]).
2. Role: While it is unquestioned that nodules work as substrate for many species of epifauna, the influence of abundance is unclear. The data of (Simon-Lledó *et al.*, 2019) as quoted by (McQuaid *et al.*, 2020) show that apart from very low abundances (<3% cover[6]) there is generally little to no influence on biodiversity or faunal composition. Indications of fauna standing stocks being associated with abundance is also not clear at a regional scale, as this study is based on very limited sampling, from one corner of an APEI, using three AUV transects, with clear local variations in cover that might relate to geomorphology. Region spanning surveys, accounting for the other key factors is needed. Alongside nodule abundance, other more locally scaled features such as location and orientation of abyssal hill slopes and knolls are also thought to be important, and even their influence on biodiversity is not certain e.g. (Lipton, Nimmo and Parianos, 2016).
3. Scale and continuity: Following in part from the above point, an assumption by (McQuaid *et al.*, 2020) that “broad patterns in nodule abundance are more important than smaller scale heterogeneity in driving regional patterns in species distributions” appears difficult to substantiate. Continuity or variance in nodule abundance is known to be locally influenced in many areas, in part by geomorphology-substrate as mentioned above. This largely drives the domaining and classification of nodule mineral resource estimates (Nimmo, Morgan and Banning, 2013; Lipton, Nimmo and Parianos, 2016; Lipton, Nimmo and Stevenson, 2019; RSC, 2023). Regional variations in morphospecies megafauna counts are documented from the CCZ e.g. (Lipton, Nimmo and Parianos, 2016), with no suggestion of control by broad patterns in abundance.

While it is very possible that nodule abundance may influence or even define habitats locally, this is better tested and managed at levels 2 or 3, with detailed seabed observations to support any such classification.

---

[5] Note that nodules are known to exist outside the abyssal plains e.g. on parts of the Manihiki Plateau (Cronan, 2013) but these did not have reasonable prospects of eventual economic extraction at the time of the MRE so were excluded from it.

[5] The relationship between cover and abundance at moderate to high abundances is known to be poor (Lipton, Nimmo and Parianos, 2016)

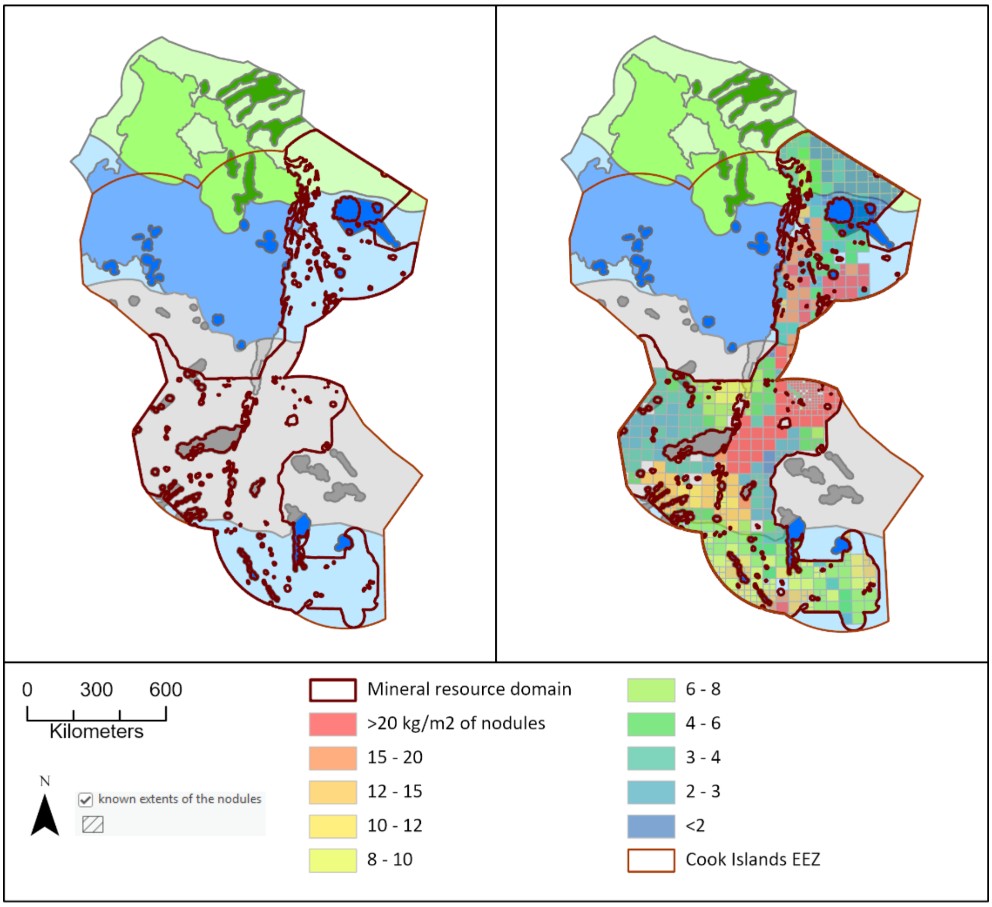


Figure 6-4: Nodule mineral resource limits and model abundances on the HMZs

6.6 How deep is deep-sea?

The HMZs study reported here worked on 200 m and deeper. 200 m is the base of photic zone and other deep-sea studies such as Macbio2028 also used 200m

Figure 6-5 shows the minimal effect of increasing the minimum depth to 500 and 1,000 m.

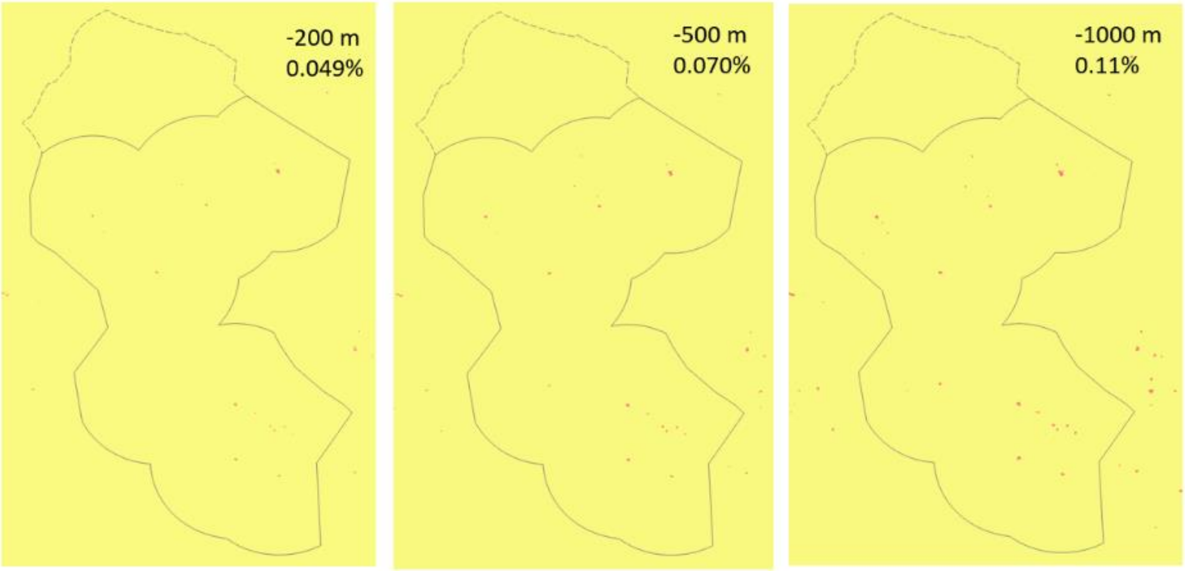


Figure 6-5: Illustrated and proportions of areas of seabed above select depths in the Cook Islands

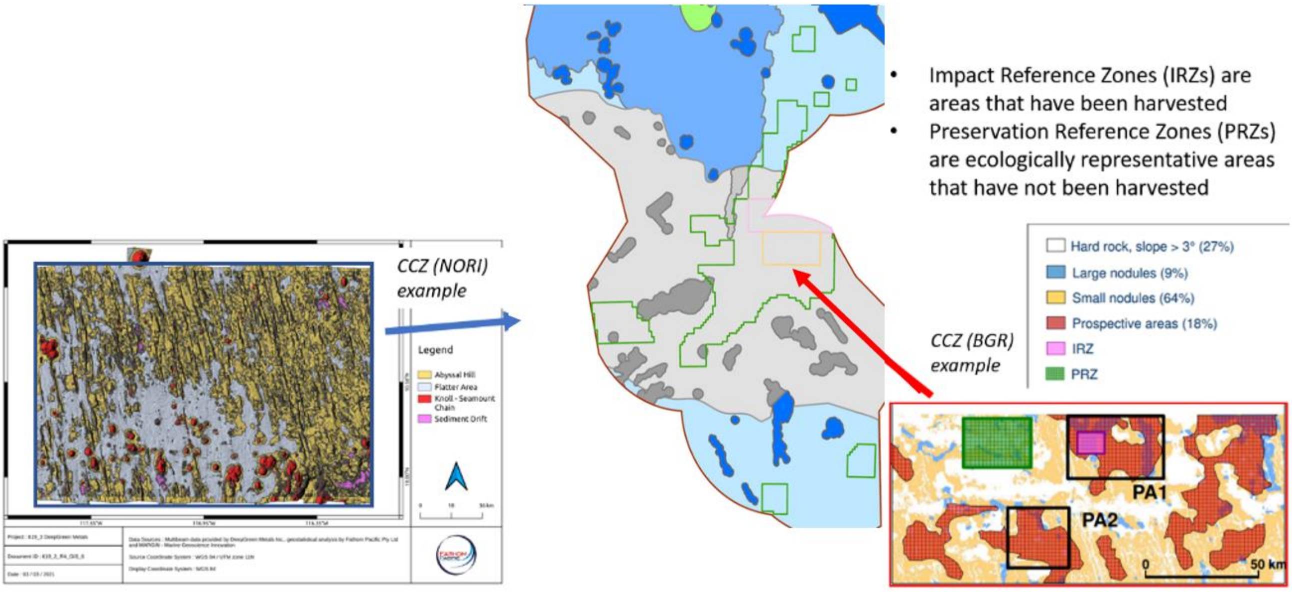
6.7 Integration and use

The HMZs are SBMA's seabed contribution to the zonation based spatial management plan required for our national Marae Moana spatial plan. They are also a contribution to a Strategic Environmental Assessment (SEA) for the Cook Islands seabed minerals deposits that will include a planned Regional Environmental Management Plan (REMP). This REMP is expected to be broadly similar in nature to REMPs required for seabed minerals by the International Seabed Authority[7], that are largely spatially based.

A key distinction between the Area (governed by UNCLOS and the ISA) and the Cook Islands seabed is that the Cook Islands EEZ already has a level of protection under the Marae Moana Act (2017), Environmental Act (2003) and Seabed Minerals Act (2019). Protection for seabed minerals activities is being primarily managed via block release policy; and currently this is only for exploration. The Marae Moana MPAs that prohibit industrial scale fishing and seabed minerals activities are thus in effect integrated into the block release policy.

Future guidance can include an understanding of existing use of the area covered by a given habitat management zone (i.e., minimum percentages or distinct habitats (and/or HMZs) can be simply not be released as a matter of policy depending on the activity being considered). As part of the precautionary approach, the onus is on licence holders to demonstrate that the effects of their activities will not be overly significant. As well as producing project EIAs, this means that licence holders are often requested to address how any proposed development relates to the espoused principles within the Marae Moana Act. Within or adjacent to nodule mineral harvesting licence areas. Licence holders are required to help define and support preservation reference zones (i.e. PRZ's as mandated by Environment (Seabed Minerals Activities) Regulations 2023), but additional special zones or set-aside areas can also be chosen if needed.

Seabed minerals harvesting is at least several years away based on work plans published by the licence holders, thus any future decisions will in this regard almost certainly benefit from a greater pool of scientific information than available today. Level 2/3 habitat management zones or habitats would likely be required at that time, similar to what is possible in the CCZ today (e.g., as illustrated in Figure 6-6).



- Impact Reference Zones (IRZs) are areas that have been harvested
- Preservation Reference Zones (PRZs) are ecologically representative areas that have not been harvested

Figure 6-6: Illustrative example of how higher-level spatial classes might rest within the level 1 HMZs. Example insets are of higher level geoforms and IRZs/PRZs from the CCZ.

---

[7] https://www.isa.org.jm/protection-of-the-marine-environment/regional-environmental-management-plans/

7 Conclusions

It is concluded that:

- A review of datasets covering the Cook Islands leads to the definition of level 1 habitat management zones based on appropriately scaled surrogates of seabed geomorphology and a model of net primary export POC;
- The assumptions behind the definition of habitat zones are likely to be better supported than trying to define habitats themselves, until more detailed local data is available. Hierarchical level 2 and 3 classifications could serve at this scale;
- Classification of three broad geomorphological types combined with three levels of modelled net export POC work to cover the area of interest (Cook Islands EEZ and ECS application);
- The limited testing possible to date broadly supports the classification;
- To assist in spatial management, the habitat management zones can be subdivided and measured by types of seas (e.g. exclusive economic zone versus territorial seas) and areas under licence;
- This classification system can likely work alongside some of the other spatial plans for the region.

It is recommended that:

- A more accurate net POC export model, calibrated by seabed sedimentation readings for the region be sought in due course;
- The HMZ's be further tested, looking for key differences and similarities between and within the zones;
- That, considering the large scale of the area (i.e., three times the land area of New Zealand), testing consider running a series of about ten transects combining sonar survey and seabed sampling.

8 References

Archer, D. E. (1999) *Opal, quartz and calcium carbonate content in surface sediments of the ocean floor.*, *PANGAEA*. doi: https://doi.org/10.1594/PANGAEA.56017.

Browne, R., Parianos, J. and Murphy, A. (2023) 'Geomorphology of the Cook Islands, tropical South Pacific Ocean', *Journal of Maps*, pp. 1–7. doi: 10.1080/17445647.2023.2169889.

Ceccarelli, D. *et al.* (2021) *Biophysically special, unique marine areas of the Cook Islands*. Rarotonga, Cook Islands. Available at: https://www.maraemoana.gov.ck/wp-content/uploads/2021/06/23.-Cook-Islands-SUMA-report-2021.pdf.

Cronan, D. S. (2013) *The distribution, abundance, composition and resource potential of the manganese nodules in the Cook Islands exclusive economic zone*.

Dyment, J., Lesur, V., Hamoudi, M., Choi, Y., Thebault, E., Catalan, M., the WDMAM Task Force*, the WDMAM Evaluators**, and the W. D. P. (2015) *World Digital Magnetic Anomaly Map version 2.0*. Available at: http://www.wdmam.org.

Fejer, A., Cecino, G. and Flynn, A. (2021) 'Habitat Mapping for Ecosystem-Based Management of Deep-Sea Mining', *Marine Technology Society Journal*, 55(6), pp. 53–64. doi: 10.4031/MTSJ.55.6.4.

Garcia, H. E. *et al.* (2019) 'World Oecean Atlas 2018 Volume 4: Dissolved Inorganic Nutrients (phosphate, nitrate and nitrate+nitrite, silicate)', *NOAA Atlas NESDIS 84*, p. 35. Available at: https://www.nodc.noaa.gov/OC5/woa18/pubwoa18.html.

GEBCO Compilation Group (2021) *GEBCO 2021 Grid*. Available at:

https://www.gebco.net/data_and_products/historical_data_sets/#gebco_2021 (Accessed: 15 January 2022).

Harris, P. T. *et al.* (2014) ‘Geomorphology of the oceans’, *Marine Geology*, 352, pp. 4–24.

Harris, Peter T. (2020) ‘Surrogacy’, in Harris, P.T. and Baker, E. (eds) *Seafloor Geomorphology as Benthic Habitat*. 2nd edn. Elsevier, pp. 97–113. doi: 10.1016/B978-0-12-814960-7.00005-1.

Jackson, M. G. *et al.* (2020) ‘Contrasting Old and Young Volcanism from Aitutaki, Cook Islands: Implications for the Origins of the Cook–Austral Volcanic Chain’, *Journal of Petrology*, 61(3). doi: 10.1093/petrology/egaa037.

JICA-MMAJ (1986) *Ocean Resources Investigation in the Sea Area of Sopac Report on the Joint Basic Study for the Development of Resources (Volume 1)*.

JICA-MMAJ (1987) *Ocean Resources Investigation in the Sea Area of Sopac Report on the Joint Basic Study for the Development of Resources (Volume 2)*.

JICA-MMAJ (2001) *Report on the Cooperative Study Project on the Deepsea Mineral Resources in Selected Offshore Area on the Sopac Region*.

Larson, R. L. *et al.* (2002) ‘Mid-Cretaceous tectonic evolution of the Tongareva triple junction in the southwestern Pacific Basin’, *Geology*, 30(1), p. 67. doi: 10.1130/0091-7613(2002)030<0067:MCTEOT>2.0.CO;2.

Li, Z. *et al.* (2023) ‘Exploring modern bathymetry: A comprehensive review of data acquisition devices, model accuracy, and interpolation techniques for enhanced underwater mapping’, *Frontiers in Marine Science*, 10. doi: 10.3389/fmars.2023.1178845.

Lipton, I., Nimmo, M. and Parianos, J. (2016) *TOML Clarion Clipperton Zone Project, Pacific Ocean*. Brisbane, Australia: AMC Consultants Pty Ltd. Available at: www.sedar.com.

Lipton, I., Nimmo, M. and Stevenson, I. (2019) *NORI Area D Clarion Clipperton Zone Mineral Resource Estimate*. Brisbane, Australia: AMC Consultants Pty Ltd. Available at: www.sedar.com.

Liu, M. and Tanhua, T. (2021) ‘Water masses in the Atlantic Ocean: characteristics and distributions’, *Ocean Science*, 17(2), pp. 463–486. doi: 10.5194/os-17-463-2021.

Lutz, M. J. *et al.* (2007) ‘Seasonal rhythms of net primary production and particulate organic carbon flux to depth describe the efficiency of biological pump in the global ocean’, *Journal of Geophysical Research*, 112(C10), p. C10011. doi: 10.1029/2006JC003706.

McQuaid, K. A. *et al.* (2020) ‘Using Habitat Classification to Assess Representativity of a Protected Area Network in a Large, Data-Poor Area Targeted for Deep-Sea Mining’, *Frontiers in Marine Science*, 7. doi: 10.3389/fmars.2020.558860.

McQuaid, K. A., Washburn, T. and Howell, K. (2019) ‘Annex K: Habitat Mapping and Environmental Data – Assessing representativity of the CCZ APEI network using habitat modelling and classification approaches’, in *Workshop Report Deep CCZ Biodiversity Synthesis Workshop Friday Harbor, Washington, USA, 1-4 October 2019*. Kingston, Jamaica: International Seabed Authority, pp. 192–206. Available at: https://www.isa.org.jm/files/files/documents/Deep CCZ Biodiversity Synthesis Workshop Report - Final-for posting-clean-1.pdf.

Müller, R. D. *et al.* (2016) ‘Ocean Basin Evolution and Global-Scale Plate Reorganization Events Since Pangea Breakup’, *Annual Review of Earth and Planetary Sciences*, 44(1), pp. 107–138. doi: 10.1146/annurev-earth-060115-012211.

Müller, R. D., Roest, W. R. and Royer, J.-Y. (1998) ‘Asymmetric sea-floor spreading caused by ridge–plume interactions’, *Nature*, 396(6710), pp. 455–459. doi: 10.1038/24850.

Nimmo, M., Morgan, C. and Banning, D. (2013) *Clarion-Clipperton Zone Project, Pacific Ocean*. Brisbane, Australia: Golder Associates Ltd. Available at: www.sedar.com.

Pavia, F. J. *et al.* (2020) ‘Atmospheric Dust Inputs, Iron Cycling, and Biogeochemical Connections in the South Pacific Ocean From Thorium Isotopes’, *Global Biogeochemical Cycles*, 34(9). doi: 10.1029/2020GB006562.

RSC (2023) *Cook Islands Polymetallic Nodule Deposit*. Dunedin, New Zealand.

Simon-Lledó, E. *et al.* (2019) ‘Megafaunal variation in the abyssal landscape of the Clarion Clipperton Zone’, *Progress in Oceanography*, 170, pp. 119–133. doi: 10.1016/j.pocean.2018.11.003.

SPREP (2020) *Strategic Environmental Assessment (SEA) Guidelines for Pacific Islands Countries and Territories*. Secretariat of the Pacific Regional Environment Programme. Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.sprep.org/sites/default/files/documents/publications/SEA-Guidelines.pdf.

Di Stefano, M. and Mayer, L. A. (2018) ‘An Automatic Procedure for the Quantitative Characterization of Submarine Bedforms’, *Geosciences*, 8(1). doi: https://doi.org/10.3390/geosciences8010028.

Taylor, B. (2006) ‘The single largest oceanic plateau: Ontong Java–Manihiki–Hikurangi’, *Earth and Planetary Science Letters*, 241(3–4), pp. 372–380. doi: 10.1016/j.epsl.2005.11.049.

Timm, C. *et al.* (2011) ‘Age and geochemistry of the oceanic Manihiki Plateau, SW Pacific: New evidence for a plume origin’, *Earth and Planetary Science Letters*, 304(1–2), pp. 135–146. doi: 10.1016/j.epsl.2011.01.025.

Walbridge, S. and Wright, D. (2012) *Benthic Terrain Modeler*, *ArcGIS Resources*. Available at: https://resources.arcgis.com/en/communities/oceans/02pp00000007000000.htm (Accessed: 10 April 2022).

Watling, L. *et al.* (2013) ‘A proposed biogeography of the deep ocean floor’, *Progress in Oceanography*, 111, pp. 91–112.

Wendt, H. *et al.* (2018) *[Draft] Marine Bioregions of the Southwest Pacific*. Suva, Fiji. Available at: http://macbio-pacific.info/wp-content/uploads/2018/03/MACBIO-Bioregions-Report_Digital.pdf.

Wessel, P. and Kroenke, L. W. (2008) ‘Pacific absolute plate motion since 145 Ma: An assessment of the fixed hot spot hypothesis’, *Journal of Geophysical Research*, 113(B6), p. B06101. doi: 10.1029/2007JB005499.

Winterer, E. . *et al.* (1974) ‘Structure and acoustic stratigraphy of the Manihiki Plateau’, *Deep Sea Research and Oceanographic Abstracts*, 21(10), pp. 793–813. doi: 10.1016/0011-7471(74)90001-1.

Wright, D. J. *et al.* (2005) *ArcGIS Benthic Terrain Modeler*, *Oregon State University, Davey Jones Locker Seafloor Mapping/Marine GIS Laboratory and NOAA Coastal Services Center*. Available at: http://www.csc.noaa.gov/products/btm/ %0A (Accessed: 1 July 2022).

9 Annex A: Summary geological evolution of the Cook Islands seabed basement

The following is taken from (RSC, 2023).

The Cook Islands include some of the oldest seafloor known (90–124 Ma; Müller et al., 2016)). To the northwest, the Manihiki Plateau is dated ~123–124 Ma (Taylor, 2006; Timm *et al.*, 2011), and might be part of a much larger submarine large igneous province that rifted apart shortly after its formation. The plateau has boundary faults and horsts on its northern and eastern sides as well as internal and broadly sub-parallel rift zones (Winterer *et al.*, 1974); Figure 9-1. Dating of the region is compromised by a lack of detailed seabed magnetic data and much of the formation formed during the Cretaceous long normal period (Chron 34, 124.6–84 Ma).

There are abyssal plains to the south and east of the plateau that can be spatially defined as three basins (Figure 9-1). The basins are bound by a combination of fracture zones and volcanic rises. The Penrhyn Basin is to the east, the Samoa-Niue Basin is to the south and the newly named Southern Cooks Basin is to the southeast. The abyssal plains include areas of long linear abyssal hills, as well as zones almost entirely covered with small volcanic knolls. The abyssal plains to the southwest strike east, parallel to an inactive spreading centre located further south called Laperouse, while those to the northeast strike north, parallel to bounding fracture zones and to abyssal hills located further to the east. The change in orientation of the abyssal hills occurs within the western Penrhyn and eastern Southern Cooks basins in association with a series of north-northwest trending troughs newly termed the Rakahanga Rifts (Figure 9-1). These rifts are interpreted to have been one arm of a triple junction associated with the breakup of the plateau shortly after formation (Larson *et al.*, 2002). The locations of presumed spreading centres that formed some of the abyssal plains are not clearly locatable (unlike the Osbourne Trough for example), but asymmetric spreading is related to plume-ridge interaction, which might explain some of the smaller, more complex arrangements of abyssal hills (e.g. as suggested elsewhere by Müller et al., 1998). While the age of formation of the east-trending abyssal hills can be constrained to the mid-Cretaceous by spreading rate estimates (Taylor, 2006), the age of the north-trending hills is harder to constrain (Larson *et al.*, 2002).

The fracture zones bound the different basins and the Manihiki Plateau. The Manihiki Plateau has a rough parallelogram plan, including the orientation of internal rifts typically trending to the northwest or north-northeast. These orientations are distinct from the oceanic plate segment fracture zones (e.g., Marquesas and Austral, which typically trend to the west-southwest, with associated volcanic chains and the Rakahanga Rifts trending to the north–northwest). Within the Project Area, the newly named Manihiki-Palmerston Fracture Zone is most prominent. The Manihiki-Palmerston Fracture Zone defines the eastern side of the Manihiki Plateau but extends south, incorporating interpreted entrained plateau fragments up to ~120 km south of Palmerston Island. Further to the south, the fracture zone disperses into what might be a horsetail arrangement of accommodation fractures.

Volcanic edifices are superimposed onto the seabed geology (Figure 9-2). These include isolated chains of seamounts and knolls as well as more continuous volcanic rises. The chains are in a variety of orientations, but predominantly west-northwest trending and some are interpreted to have resulted from hotspot activity (Wessel and Kroenke, 2008; Jackson *et al.*, 2020). One key exception is the short curvilinear northeast-trending seamount chain summiting at Palmerston Island adjacent to the Manihiki-Palmerston Fracture Zone that is associated with similarly oriented hills and may represent accommodation structures from the Manihiki-Palmerston Fracture Zone. Knolls and seamounts are found on the plateau as well as the abyssal plain, not least in the western Manihiki Plateau.

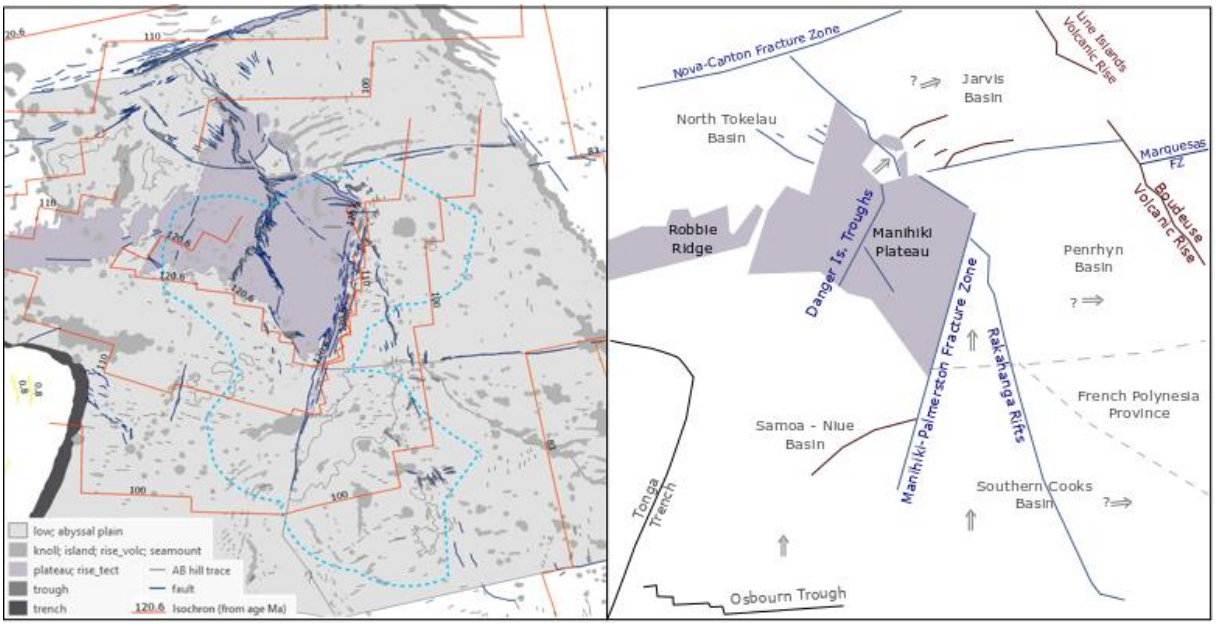


Figure 9-1: Large scale geomorphological units and tectonic setting. Isochrons after (Müller *et al.*, 2016)

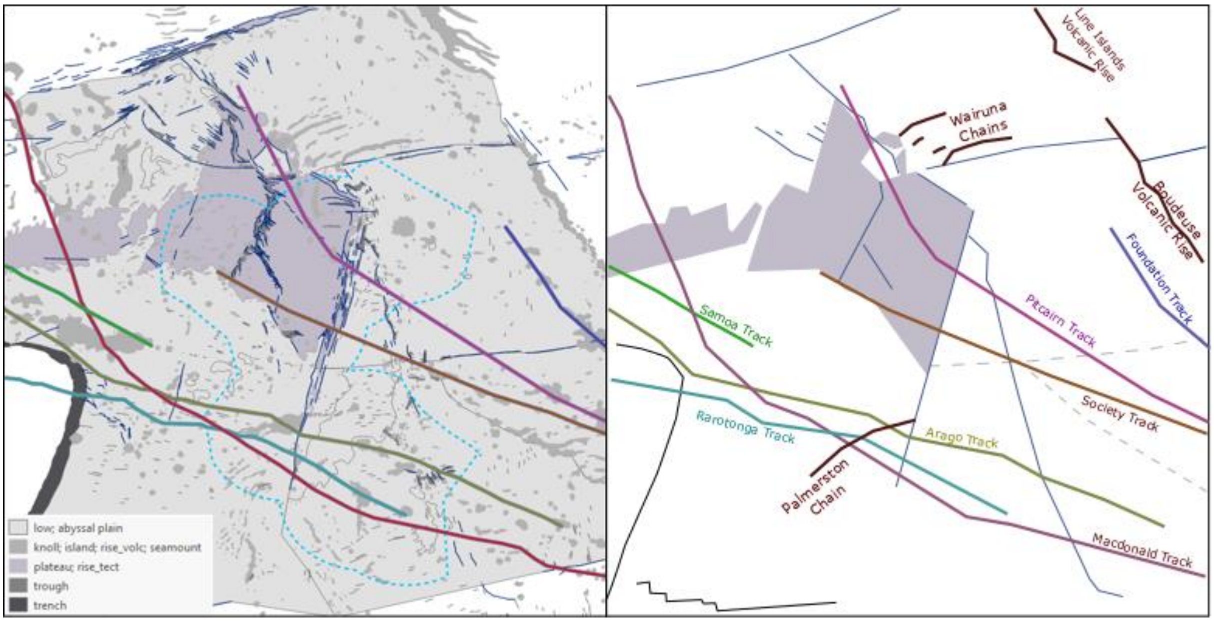


Figure 9-2: Volcanic chains and hotspot tracks.

Tracks after (Wessel and Kroenke, 2008) *and* (Jackson *et al.*, 2020). *Refer to Figure 9-1 for the names of other features.*

10 Annex B: Annual surface primary productivity and net export model

Annual averages of PP broadly support the very low NPP zone.

El Nino conditions are usually most manifest between October and March, so these calendar year averages are probably not ideal; future work might better compare with ENSO cycles rather than calendar years.

Inter-year variations are fairly minor but La Nina years may result in the lower surface primary productivity zone being located slightly further south.

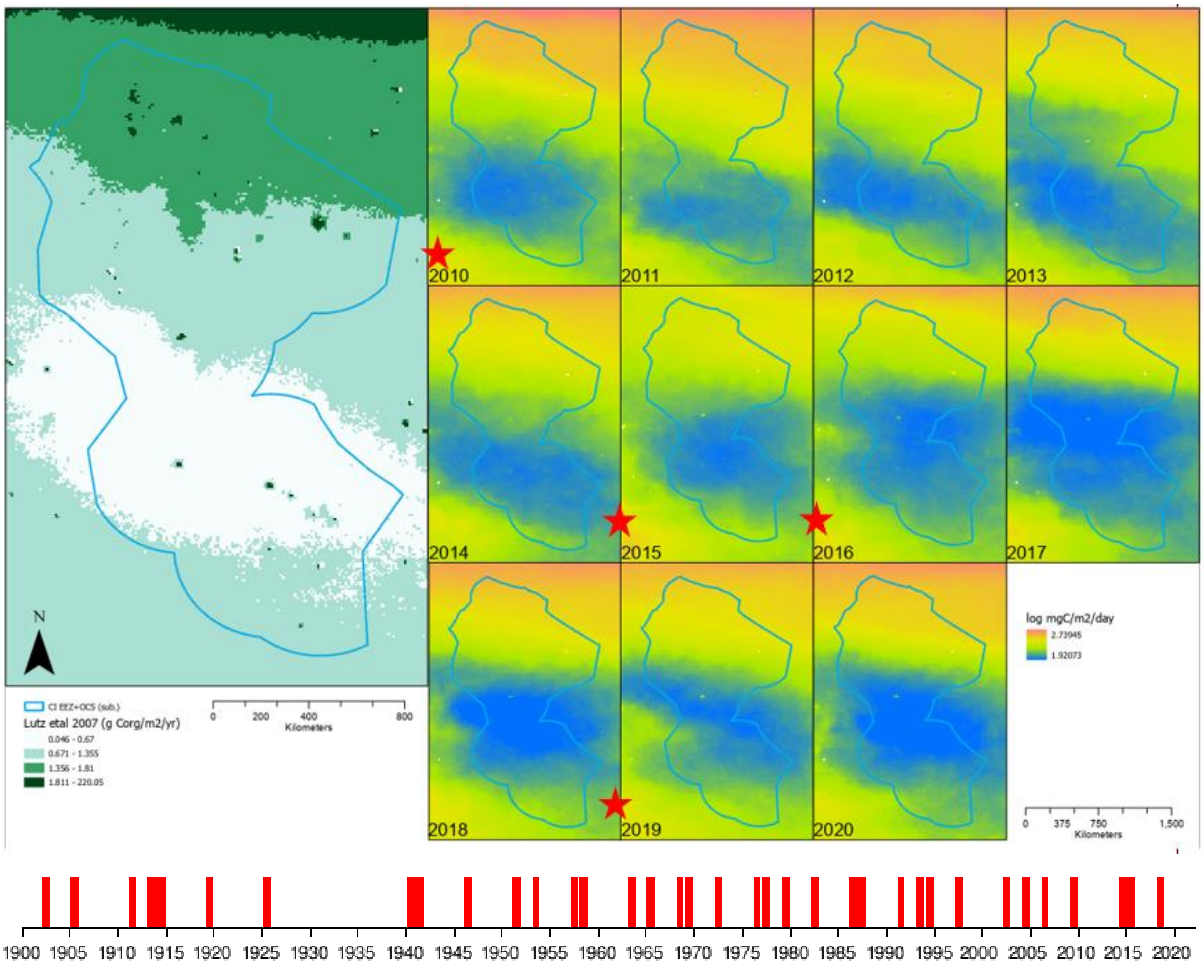


Figure 10-1: Annual averages surface chlorophyll and periods of El Nino

Source: https://en.wikipedia.org/wiki/E l Ni%C3%B1o

11 Annex C: Comparison with MacBio2018 and SUMAs

There are no shortage of classification schemes for the Pacific (e.g. Figure 11-1), many of which deal with specific fish or other fauna classes.

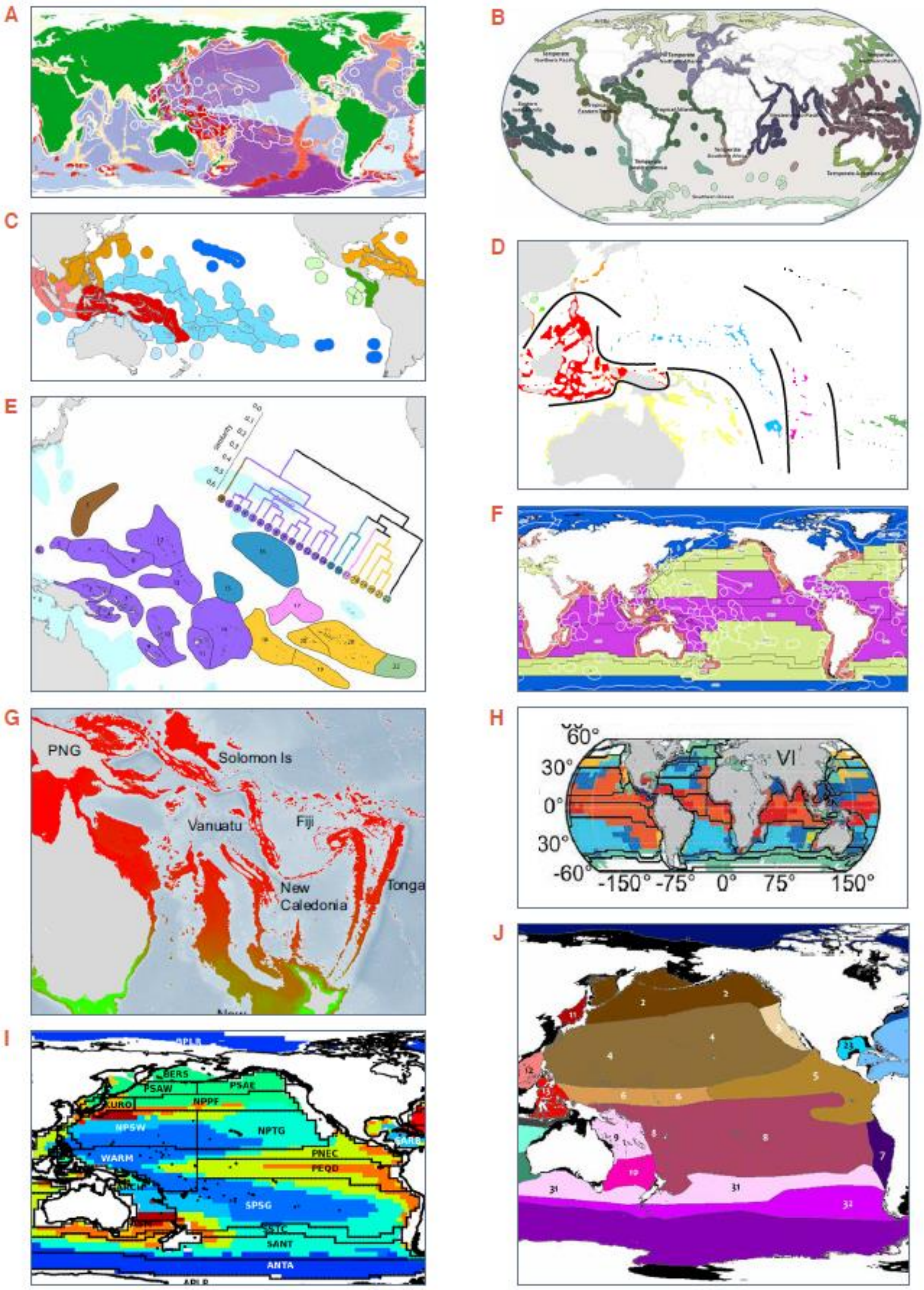


Figure 11-1: Some other regional classification schemes

Refer to (Wendt *et al.*, 2018) *for original references.*

11.1 MacBio2018

This joint study by GIZ, IUCN and SPREP (Wendt *et al.*, 2018), ran two parallel programs for broad classification of deepwater areas as well as a finer classification for reef associated areas (not considered further here). Input data was restricted to published datasets.

The deepwater program was based on cluster analysis of a range of surface and subsea data. While seabed bathymetry and water depth were considered there was a paucity of data below 1,000 m leading the team to conclude it to be unreliable in the deepwater analysis. Bathymetry was weighted by a factor of two in the analysis due to its “disproportionate influence … upon deepwater habitats and species”.

Comparison of the Macbio bioregions and the HMZs is in Figure 11-2. The zones are broadly parallel to the net export based HMZ classes and separate most of the Manihiki Plateau. Attempts to further discriminate the bioregions further was not especially clear to the HMZ team, but this might be due to influence in the characterization levels of various inputs and from non-contiguous areas.

Note that “deepwater” for this analysis (MACBIO) was defined at the 200 m depth or 20 km out whichever was the furthest from land.

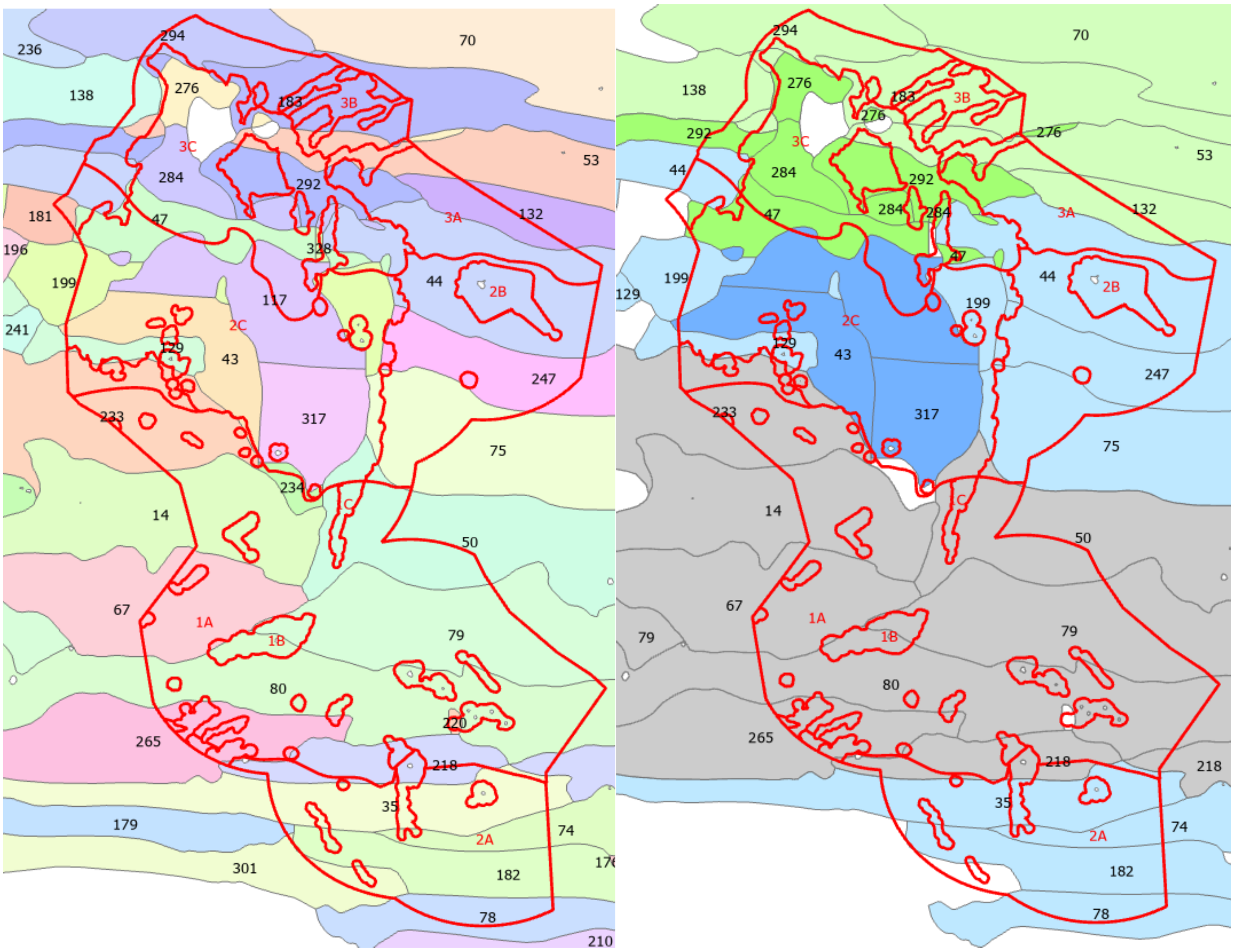


Figure 11-2: HMZs over MACBIO2018 Bioregions

One issue with regards to seabed marine habitats is that, with the exception of depth, the Macbio study characterises the bioregions with seabed geomorphology type rather than being defined by it. Thus, seamounts are integrated with abyssal plains etc.

Nonetheless the Macbio approach may integrate well with the HMZs presented here, especially as most of the datasets relate the water column, especially the upper 1,000 m of the water column. It is suggested that at the scale of the Cook Islands EEZ/ECS this data be reanalysed for a spatial layer for that level.

As the Macbio report itself states: “People’s expertise in the Pacific marine environment extends beyond the available datasets. An important, subsequent, non-analytical step, not described in this report, will be to review and refine the resultant draft bioregions with marine experts in the respective Pacific Island countries and territories prior to their use in planning”.

11.2 SUMAs

Special, Unique Marine Areas (SUMAs) were classified in a specially convened workshop by a team several years after the Macbio project, but with some authors in common (Ceccarelli *et al.*, 2021). It was coordinated and managed by the Cook Islands Ridge to Reef (R2R) project, which is funded by the UNDP and Global Environment Facility (GEF) in partnership with the Cook Islands Government.

As for Macbio, there were parallel processes for inshore and offshore environments, with only the offshore environments considered further here. Seven offshore SUMAs were chosen with a strong focus on geomorphology, including several groups of seamounts and the Manihiki plateau as well as a better-known part of the nodule fields and a marine mammal migratory pathway between the southern group and Samoa/Tonga.

Many of the offshore SUMAs were given relatively low scores during the process due to a then recognised lack of research.

Comparison with the HMZs (Figure 11-3) shows a close correspondence due to the use of geomorphology in definition of the SUMAs.

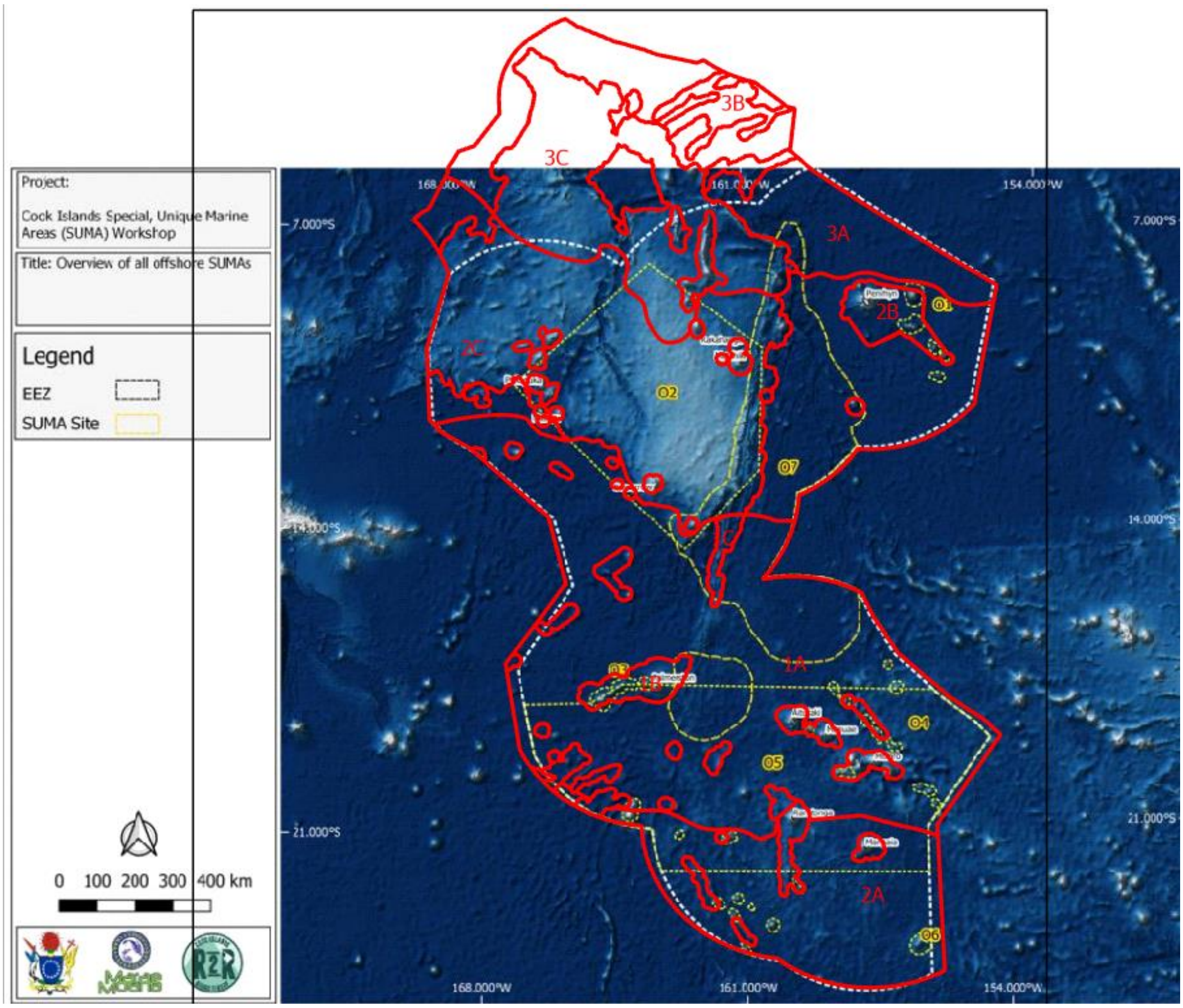


Figure 11-3: HMZs over 2021 SUMAs

12 Annex D: comparison with other BTM products

Modelling was done by Suzanne Bergman of Kenex, using the code for ArcGIS products by (Wright, D. J. *et al.*, 2005; Walbridge and Wright, 2012).

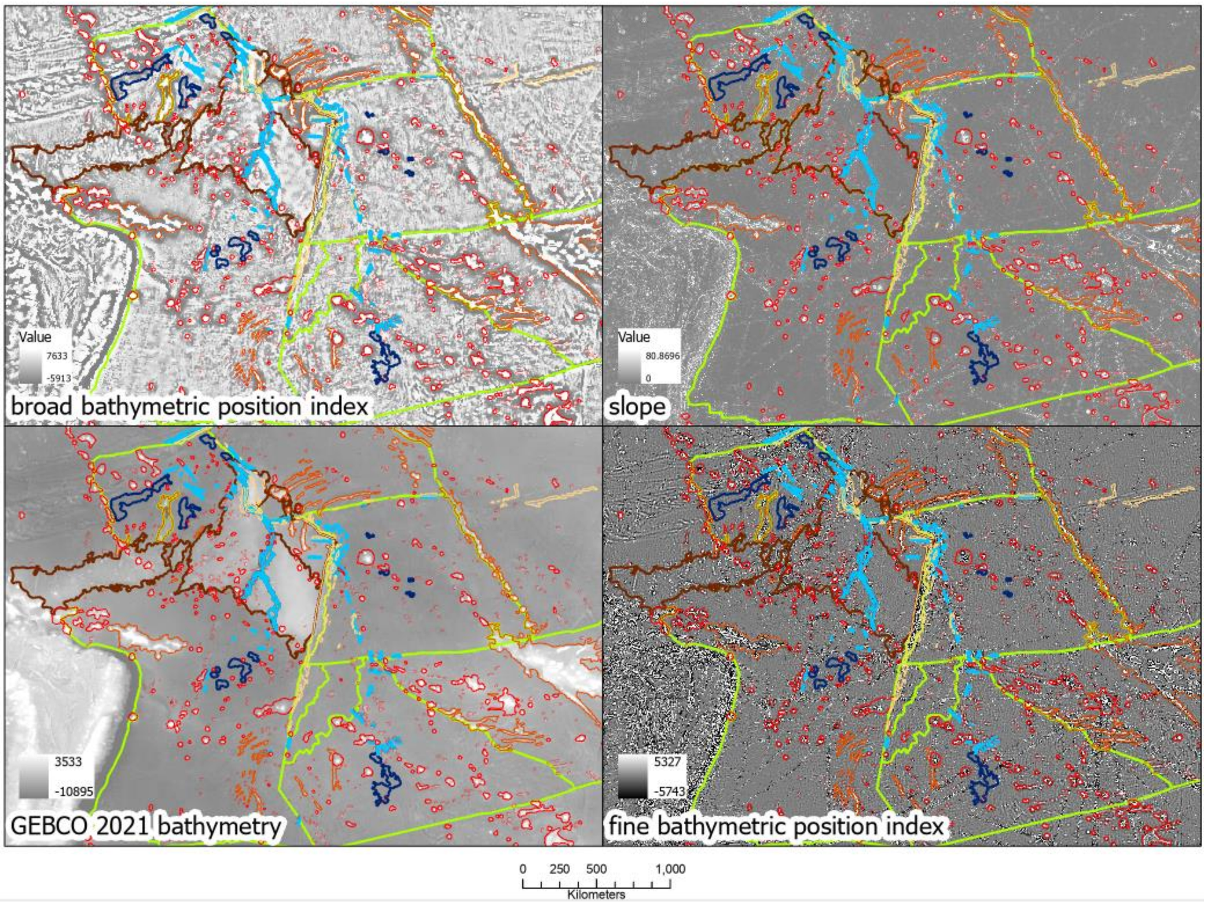


Figure 12-1: Geomorphology units compared with all outputs of the BTM process package