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Potential seamount location in the South Pacific RFMO area: prerequisite for fisheries management and conservation in the high seas.

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Abstract

Seamounts are habitats of considerable interest in terms of conservation and biodiversity, and in terms of fisheries for bentho-pelagic and pelagic species. A total of 13 previously compiled datasets including seamount/underwater feature lists and bathymetric maps from different sources (ship-derived and satellite altimetry-derived) at different spatial scales (from individual cruise to worldwide satellite data) have been gathered to compile an enhanced list of underwater features for the South Pacific Regional Fisheries Management Organisation high seas area. The KL04 dataset (Kitchingman and Lai, 2004. Fish. Cent. Res. Rep. 12, 7-12) listing seamount automatically detected from satellite altimetry-derived bathymetry, provided the baseline data for this study. All KL04 potential seamounts were cross-checked with other datasets to remove duplicate records, to add seamounts undetected by KL04 and to update the overall database (geolocation, depth, elevation, name and typology). The final dataset includes 1506 underwater features with agreed upon position and information. This enhanced list should have many applications in fisheries management and conservation.

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1. Introduction

Seamounts are major geomorphological features of the ocean floor of considerable interest for geological, oceanographic and biological knowledge. Biologically, they are considered as biodiversity hotspots with high levels of endemism (Richer de Forges et al., 2000; Worm et al., 2003). They also aggregate commercially valuable fish, both benthic / bentho-pelagic (e.g. orange roughy, alfonsino) and pelagic (e.g. tuna) (e.g., Clark 1999, Fonteneau, 1991). By providing both commercial resources and, unique biodiversity, seamounts are clearly of particular interest for conservation and ideal candidates for offshore and high-seas marine protected areas (Roberts, 2002; Alder and Wood, 2004; Schmidt and Christiansen, 2004; Davies et al., 2007).

However seamounts are still poorly known: it is estimated that from the 100,000 potential seamounts worldwide, less than 200 have been investigated in detail (Gjerde, 2006). Clark et al. (2006) in their review on the vulnerability of deep-sea corals on seamounts identified 12 important gaps in our knowledge of seamounts that need to be addressed to answer questions from policy makers, managers and scientists. One of them is to “obtain better seamount location information”. Moreover, depth of summit has been identified as the most important physical factor in determining abundance and diversity of benthic communities (Clark et al., 2006). Developing a listing of seamounts characterized by their position and summit depth is then invaluable for fishery management (Rogers, 1994).

Broad scale works relying on automatic detection of potential seamounts by analysis of altimetry-satellite data and direct ship-tracks have been conducted recently (Hillier and Watts, 2007) supplementing non-automated studies (e.g. Batiza, 1982; Marova, 2000). The number of seamounts detected varies widely between these studies particularly because of the quality of the baseline bathymetric data. Moreover, since ground-truthing has been limited, seamount databases have largely remained unvalidated. This situation will continue to cast doubt on the validity of oceanographic studies, on fishery management decisions and conservation strategies associated with seamounts until uncertainties in the different datasets have been clarified.

In this context, an accurate inventory of seamounts is necessary.

Several on-line databases providing seamount information, bathymetric map, and surface feature maps are publicly available. However it is puzzling to realize with a simple, geocorrected, overlay of the different datasets the large discrepancies. This casts doubts on the reliability of the different sources and warrants proper quality control. Screening, cross-checking and validation of 20 seamount datasets allowed identifying dataset shortcomings and the compilation of an enhanced seamount location database in the EEZs of the western and central Pacific Ocean (Allain et al., 2008). We report here on the conclusions of the extension of this exercise to the high seas area under consideration for the South Pacific RFMO.

The potential seamounts identified by Kitchingman and Lai (2004) (hereafter referred to as KL04) were used as the base reference. KL04 features were spatially cross-checked with 12 different seamount and bathymetry datasets available from the literature and on the internet. Specifically, we aimed to remove from KL04 duplicates incorrectly identifying several seamounts instead of a single large feature, to add seamounts which analysis had not detected, and to update the overall database (geolocation, depth, elevation, name, and typology).

2. Material and Methods

2.1 Area of interest

Area considered in this study is the high seas area proposed for the new South Pacific RFMO and still under discussion (Figure 1).

2.2 Datasets

Thirteen datasets: 12 seamount lists and one bathymetric chart have been collected from the literature and from a variety of websites. Data came from two main sources: satellite altimetry and/or ship-derived bathymetry. They had variable spatial coverage and resolution and provided different types of information with specific shortcomings and assets (Table 1).

S2004 was considered to be the best global bathymetric grid presently available and provided background bathymetry.

Two major seamount lists were obtained by automatic extraction based on the same satellite altimetry data (Table 1). The Wessel (2001) list was extracted from vertical gravity gradient and provided 2451 seamounts in the SPRFMO area. The Kitchingman and Lai (2004) (KL04) list was extracted from ETOPO2 bathymetry based on the Smith and Sandwell (1997) bathymetry computed from satellite altimetry-derived gravity, providing 1484 seamounts in the SPRFMO. Hillier and Watts (2007) was the third major list and it was obtained by automatic extraction from archived single-beam ship bathymetry. Albeit they were able to detect features with elevation as low as 100 m, in our study we only considered the 1451 features higher than 1,000 m in the SPRFMO area.
New Zealand Seamounts was considered the most reliable dataset including low-elevation underwater features (< 1000 m). GEBCO, Seamount Catalog, Seamount Online and NGA Underwater features were compilations of non-standardized information for which no metadata were available; confidence in these datasets was limited. Other minor lists came from direct ship observation and were considered reliable. The number of seamounts per datasets varied from 1 to 102 (Table 1).

Some interdependence exits between satellite-derived datasets: S2004, KL04 and Wessel (2001) were not considered independent while ship-derived datasets were.

2.3 Primary reference dataset and cross-checking method

As an extension of the seamount screening in the western and central Pacific Ocean (Allain et al., 2007; Allain et al., 2008), the same primary reference dataset was chosen: Kitchingman and Lai (2004) (KL04). The same cross-checking method was followed and a brief description is provided here, method is fully detailed in Allain et al. (2008).

All datasets were imported into a Geographical Information System (GIS) system for cross-checking to assess the degree of overlap between the different layers.
The first step was to validate the KL04 features that were confirmed by at least one of the other datasets derived from ship sounding. When the feature was only confirmed by non-independent datasets (S2004 and Wessel (2001)), it could not be considered as ‘validated’, it was noted ‘cross-checked’.

Seamounts not listed in KL04 but occurring in another dataset were added to the database after cross-checking. Many seamounts were only identified by Wessel (2001) and Hillier and Watts (2007) but were not added to the final database.
Geographically aggregated potential seamounts were examined separately. They were plotted on top of S2004 bathymetric map to confirm if they represented several spatially close seamounts or a single large feature misidentified as several seamounts. The multiple KL04 records capturing one discrete large feature (duplicates) were removed from the database. Only the record located at the center of the feature was retained.

The second step was to select from the different datasets the best attributes available for type, position, summit depth, elevation and name.
A geomorphologic typology of underwater features has been compiled based on the nomenclature provided by the other datasets, mainly NGA underwater features, Seamount Catalog and Seamount Online (Table 2). Despite definitions provided by the International Hydrographic Organization and Intergovernmental Oceanographic Commission (2001), it must be acknowledged that the different nomenclatures did not always properly reflect the actual shape of the labeled feature. In cases of lack of geomorphological terminology, the feature was labeled as "Unknown".
The coordinates of the record closest to the center of the feature were assigned to the KL04 potential seamount. If the distance between that record and the center of the feature on the bathymetry map was more than 8 km, we assigned that central position.
Summit depth information provided by ship cruise datasets were retained preferably to KL04 data.
The feature names were included in the database when mentioned in the datasets.

2.4 Seamount fish habitat distribution

Based on information collated in the SPRFMO species profiles[3] and in the literature (Rogers, 1994; Morato and Clark, 2007), presence on seamount and preferred depth was determined for some benthopelagic fish species of commercial interest. Preferred depth was then used as a surrogate to habitat index and was crossed-check with underwater features summit depth to determine the underwater features where these

[3] http://www.southpacificrfmo.org/science-working-group/swg-profiles/species-profiles/

fish could potentially be present. Geographic distributions of species were not taken into account mainly because of the lack of data in the SPRFMO remote areas far from any land and for which barely any information is available.

3. Results

3.1. Total number of underwater features, distribution, validation and typology

Of the 1478 KL04 potential seamount screened, 126 (8.5%) were duplicates of discrete large features and were then removed from the final database. On the other hand 154 features not identified by KL04 but detected by other datasets were added. Most of the additions came from New Zealand seamounts database. The final database hence contained a list of 1506 underwater features widespread in the SPRFMO (Figure 1, Annex 1).

A total of 58% (878) of these features were validated by other datasets while 42% (628) could only be cross-checked with S2004 and/or Wessel (2001). The majority of the validated features (681 – 78%) were recognized only by 1 independent dataset, 17% (147) were detected by 2 datasets and 6% (50) were detected by 3 to 6 datasets.

A geomorphologic type could be attributed to only 27.4% of the underwater feature, of which 207 (13.7%) were classified as 'seamounts'; 1094 (72.6%) features were 'unknown' (Table 2).

3.2. Underwater features summit depth and potential fish distribution

In the absence of any other source of information the summit depth provided by KL04 was kept for 80% of the 1491 features for which depth information was available (no summit depth was provided for 15 features). More reliable sources could be considered for 20% (299) of the cases. The information mainly came from New Zealand seamounts and Seamount Catalog.

Albeit there is a large uncertainty on KL04 summit depth (Allain et al., 2008), these data were considered, as well as more reliable information, to determine features distribution according to summit depth.

Taking into account fishing techniques, bottom-trawl fishing on seamounts is, at the moment, limited to a depth range of about 250 to 1500 m. In the SPRFMO area, it concerns 240 underwater features (16.1%) which are mainly located on the Louisville, Nazca and Sála y Gomez Ridges and on the East Pacific Rise (Figure 2).

According to available information on underwater features summit depth and on species preferred depth, it appears that only a small number of the detected seamounts could be potential habitat for some of the demersal commercial species (Table 4 and Figure 3).

4. Discussion

This study has compiled a number of different datasets into a single list of underwater features, clarifying the number of seamounts and other underwater features, their depth and position in the SPRFMO potential area. This database is more reliable and complete than any other available database in the region but could still be augmented by the inclusion of 1611 remaining Wessel (2001) potential seamounts and by the addition of 756 Hillier and Watts (2007) underwater features higher then 1000 m in height. Moreover the addition of 34,256 Hillier and Watts (2007) underwater features smaller than 1000 m in height should also be considered.

4.1 Database uncertainties

Quality of the final dataset depends on the quality of initial datasets. A previous study on the western and central Pacific Ocean based on the same procedure and datasets highlighted the main factors introducing uncertainties in results such as positions, summit depth and total number of features. Briefly, misregistration in ETOPO2 bathymetric map used by KL04 induced a 2-8 km horizontal systematic offset to the northeast. Moreover resolution of the background altimetry-satellite-derived bathymetric maps used to automatically extract potential seamounts locations did not allow to detect seamounts smaller than 1000 m height and summit depth estimates are poor with this technique. Flaws of the KL04 dataset and other datasets are discussed in details in Allain et al. (2008).

Results indicated that only 58% of the features were validated and the majority of those (78%) were validated by only one other dataset. Moreover a geomorphological

type was not attributed to about 73% of the underwater features. Thus, few seamounts were really well described by different sources of information, and very few seamounts have been thoroughly explored in situ. It is estimated that from the 100,000 potential seamounts worldwide, less than 200 have been investigated in detail (Gjerde, 2006).
Hence there are still large uncertainties on the number of seamounts and their location but also on their characteristics such as summit depth which is of particular importance and will have consequences on fishing grounds predictions but also for the determination of abundance and diversity of benthic communities (Clark et al, 2006).

4.2 Application of underwater feature list for fisheries management and conservation
Some seamounts do tend to aggregate fish of commercial interest in quantities allowing the development of fisheries. Large-scale fisheries for seamount-aggregaring species date from mid-1960s and they have been characterized by rapid increase shortly followed by rapid decrease in catch (Clark et al., 2007). Based on their basic life history traits and ecological characteristics, seamount-fish species have been showed to be highly vulnerable to exploitation and simulations suggested that exploitation rates of more than 5% are not sustainable (Morato et al., 2006; Morato and Clark, 2007). Moreover these large-scale fisheries are using bottom trawls that induce important damages to the habitat jeopardizing the seamount ecosystem (Hall-Spencer et al., 2002; Clarck and Koslow, 2007). Indeed seamounts are unique ecosystems with high levels of endemism (Richer de Forges et al., 2000) and they are sometimes considered as biodiversity hotspots (Worm et al., 2003); moreover they are highly vulnerable (Gianni, 2004). Hence because of their economical importance for fisheries highly susceptible to over exploitation but also for their high conservation interest and because of their vulnerability, determining management and conservation tools applicable to seamounts located in the SPRFMO is of high importance.

At the moment, the International Seabed Authority is the only regulatory body responsible for protecting deep seabed but its activities only cover seabed mining while deep-sea fishing impacting the seabed is not regulated (Probert et al., 2007). However recent negotiations at the Unites Nations General Assembly (UNGA) finalized decisions about bottom trawling on the high seas (UNGA resolution 61/105 in SPRFMO-III-SWG-17). Specifically, “in areas covered by RFMO under negociation: interim measures on bottom trawling to be implemented by December 2007 and to make these publicly available". Indeed, RFMO are seen as the regulatory bodies who could establish protective measures for seamount ecosystems beyond national jurisdiction. However they need to extend their competences to make sure they can regulate activities impacting vulnerable ecosystems, living marine resources other than target fish stocks and biodiversity in general (Probert et al., 2007). That is the case of the SPRFMO which key requirements relate to implementing measures to either avoid fishing on Vulnerable Marine Ecosystems[4] (VMEs) or to implement fishing practices and/or mitigation methods to "prevent significant adverse impacts on VMEs" or " determine that such activities will not have adverse impacts" on VMEs (SPRFMO-IV-SWG-06).

Two main approaches are considered for seamount management: measures regulating activities themselves (e.g. fishing gear type used) and measures regulating access to the seamounts (e.g. Marine Protected Areas, MPA) (Probert et al., 2007).
While monitoring and restriction of anthropogenic impacts such as mining and fisheries activities are valuable management options, the implementation of marine protected areas (MPAs) encompassing seamounts is believed to be the most efficient option for their conservation (Johnston and Santillo, 2004; Schmidt and Christiansen, 2004). Moreover, several international bodies have called for the implementation of offshore and high seas MPAs for biodiversity protection and conservation, and seamounts have been identified as good candidates (Convention on Biological Diversity, 2003; Scovazzi, 2004; Davies et al., 2007).

The worldwide level of seamount protection was summarized by Alder and Wood (2004). They calculated that approximately 346 seamounts were included in 84 MPAs in various EEZs, but seamounts remained completely unprotected in the high seas. In the Pacific Ocean, more than 17 seamounts in the Huon Commonwealth Marine Reserve in Tasmania, Australia have been protected since 28 June 2007[5]. Approximately 66 seamounts in the Papahānaumokuākea Marine National Monument in Hawaii, USA (formerly the Northwestern Hawaiian Islands

[4] The SPRFMO interim recognizes that vulnerable marine ecosystem (VMEs) "include seamounts, hydrothermal vents, cold water corals and sponge fields" (SPRFMO-IV-SWG-06).
[5] http://www.environment.gov.au/coasts/mpa/southeast/huon/index.html

Marine National Monument) and the Bowie seamount in British Columbia, Canada (Canessa et al., 2003) are included in MPAs. In other countries, management options such as closure to trawling and dredging have been implemented; e.g. 19 seamounts have been closed since May 2001 in New Zealand, and new regulations have been enforced since November 2007[6]. In New-Caledonia, at least 9 seamounts have been closed since April 2004[7]. The SPRFMO-III-SWG-17 report indicates there is one management measure in place on the high seas controlling access to seamount habitat in the western Tasman Sea. On a regional scale, seamounts, like most shallow marine habitats, remain poorly protected (Alder and Wood, 2004).

4. Conclusion

Cross-checking of available seamount datasets provided a much needed enhanced list of seamounts and other underwater features in the SPRFMO. The list is still incomplete in terms of number of seamounts but also in terms of characteristics of the seamounts (e.g. summit depth…). Those gaps in our knowledge are mainly due to the lack of data in this wide, largely unexplored, area and because of the poor resolution of altimetry data not allowing to detect seamounts smaller than 1000 m in height and providing inaccurate depth estimates. Nevertheless, we hope and expect that the list of seamounts and underwater features produced by this study will quickly be used for numerous applications in biodiversity conservation and fisheries management. It was indeed a major prerequisite to help managers and stakeholders by identifying and quantifying potential fishing grounds that need monitoring and potential conservation/protection areas.

[6] http://www.fish.govt.nz/en-nz/Environmental/Seabed+Protection+and+Research/Benthic+Protection+Areas.htm

[7] ftp://ftp.juridoc.gouv.nc/jonc/7777.pdf

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Annex

Annex 1. List of the 1506 underwater features cross-checked and validated in the SPRFMO area along with information and sources of information. Numbers in sources and primary reference fields correspond to sources as cited in Table 1 of Allain et al. 2008. SPRFMO-V-SWG-05.

Annex is available from the author in an XLS format.

Tables

Table 1. List of the 13 datasets collected for the screening and cross-checking of the seamount database in the SPRFMO indicating the number of features used.

Dataset (date of publication or data extraction)	Product description and shortcomings	Number and source	
Bathymetric maps			
1 S2004[a,b]	Worldwide bathymetry grid combining Smith & Sandwell (1997) and GEBCO grids. Poor bathymetric prediction in shallow waters, GEBCO limited by chart accuracy	c	
Seamount / underwater features datasets			
2 KL04 - Kitchingman & Lai (2004)[a]	Worldwide list of seamount positions and summit depth extracted automatically from ETOPO2 bathymetric chart. Flaws: several seamounts identified within one single large feature, low-relief emergent features misidentified as potential seamounts, position incorrect, summit depth inacurrate.	d	1484
3 NGA underwater features (Feb 2006)[b]	Partial worldwide list of undersea features positions, names and types from National Geospatial-Intelligence Agency. Poor positioning, inconsistencies in	e	102
4 Seamount Catalog (Apr 2006)[b]	Partial worldwide list of seamounts positions, names, summit depths, elevations and types. Emerged features included	f	26
5 Seamount Online (Jan 2006)[b]	Partial worldwide list of positions, names and types of seamounts. Some seamounts not visible on bathymetric maps	g	29
6 Volcano NGDC (Feb 2006)[b]	Worldwide list of submarine volcanoes positions and names from US National Geophysical Data Center. Poor positioning, some volcanoes not visible on	h	5
7 MUSORSTOM cruises (Feb 2006)[b]	Partial south-west Pacific list of positions, depths and names of seamounts. Depth and positions of sampling not of the summit	i	1
8 New Zealand seamounts (Apr 2006)[b]	New Zealand list of positions, names, depths and elevations of underwater features. Includes smaller features than seamounts	j	247
9 Australia ETBF seamounts (May 2006)[b]	Partial south-east Australia list of seamount positions and names in the Australian eastern tuna and billfish fishery	k	5
10 Wessel (2001)[a]	Partial worldwide list of seamount positions and elevations extracted automatically from gravity anomaly data derived from ERS-1 and Geosat	l	2451
11 GEBCO (Jul 2006)[b]	General Bathymetric Chart of the Oceans. Partial worldwide list of positions, summit depth, elevations, names and types of undersea features. Emerged	m	31
12 Hillier & Watts (2007)b	Worldwide list of seamount positions and height automatically extracted from NGDC archived single-beam ship bathymetry. Only seamounts with height higher than 1,000 m are considered in this study.	n	1451
13 IATTC	Partial East Pacific list of seamount position and name identified by fishermen and used as reference points in baitboat tuna fishery	o	5

a-Satellite-derived data, b-Ship-derived data

c-Smith (unpublished), Marks and Smith (2006), ftp://falcon.grdl.noaa.gov/pub/walter/Gebco_SandS_blend.bi2

d-Kitchingman and Lai (2004), http://www.seaaroundus.org/report/seamounts/05_AKitchingman_Slai/AK_SL_TEXT.pdf

e-NGA - GEOnet Names Server (GNS), http://earth-info.nga.mil/gns/html/index.html

f-Seamount Biogeosciences Network, http://earthref.org/SBN/

g-Stocks (2005), http://seamounts.sdsc.edu/

h-Smithsonian Institution - Global Volcanism Program, http://www.volcano.si.edu/world/globallists.cfm

i-IRD (Institut de Recherche pour le Développement)- Bertrand Richer de Forges, http://www.mnhn.fr/musorstom/

jNIWA (National Institute of Water and Atmospheric Research)- Malcolm Clarck, Rowden et al. (2005)

k-Campbell and Hobday (2003)

l-Wessel (2001), http://www.soest.hawaii.edu/pwessel/

m-IHO-IOC GEBCO SCUFN (International Hydrographic Organization - Intergovernmental Oceanographic Commission) - Ma

n-Hillier and Watts (2007), ftp://ftp.agu.org/apend/gl/2007gl029874

o-Robert Olson, IATTC

Table 2. Underwater feature typology with corresponding number of identified features inventoried in the SPRFMO area of interest.

Feature type	Description	Number of features
Seamount	Underwater mountain rising more than 1000m from the ocean floor and having a peaked or flat topped summit below the surface of the sea	207
Hill	Elevation rising generally less than 500m	49
Knoll	Elevation rising generally more than 500m and less than 1000m and of limited extent across the summit	72
Guyot	Flat-topped submarine mountain	51
Deep Bank	Large elevated area of the sea floor which is relatively deep	1
Ridge	Long narrow elevation with steep sides	32
Unknown	No information is available on the feature but it is identified by an elevation on the bathymetric maps	1094

Table 3. Distribution of the number and percentages of underwater features per summit depth in the SPRFMO area. Of the 1506 underwater features, summit depth was not available for 15 of them explaining the total of 1491 features.

Summit depth range (m)	Number of features	Percentage
0-99	17	1.14%
100-499	41	2.75%
500-999	91	6.10%
1000-1499	114	7.65%
1500-1999	222	14.89%
2000-2999	536	35.95%
3000-3999	326	21.86%
> 4000	144	9.66%
Total	1491	100.00%

Table 4. Number and percentages of underwater features where commercial species could be present in the SPRFMO area, according to features summit depth and species preferred depth distribution.

Species Preferred depth range (m)	Number of features	Percentages
Beryx spp. - alfonsino 300-700m	64	4.29%
Hoplostethus atlanticus - orange roughy 700-1100m	78	5.23%
Epigonus telescopus - cardinalfish 600-900m	55	3.69%
Hyperoglyphe antarctica - bluenose 200-750	80	5.37%
Allocytus niger - oreos 600-1000m	73	4.90%
Pseudocyttus maculatus - oreos 700-1400m	137	9.19%

Figures

Figure 1. Geographic distribution in the SPRFMO area (bold blue line) of seamount and underwater features cross-checked and validated.

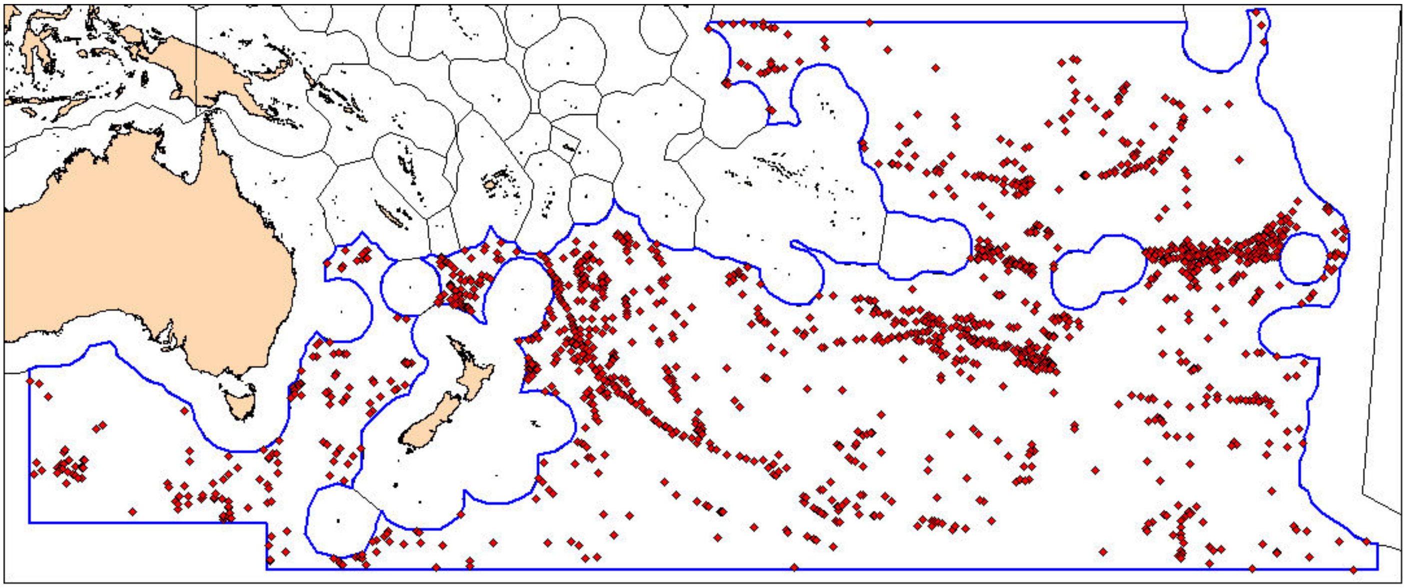

Figure 2. Geographic distribution in the SPRFMO area of potentially trawlable seamounts, i.e. seamounts which summit depth is located between 250 and 1500 m depth.

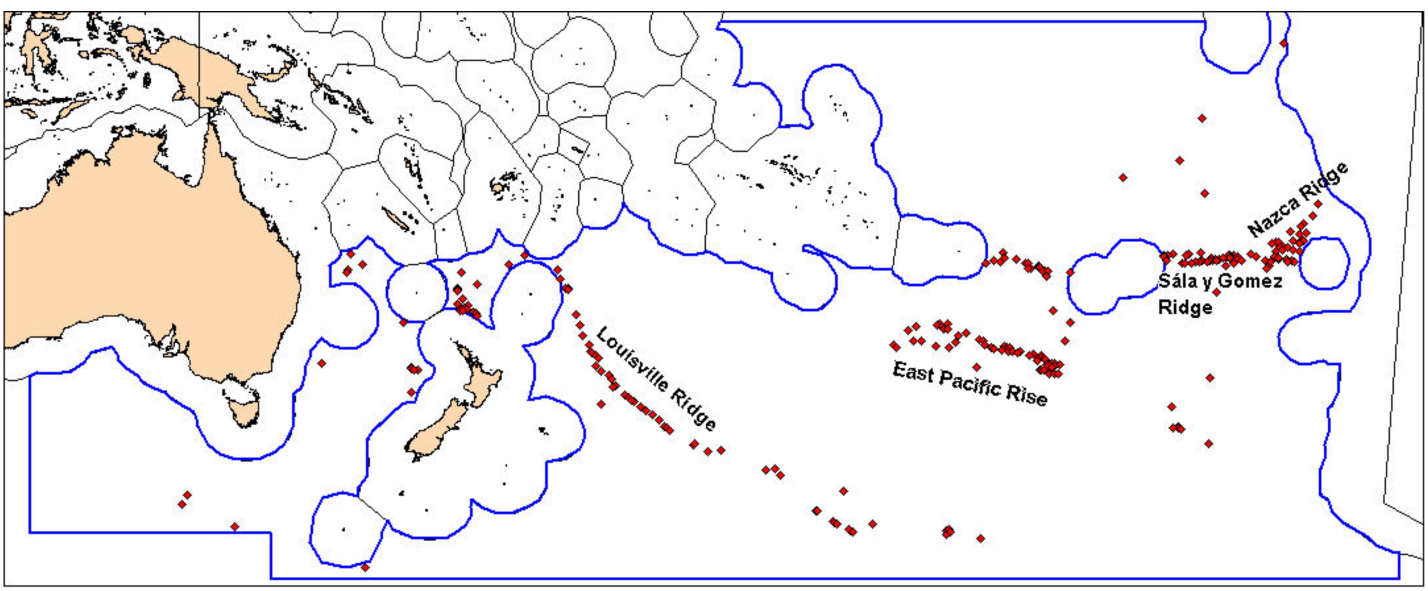

Figure 3. Geographic distribution in the SPRFMO area of seamounts which could be potential habitats of commercial fish species. A) *Beryx spp*. and *Hoplostethus atlanticus*, B) *Epigonus telescopus* and *Hyperoglyphe antarctica*, C) *Allocytus niger* and *Pseudocyttus maculatus*.