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Enhanced seamount location database for the western and central Pacific Ocean: Screening and cross-checking of 20 existing datasets

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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. Twenty previously compiled datasets including seamount/underwater feature lists, bathymetric maps and emerged feature maps from different sources (ship-derived and satellite altimetry-derived) at different spatial scales (from individual cruise to worldwide satellite data) were gathered in order to compile an enhanced list of underwater features for parts of the western and central Pacific Ocean (WCPO). The KL04 dataset [Kitchingman, A., and Lai, S., 2004. Inferences on potential seamount locations from mid-resolution bathymetric data. Fisheries Centre Research Reports 12 (5), 7–12], listing seamount positions and depths as calculated from satellite altimetry-derived bathymetry, provided the baseline data for this study as it covered the entire region of interest and included summit depth information. All KL04 potential seamounts were cross-checked with other datasets to remove any atolls and islands that had been incorrectly classified as seamounts, to add seamounts undetected by KL04, to update the overall database (geolocation, depth, elevation, and name) and to compile a 12-class typology of the different types of underwater features. Of the 4626 potential seamounts identified in KL04, 719 were multiple identifications of the same large underwater features and 373 (10%) were actually emerged banks, atolls and islands, leaving 3534 actual underwater features. Conversely, 487 underwater features were documented in other datasets but not registered by KL04. The screening of all the potential WCPO seamounts produced a final list of 4021 underwater features with agreed upon position and information. This enhanced list should have many applications in oceanography, biodiversity conservation and studies of the influence of seamounts on pelagic ecosystems and fisheries.

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1. Introduction

Submarine mountains, or ‘seamounts’ are major geomorphological features of the ocean floor. They are of considerable geological, oceanographic and biological interest. Geologically, the abundance and distribution of seamounts provide information on seafloor formation (Batiza, 1982; Smith and Jordan, 1988; Hillier and Watts, 2007). From the oceanographic point of view, seamounts

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have an impact on circulation of the water masses (White et al., 2007) and their correct position is also necessary to properly forecast tsunami propagation (e.g., Mofjeld et al., 2001). 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 such as orange roughy and tuna (e.g., Fonteneau, 1991; Clark, 1999). Listings of seamounts characterized by their position and summit depth can be invaluable for fisheries management (Fonteneau, 1991; Rogers, 1994). By providing both commercial resources and often 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). In this context, an accurate inventory of seamounts is necessary at both national and regional scales.

Several studies have been recently conducted to locate and quantify these features at the global scale (Wessel, 2001; Kitchingman and Lai, 2004; Hillier and Watts, 2007). These broad-scale works rely on automatic (i.e., algorithmic) detection of potential seamounts by analysis of global gravity or bathymetric data obtained by satellite and direct ship tracks. Large-scale non-automated studies also exist (Batiza, 1982; Marova, 2002). The number of seamounts detected varies widely among the different datasets. A primary source of variability lies in the definition of a seamount, its mathematical definition in the algorithm as well as on 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, fisheries management decisions and conservation strategies associated with seamounts until uncertainties in the different datasets have been clarified.

Various communities of users have access to numerous online databases providing seamount information, bathymetric maps, surface feature maps and so on. For people willing to use these publicly available datasets, it is puzzling to realize, with a simple, geocorrected, overlay of the different datasets, the large discrepancies. This casts doubt on the reliability of the different sources and warrants proper quality control, regardless of where the data came from, and the historical links between datasets. As a first step towards an improved database of seamount location and morphometric characteristics, existing lists of seamounts needed to be compiled, screened and cross-checked. We report here on the conclusions of this exercise for a number of Exclusive Economic Zones (EEZ) and international waters of the western and central Pacific Ocean (WCPO). Our targeted application is tuna fisheries management, but the exercise is useful beyond just fisheries. The potential seamounts identified by Kitchingman and Lai (2004) (hereafter referred to KL04) were used as the base reference. KL04 features were spatially cross-checked with 19 different seamount and bathymetry datasets available from the literature and on the internet. Specifically, we aimed to remove features incorrectly classified as seamounts from KL04, to add seamounts not detected by these authors, to update the overall database (geolocation, depth, elevation, name) and finally to compile a consistent typological framework to classify the potential seamounts into a number of geomorphological types.

2. Materials and methods

2.1. Area of interest

The study area located in the WCPO area was bounded by the 45°S–32°N and 130°E–120°W domain (Fig. 1).

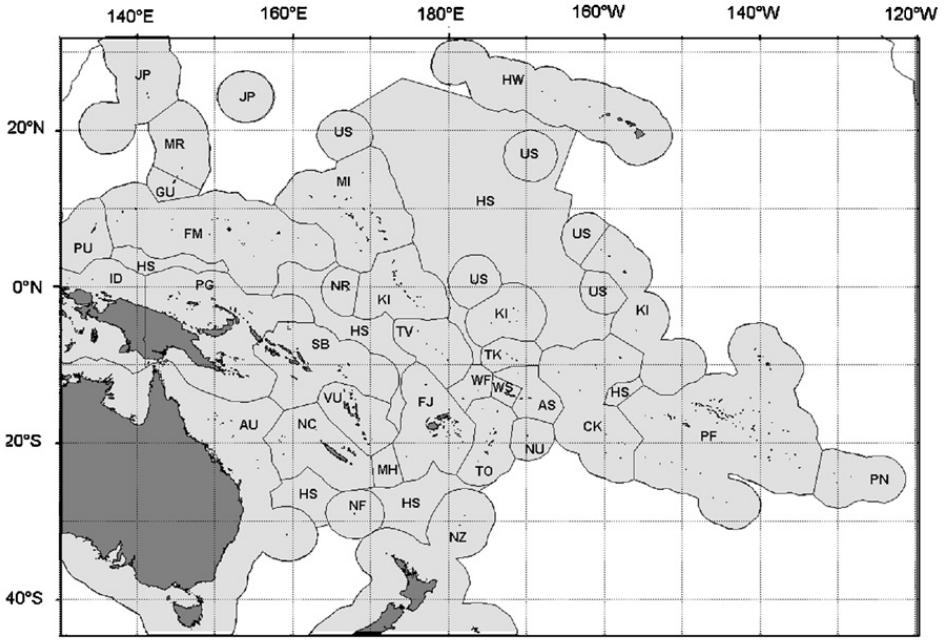

Fig. 1. Area of interest. It includes Exclusive Economical Zones of most Pacific Ocean countries (country codes are detailed in Table 4), and several high-seas international areas (HS).

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We focused here on a number of national EEZs and international waters or high-seas areas which are relevant for on-going tuna fisheries and other pelagic offshore fisheries monitoring programs.

2.2. Datasets

Twenty datasets of seamount lists, bathymetric charts and maps of sub-surface and emerged features were collected from the literature and from a variety of official websites. Data, sometimes with common origins, came from two main sources: satellite altimetry-derived gravity and bathymetry, and/or ship-derived bathymetry. Fig. 2 summarizes the relationships among the different datasets, which have variable spatial coverage and resolution and provide different types of information with specific shortcomings and assets (Table 1). As this study was conducted from a user's point of view, no interpretation or recalculation was carried out on the datasets; only the information provided as detailed in Table 1 was used.

By blending GEBCO and Smith and Sandwell (1997) bathymetry, S2004 (Dataset 1) was considered to be the best global bathymetric grid presently available. Other bathymetric maps considered in this work (Datasets 2–5) had much smaller spatial coverage but with higher precision and better accuracy, having being developed from multibeam shipborne instruments. These maps provided background bathymetry for this study, with the highest resolution in any area used.

For shallow, emerged and partially emerged features maps, the Millennium Coral Reef Mapping Project (MCRMP—Dataset 6) was the selected reference. MCRMP products come from 30 m spatial resolution satellite imagery captured with Landsat Enhanced Thematic Mapper Plus sensor. This was complemented by the Shuttle Radar Topographic Mission Water Bodies Database (SWBD—Dataset 7) which provided land emerged areas (Table 1). MCMRP provided information on positions and typology of shallow intertidal coral reef flats and patches along banks, atolls and islands which were not visible on the radar imagery used by SWBD. Large sub-surface reefs

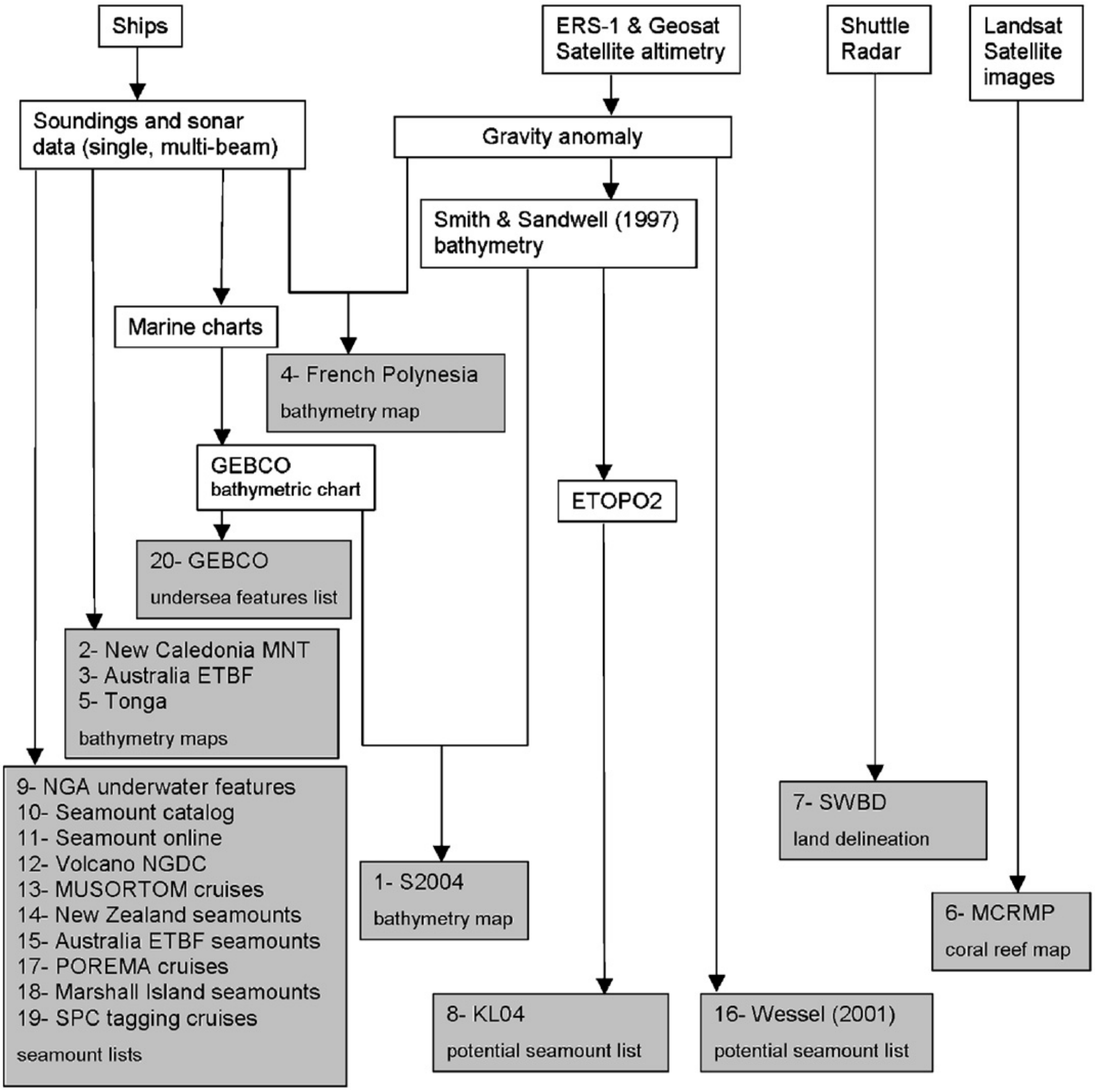

Fig. 2. Sources of the datasets used in the cross-checking (shaded cells) and their relationships. Descriptions of datasets are detailed in Table 1.

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Table 1

List of the 20 datasets collected for screening and cross-checking of the seamount database in the WCPO, indicating the number of features used. Three types of data were gathered: bathymetric maps, emerged features maps, seamount and underwater feature lists

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 and Sandwell (1997) and GEBCO grids. Poor bathymetric prediction in shallow waters, GEBCO limited by chart accuracy	[c]
2	New Caledonia MNT bathymetry[b]	New Caledonia ('Modèle Numérique de Terrain') bathymetry grid from single-beam and multibeam data. Limited spatial coverage	[d]
3	Australia ETBF bathymetry[a]	South-East Australia bathymetry grid ('Eastern Tuna and Billfish Fisheries') from US National Geophysical Data Center 8.2 nc. Limited spatial coverage, low resolution	[e]
4	French Polynesia bathymetry[a,b]	French Polynesia bathymetry grid combining satellite, soundings, single-beam and multibeam data. Limited spatial coverage	[f]
5	Tonga bathymetry[b]	Partial Tonga bathymetry grid from multibeam data. Limited spatial coverage, partial coverage of the EEZ	[g]
Emerged and partially emerged features maps			
6	MCRMP—Millennium Coral Reef Mapping Project[a]	Partial worldwide delineation of coral reefs detected using Landsat satellite images. Partial coverage of the Pacific at the time of the study due to limited Landsat imagery availability for high seas and analysis of Melanesia area in progress	[h]
7	SWBD-SRTM Water Body Data[a]	Worldwide land delineation from Shuttle Radar Topographic Mission. Shallow intertidal reefs along land masses and sub-surface reefs without any land not visible	[i]
Seamount/underwater features datasets			
8	KL04—Kitchingman and Lai (2004)[a]	Worldwide list of seamount positions and summit depth extracted automatically from ETOPO2 bathymetric chart. Flaws detailed in the study	4626[j]
9	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 feature-type labeling	317[k]
10	Seamount Catalog (Apr 2006)[b]	Partial worldwide list of seamounts positions, names, summit depths, elevations and types. Not standardised. Emerged features included	438[l]
11	Seamount Online (Jan 2006)[b]	Partial worldwide list of positions, names and types of seamounts. Not standardized. Some seamounts not visible on bathymetric maps	73[m]
12	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 bathymetric maps	42[n]
13	MUSORSTOM cruises (Feb 2006)[b]	Partial south-west Pacific list of positions, depths and names of seamounts. Depth and positions of benthic sampling not of the summit	31[o]
14	New Zealand seamounts (Apr 2006)[b]	New Zealand list of positions, names, depths and elevations of underwater features. Includes smaller features than seamounts	456[p]
15	Australia ETBF seamounts (May 2006)[b]	Partial south-east Australia list of seamount positions and names in the Australian eastern tuna and billfish fishery	24[q]
16	Wessel (2001)[a]	Partial worldwide list of seamount positions and elevations extracted automatically from gravity anomaly data derived from ERS-1 and Geosat altimetry data. Partial coverage of the south west Pacific, numerous features only located by this dataset, some misidentifications observed	2185[r]
17	POREMA cruises (2004)[b]	Partial French Polynesia list of positions, names and summit depth of seamounts	6[s]
18	Marshall Islands seamounts (1999)[b]	Partial Marshall Islands list of positions and summit depth of seamounts. Some seamounts not visible on bathymetric maps	12[t]

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Table 1 (*continued*)

Dataset (date of publication or data extraction)		Product description and shortcomings	Number and source
19	SPC tagging cruises (Apr 2006)[b]	Partial western and central Pacific list of positions and names of seamounts from the Secretariat of the Pacific Community. Position of fishing not of the summit	30[u]
20	GEBCO (Jul 2006)[b]	General Bathymetric Chart of the Oceans. Partial worldwide list of positions, summit depth, elevations, names and types of undersea features. Not standardised. Emerged features included, some seamounts identified by several records, poor positioning	335[v]

[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] Government of New Caledonia-Zoneco programme, http://www.georep.nc/downloadspub.htm.

[e] Campbell and Hobday (2003).

[f] Bonneville and Sichoix (1998), Sichoix and Bonneville (1996).

[g] Wright et al. (2000), http://dusk2.geo.orst.edu/tonga/.

[h] Andréfouët et al. (2006), http://imars.marine.usf.edu/corals/index.html.

[i] NASA/NGA, Version 2.0—ftp://e0srp01u.ecs.nasa.gov/.

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

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

[l] Seamount Biogeosciences Network, http://earthref.org/SBN/.

[m] Stocks (2005), http://seamounts.sdsc.edu/.

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

[o] IRD (Institut de Recherche pour le Développement)—Bertrand Richer de Forges, http://www.mnhn.fr/musorstom/.

[p] NIWA (National Institute of Water and Atmospheric Research)—Malcolm Clarck, Rowden et al. (2005).

[q] Campbell and Hobday (2003).

[r] Wessel (2001), http://www.soest.hawaii.edu/pwessel/.

[s] Government of French Polynesia-ZEPOLYF programme, Ponsonnet (2004).

[t] SOPAC (Pacific Islands Applied Geoscience Commission)-Kojima (1999).

[u] SPC—OFP (Secretariat of the Pacific Community—Oceanic Fisheries Programme), Valerie Allain.

[v] IHO—IOC GEBCO SCUFN (International Hydrographic Organization—Intergovernmental Oceanographic Commission)—March 2006 Gazetteer, http://www.ngdc.noaa.gov/mgg/gebco/underseafeatures.html.

without any land were not visible on SWBD data; thus, relying only on SWBD information on land presence/absence would be misleading. MCRMP coverage at the time of the analysis was not exhaustive, including most of the area of interest but excluding North Papua New Guinea, East Solomon Islands and Fiji. SWBD was exhaustive. Those two datasets were considered highly reliable.

The two major seamount lists were obtained by automatic extraction based on the same satellite altimetry data (Fig. 2, Table 1). The Wessel (2001) list of seamounts (Dataset 16) was extracted from vertical gravity gradient on a worldwide basis with, however, a gap in the New Caledonia-Tonga area of the south-west Pacific. In the WCPO it provided 2185 seamount positions, radius and height. The Kitchingman and Lai (2004) (KL04—Dataset 8) list of seamounts was extracted from the ETOPO2 bathymetric map, which is based on the Smith and Sandwell (1997) bathymetry computed from satellite altimetry-derived gravity (Fig. 2). In the WCPO this dataset provided 4626 seamount positions and summit depth.

New Zealand Seamounts (Dataset 14) was considered the most reliable dataset for deep features, but is spatially limited to the New Zealand area. It included seamounts higher than 1000 m but also numerous low-elevation underwater features described as knolls and hills.

GEBCO (Dataset 20), Seamount Catalog (Dataset 10), Seamount Online (Dataset 11) and NGA Underwater features (Dataset 9) were compilations of non-standardized information for which no metadata were available; confidence in these datasets was limited. Other minor lists of seamounts or underwater features (Datasets 12, 13, 15, 17–19) came from direct ship observation and were considered reliable. The number of seamounts per datasets varied from 6 to 438 and the information provided differed from one dataset to the other. In each dataset, information was not standardized and could include seamount positions, summit depth, feature type, elevation and name (Table 1).

Information from ship-derived datasets was considered more reliable than satellite-derived information. It is also important to acknowledge the degree of interdependence between satellite-derived datasets: hence S2004, KL04 and Wessel (2001) were not considered independent while ship-derived datasets were considered independent (Fig. 2). The lack of metadata did not allow us to determine whether large compiled datasets such as Seamount Online, Seamount Catalog, NGA underwater features and GEBCO were completely independent, though they were considered as such in this study.

2.3. *Primary reference dataset*

The Kitchingman and Lai (2004) (KL04) dataset was selected for this study as the prime referential against which the other datasets were cross-checked. KL04 is a seamount list that has been developed in biodiversity

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and fishery contexts and is easily accessible and widely used by fisheries scientists. Moreover, compared to Wessel (2001), the other global seamount list, KL04 provided the highest number of features with the best spatial coverage in the WCPO, and also gave summit depth data. The latter information is crucial for fisheries applications.

2.4. *Cross-checking method*

All datasets of seamounts/underwater features, bathymetric charts and sub-surface/emerged features maps were imported into a Geographical Information System (GIS) system prior to cross-checking. Standard GIS spatial analysis tools were used 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 (Fig. 2). When the feature was only confirmed by satellite-derived datasets (S2004 and Wessel, 2001, i.e., non-independent datasets), the KL04 feature could not be considered as 'validated', but was noted as 'cross-checked'.

Cross-checking was conducted spatially by overlaying all the available data, one EEZ after the other and then the high seas. To compare between the different datasets, we defined an 8-km buffer around each KL04 feature.

The underwater features were first compared to the MCRMP and SWBD datasets (Table 1). Potential seamounts misidentified for atolls and islands were flagged according to the overlays between KL04, MCRMP and SWBD datasets. Features were then compared to the rest of the datasets altogether and their presence on bathymetric maps was verified.

Seamounts not listed in KL04 but occurring in another dataset were added to the database after screening and cross-checking with bathymetric maps and other datasets. Since it was considered the most reliable, the first source of addition was the New Zealand seamounts database. Other sources of addition were, in order, Seamount Catalog, GEBCO, Volcano NGDC data and NGA Underwater features (Table 1). Many seamounts without information other than position and elevation were only identified by Wessel (2001). The lack of co-occurrence in other seamount datasets, the fact that we selected KL04 as the primary reference and considering the time necessary to screen the large number of Wessel (2001) features against bathymetric maps, we chose not to add them to the final database.

Geographically aggregated potential seamounts were examined separately. They were plotted on top of the best-resolution bathymetric map available for the area of interest (i.e., multibeam maps for several EEZs or else S2004—Table 1) to confirm if they represented several spatially close seamounts or a single large feature misidentified as several seamounts. Decision criteria were based on visual interpretation of the bathymetric map that was trusted over the automatic KL04 extraction. If only one peak or one flat top was clearly visible on the bathymetric map, the multiple KL04 occurrences capturing this discrete large feature were discarded. Quantitative and exactly reproducible criteria for these processes would be ideal, but are non-trivial to derive and therefore beyond the scope of this paper. Redundant records or duplicates were removed from the database. Only the record located at the center of the feature was retained.

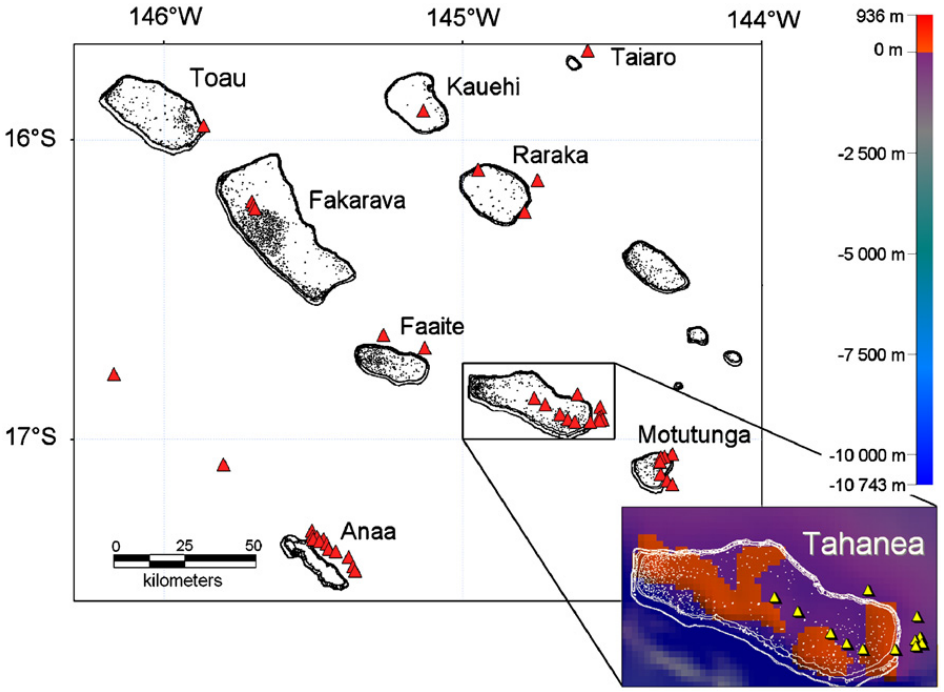

Fig. 3. Illustration of problems identified in the Kitchingman and Lai (2004) dataset. Top panel: regional view of the patterns in Tuamotu Archipelago (French Polynesia) highlighting misidentification of KL04 seamounts (triangles) for atolls mapped by MCMRP and SWBD datasets defined in Table 1 (black lines and dots show atoll rims and coral patches inside the atoll lagoons). This example also illustrates how large single features, here atolls, are identified as several potential seamounts. Bottom panel: enlargement and illustration of the same issues around Tahanea Atoll in Tuamotu Archipelago with French Polynesia bathymetry (Dataset 4) in the background.

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2.5. Updating the database: typology, position, summit depth, elevation and name of underwater features

The second step was to select from the different datasets the best attributes available for type, position, summit depth, elevation and name.

To work consistently between datasets and to classify the potential seamounts, a geomorphologic typology of underwater features was compiled. No standardized global geomorphologic typology was available despite the number of definitions of underwater features (International Hydrographic Organization and Intergovernmental Oceanographic Commission, 2001). Compilation and classification into the different types was made according to the nomenclature used in the different datasets; it was not based on a new examination of the geomorphology of the feature.

For shallow features, we used the nomenclature from the MCRMP. This provided a global standardized typology of coral reef geomorphological types (Andréfouët et al., 2006).

For deep features, the geomorphologic typology was based on the nomenclature provided by the other datasets, mainly NGA underwater features (Dataset 9), Seamount Catalog (Dataset 10) and Seamount Online (Dataset 11) (Table 1). However, it must be acknowledged that the different nomenclatures did not always properly reflect the actual shape of the labeled feature. The most frequent nomenclature was retained if the same feature was labeled differently by several datasets (e.g., Capricorn seamount, Capricorn guyot, Gora Kaprikorn, Capricorn tablemount). In the specific case of the New Zealand seamount dataset (Dataset 14), underwater features were classified into seamount, knoll and hill according to their elevation, following the standardized terminology of the International Hydrographic Organization and Intergovernmental Oceanographic Commission (2001). In cases of complete lack of geomorphological terminology in any of the datasets, the feature type was labeled as ‘Unknown’.

To update the coordinates of each KL04 potential seamount, we overlaid all the records from all datasets over the best resolution bathymetry. Then, using the bathymetry showing the real extent of the feature, we identified the record closest to the visually determined center of the feature. The coordinates of this record 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.

If available, summit depth information provided by ship cruise datasets was retained since they were considered more accurate than altimetry-derived data, particularly in shallow areas. All completely submerged features identified by MCRMP (Dataset 6) were assigned an average 40 m depth value, which corresponds to the maximum depth of penetration measured by Landsat satellite images acquired over clear oceanic waters. When several independent datasets provided different depth for the same feature, the most frequently cited value was recorded. Finally, when no other information was available, the KL04 depth data were kept unchanged.

Elevation data were provided primarily by the New Zealand Seamount dataset (Dataset 14), then by Seamount Catalog (Dataset 10) and GEBCO (Dataset 20) and finally by Wessel (2001—Dataset 16) when no other information was available.

The name of the feature was included in the database when it was mentioned in one of the datasets, e.g., Capricorn, Cross, Aotea. When different names were provided by several datasets for the same feature, all names were kept.

3. Results

3.1. KL04 dataset screening

Overlays between datasets identified four major problems with the KL04 dataset. These are illustrated in Fig. 3 for a Tuamotu Archipelago (French Polynesia):

(i) *Type 1 error*: several potential seamounts (duplicates) were identified within one discrete large feature,
(ii) *Type 2 error*: shallow and low-relief emergent features such as atolls and islands were misidentified as potential seamounts,
(iii) *Type 3 error*: potential seamounts were incorrectly positioned,
(iv) *Type 4 error*: summit depths were not accurate, especially for shallow features.

From the 14,287 potential seamounts identified globally by KL04, 8952 were located in the Pacific. Specifically, in our region of interest (Fig. 1), 4626 potential seamounts were identified by KL04 and screened in this study.

A total of 719 potential seamounts were duplicates (Type 1 error), leaving 3907 discrete features.

Of those 3907 discrete features, 373 (9.6%) were actually emerged or partially emerged features (island, atoll, bank—Type 2 error). When considering all KL04 potential seamounts, with the duplicates, 823 (17.8%) of the 4626 features are in fact low-relief emergent features.

Of the 3907 discrete features, 63.1% (2464) could only be cross-checked with other satellite-derived datasets. Therefore 36.9% (1443) could be validated by an independent ship-derived dataset.

Considering only the 3907 discrete features, the geographic position provided by KL04 matched approximately the center of the feature on the bathymetric map in 73.2% of the cases. For the remaining 26.8% of features, another source of geographic position was considered and the distance between the new position and the KL04 positions was calculated (Type 3 error). If these distances were less than the known uncertainties in longitude and latitude positions, they were discarded. Distances varied from 1 to 47 km: 85% of the distances calculated were less than 10 km, 13% of the distances were between 10 and 20 km and less than 2% of the distances were more than 20 km. Examination of the data showed that values larger than 20 km were due to the identification of geomorphologic structures as large as 50–160 km in width such as large atoll plateaus.

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In the absence of any other source of information, the summit depth provided by KL04 was kept for 83.6% of the 3907 discrete features; other sources were considered for the remaining 16.4% of the cases. When confirmed by an independent source of information other than KL04, the difference between the depth estimates was calculated (Type 4 error). In the case of the 373 emerged discrete features (islands, banks and atolls), KL04 provided summit depth values from 1 down to 1727 m. In 89% of the cases the difference was less than 200 m and for 64% it was less than 10 m (Table 2). For the 270 underwater discrete features for which the final depth was imported from another source than KL04, in 13.3% of the cases KL04 provided a shallower value than the validated one and in 86.7% the KL04 value was deeper. The absolute difference varied between 3 and 3393 m. It was less than 1000 m for 84% of the underwater features and less than 300 m for 46% (Table 2).

3.2. Final database

Compilation of the existing terminology found in the various datasets was used to produce a 12-class geomorphologic typology based on existing published definitions (Table 3). According to many previous definitions, seamounts are underwater mountains rising more than 1000 m above the ocean floor and have a summit below the surface of the sea (Rogers, 1994). In the final database, 589 discrete features (13.3%) were labeled as seamounts, 394 (8.9%) were emerged land (atolls, islands and banks), 590 (13.4%) were assigned a different geomorphological label (Table 3) and 2842 (64.4%) were left unlabeled due to lack of information.

To summarize, a total of 4415 discrete features have been confirmed in our area of interest (3907 KL04 and 508 from other databases), of which 4021 are underwater (3534 KL04 and 487 from other databases). Of the 4021 discrete underwater features, 1557 (38.7%) were validated by a ship-derived dataset while 2464 (61.3%) could only be cross-checked with a satellite-derived dataset. An example of the results of the screening and cross-checking is provided for Wallis and Futuna waters (Fig. 4). The complete list of validated underwater features and their attributes (i.e., reference number, KL04 reference number, latitude, longitude, source of chosen position, summit depth, source of chosen depth, elevation, source of chosen elevation, name, feature type, EEZ and cross-checking/validation) is available as an Online Supplementary Material.

Table 2
Quantification of KL04 Type 4-error on summit depth estimate. Frequency distribution of the number of emerged and underwater features per absolute difference in meters between KL04 depth estimate and chosen depth estimate from other sources

Depth difference in meters (KL04 depth−chosen depth)	% of emerged features ($n = 373$)	% of underwater features ($n = 270$)
1–9	63.54	2.96
10–99	15.28	14.44
100–199	10.19	17.41
200–299	4.02	11.11
300–399	2.41	11.48
400–499	2.14	7.04
500–999	1.61	19.63
1000–1999	0.80	13.70
2000–2999		1.48
>3000		0.74

Table 3
Underwater feature typology with corresponding number of identified features inventoried in the area of interest (Fig. 1)

Feature type	Description	Number of features
Deep		
Seamount	Underwater mountain rising more than 1000 m from the ocean floor and having a peaked or flat-topped summit below the surface of the sea	589
Hill	Elevation rising generally less than 500 m	189
Knoll	Elevation rising generally more than 500 m and less than 1000 m and of limited extent across the summit	155
Guyot	Flat-topped submarine mountain	74
Deep Bank	Large elevated area of the seafloor which is relatively deep	29
Ridge	Long narrow elevation with steep sides	61
Plateau	Flat-topped feature of considerable extent, dropping off abruptly on one or more sides	2
Shallow		
Drowned Bank	Large and shallow (summit at 40 m depth max.) elevation rising from the seafloor, but entirely submerged	47
Bank	Large and shallow elevation rising from the seafloor which have an emerged or intertidal part	42
Drowned Atoll	Entirely submerged and shallow elevation rising from the seafloor, clearly showing a drowned rim (40 m depth max.) surrounding lagoon features	33
Atoll	Shallow elevation rising from the seafloor showing an intertidal or emerged rim surrounding lagoon features	206
Island	Volcanic and carbonate land mass, entirely surrounded by water, with or without the presence of shallow reefs	146
Other		
Unknown	No information is available on the feature but it is identified by an elevation on the bathymetric maps	2842

The terms definitions were based on MCRMP for shallow features and on IHO-IOC (2001)/GEBCO terminology for deep features.

4. Discussion

This study has compiled a number of different datasets into a single list of underwater features in the WCPO. Duplicates and false positives have been removed, thus clarifying the number of seamounts, their depth and position in this region. This database is more complete than any other available database in the region but could still be augmented by the inclusion of Wessel (2001) potential seamounts and Hillier and Watts (2007) underwater features; the latter were not available at the time of the screening process. Spatial resolution and seamount typology were the main factors introducing uncertainties

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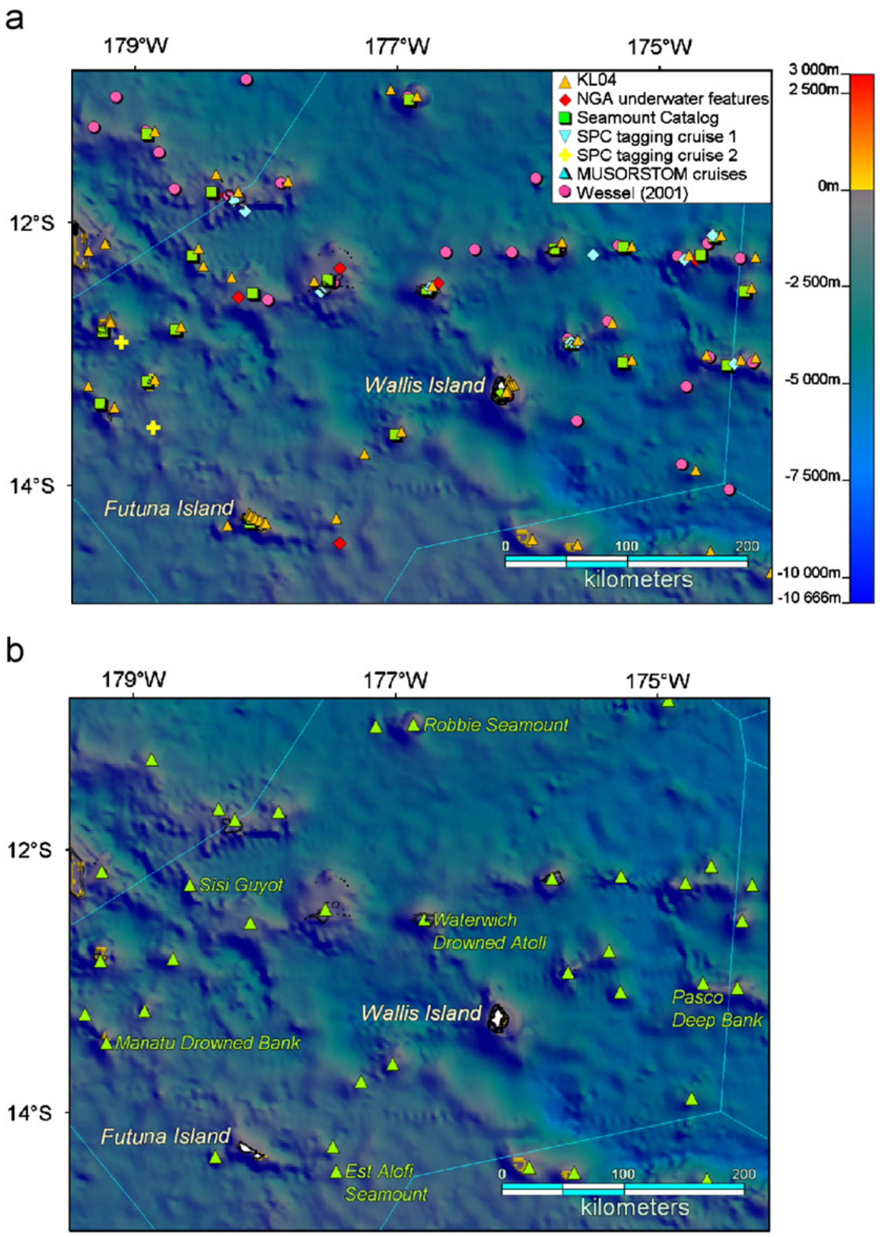

Fig. 4. Example of the seamount databases before and after cross-checking for the Wallis and Futuna area. Top panel: all datasets are presented, using different colors and markers. Bottom panel: only the final validated underwater features are shown. Duplicates and false-positives have been removed. Background bathymetry is S2004 (Dataset 1) with MCRMP (Dataset 6) showing sub-surface and emerged features in black lines. Light blue lines delineate Wallis and Futuna EEZ.

in the results. These two points are discussed below (Sections 4.1 and 4.2), followed by discussion of potential applications of the new enhanced seamount dataset (Section 4.3).

4.1. Spatial resolution

The main limitation to inferring the position, depth and number of potential seamounts is the resolution of the initial bathymetric grid. This was particularly obvious for the KL04 dataset, which presented four types of problem: misidentification of emerged features, multiple detections for a discrete feature, wrong position and inaccurate summit depth. They all result from the ETOPO2 bathymetric grid limitations (US National Geophysical Data Center, 2001—http://www.ngdc.noaa.gov/mgg/fliers/01mgg04.html). For our area of interest ETOPO2 is itself based on the Smith and Sandwell (1997) 2-min Mercator-projected bathymetry grid, derived from merged satellite gravity data and ship measurements (Fig. 2). Etnoyer (2005) considered that for bathymetry grids based on Smith and Sandwell (1997), 50–90% of the depth discrepancy between actual ship data and predictions can be explained by large cell size, i.e., low resolution. In their review of global bathymetry grids, Marks and Smith (2006) confirmed the drawbacks of ETOPO2: low resolution (2 min, i.e., 13.7 km^2 at the equator), misregistration in latitude and longitude inducing a 2–8 km horizontal systematic offset to the north-east as observed in our study, smoothing effect resulting

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in blurred features, especially for seamount summits, and poor bathymetry prediction in shallow waters. Watts et al. (2006) confirmed that satellite-altimetry bathymetric predictions were highly variable at the ca. 10 km scale. These facts alone explain most of the errors we noticed in the cross-checking exercise.

The absolute difference in summit depth between KL04 values and final validated values varied between 3 and 3393 m. However, differences were less than 100 m for 79% of the emerged features, and less than 1000 m for 84% of the underwater features. Absolute errors on summit depth (or on seamount height) were previously quantified by comparing satellite-derived bathymetry with seabeam acoustic data. For instance, errors as high as ±25% of the actual value were reported by Wessel and Lyons (1997) and errors in the order of ±13% to 15% were calculated by Baudry (1991). In their study on bathymetric prediction from satellite altimetry, Smith and Sandwell (1994) concluded that peak amplitudes are not well resolved. Consequently, summit depths are often not reliable. Evaluating the fit between their predictions and soundings, they concluded that errors were less than 96 m for 50% of the seamounts. More than 80% of the differences were lower than 257 m. Smith and Sandwell (2004) also showed that the accuracy of seamount detection from altimetry data decreased when water depth increased.

A further problem is that the spatial resolution of computed global bathymetry grids based on altimetry data only allows detection of large seamounts. In their study, Kitchingman and Lai (2004) used a 1000 m-height criterion to define and detect seamounts. Wessel and Lyons (1997) had a 1500 m resolution limit. These authors respectively detected 4626 and 4278 features in our area of interest (Fig. 1). On the other hand, a recent analysis available to us after the completion of this present work (Hillier and Watts, 2007) used high-resolution ship-track bathymetry to detect features with elevations from the seafloor between 100 and 6700 m. They reported many more smaller underwater features such as hills and knolls and identified 28,369 features in our area of interest, i.e., one order of magnitude more than previous counts. However, when considering only features higher than 1000 m, the number of seamounts detected was approximately the same (3525), scattered only along ship tracks and thus without exhaustive spatial coverage. This later study demonstrates clearly that fine-resolution data are required to accurately detect all features.

Marks and Smith (2006) and Sandwell et al. (2006) recently argued in favor of a new bathymetry from space mission to obtain higher-resolution data. Such data would avoid most of the island and atoll misidentifications from the beginning of the process, and would not have to cross-check *a posteriori* as we have done here. It would also allow detection of small and narrow seamounts (pinnacles) that at the moment fall below the resolution of existing data (Smith and Sandwell, 1997). Sandwell et al. (2006) estimated that an improvement in altimeter height resolution by a factor of 2 should increase by 18-fold the total number of seamounts mapped.

4.2. *Typology*

The second major limitation to the proper identification of underwater features as seamounts is the absence of standardized terminology to geomorphologically label and name undersea features. Here, we compiled a 12-class geomorphological typology to clearly separate seamounts from other undersea features. For shallow features (large coral reefs, atolls and drowned atolls), the classification provided by MCRMP (Dataset 6) was standardized based on the geomorphological zonations detectable consistently worldwide with Landsat images. However, for deep features, it appeared that the labels extracted from the different datasets and charts did not always properly reflect the actual geomorphology as seen on bathymetric maps, despite the existing terminology of underwater features (International Hydrographic Organization and Intergovernmental Oceanographic Commission, 2001).

We noticed that 64% of screened features lacked any geomorphologic label at all and were not described. Moreover, the majority of underwater features (61.3%) were only identified by satellite-derived datasets; 29.1% were identified by 2 independent datasets and only 9.6% were identified by 3–8 independent different datasets. 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).

Good-quality topography information is essential for a proper geomorphologic description and labeling. The development of a worldwide project equivalent to Millenium Coral Reef Mapping Project for shallow coral reefs (Andréfouët et al., 2006) would provide a proper, exhaustive and consistent classification of undersea features worldwide. Such a study would require the acquisition of detailed bathymetric maps to distinguish the geomorphology of the features, and a validation process with standardized criteria to consistently label the different structures observed. Another line of research would be to refine the algorithms detecting and describing seamounts in order to automatically account for the diversity of seamount morphology (Wessel and Lyons, 1997; Kitchingman and Lai, 2004).

4.3. *Application of the new seamount list for fisheries management and conservation*

There are many potential applications for an accurate list of seamounts providing exact positions and summit depths. Two applications of particular interest for the countries, territories and regional organizations of the WCPO are the study of the influence of seamounts on pelagic fisheries and the identification of specific seamounts for biodiversity conservation.

The exploration of the relationships between seamounts and fisheries at the regional level is a key application. Seamounts and other elevations are known to aggregate benthic, bentho-pelagic and pelagic fish, a characteristic used by the fishers to find commercial

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resources in vast open ocean areas. Benthic and benthopelagic fisheries (such as for orange roughy) have been the focus of some studies because of the impact on benthic habitats by bottom trawling (Koslow et al., 2000; Hall-Spencer et al., 2002; Clark and O'Driscoll, 2003; Gianni, 2004). Less destructive practices (e.g., bottom longline and handline) are also used to catch commercial species such as deep-sea snappers or alfonsino (Seki and Tagami, 1986; Kirkwood, 1999). Pelagic fisheries have also developed around seamounts and other underwater features but are less well documented (Fonteneau, 1991). These fisheries target tuna, billfish and other large pelagic fish caught with purse seine, pelagic longline and by the sport fishery (Muhlia Melo et al., 2003). Several hypotheses exist to explain the aggregation of pelagic fish around seamounts. They are mainly related to the presence of enhanced feeding sources, e.g., enhanced productivity created by the particular oceanographic conditions and the trapping of the so-called deep-scattering layer (DSL) of micronektonic fish, molluscs and crustaceans. The work of Bett (2001) indicates that any elevated feature, even as small as a 12 m elevation, can have an impact on the surrounding ecosystem. The summit depth is as important as the elevation itself. Seamounts of interest for pelagic fisheries are probably those with summits, in the euphotic zone, or in intermediate position (summit does not reach the euphotic zone but is above the lower limit of the DSL).

Table 4

Number of confirmed underwater features in the high seas and in EEZs of the Western and Central Pacific Ocean as shown in Fig. 1

Area	EEZ 2-digit code	Number of underwater features
High seas	HS	654
EEZs		
East Australia	AU	50
East Indonesia	ID	26
Hawaii	HW	219
North New Zealand	NZ	420
South Japan and territories	JP	259
USA Territories	US	207
PICT EEZs		
American Samoa	AS	34
Cook Islands	CK	108
Fiji	FJ	112
Federated States of Micronesia	FM	236
French Polynesia	PF	341
Guam	GU	45
Kiribati	KI	255
Marshall Islands	MI	153
Matthew and Hunter	MH	23
Northern Mariana	MR	147
Nauru	NR	6
New Caledonia	NC	57
Niue	NU	14
Norfolk Island	NF	26
Palau	PU	110
Pitcairn	PN	34
Papua New Guinea	PG	91
Samoa	WS	15
Solomon Islands	SB	157
Tokelau	TK	32
Tonga	TO	73
Tuvalu	TV	60
Vanuatu	VU	27
Wallis and Futuna	WF	30

PICT: Pacific Island Countries and Territories.

In the WCPO, tuna fisheries caught an estimated 2.2 million tonnes of tuna in 2006, representing 51% of the global tuna catch for an economic value of US$2964 million (Williams and Reid, 2007). Pelagic fisheries around some seamounts in Australia, Hawaii and Tonga have been documented and are well known by fishers (Yasui, 1986; Itano and Holland, 2000; Campbell and Hobday, 2003; Beverly et al., 2004). However, despite the existence of large pelagic fisheries datasets covering the whole WCPO (Secretariat of the Pacific Community repository), the previous gaps in accurate seamount data have prevented quantification of the relationship between seamounts and pelagic fisheries production at the regional scale. Positions and depths of seamounts and other underwater features of interest for fisheries can now be more confidently cross-checked with tuna fisheries data in the region to assess the importance of seamounts for tuna production and fisheries dynamics.

Seamounts are vulnerable ecosystems (Gianni, 2004). 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. In the Pacific Ocean, more than 17 seamounts in the Huon Commonwealth Marine Reserve in Tasmania, Australia have been protected since 28 June 2007 (http://www.environment.gov.au/coasts/mpa/southeast/huon/index.html). Approximately 66 seamounts in the Papahānaumokuākea Marine National Monument in Hawaii, USA (formerly the Northwestern Hawaiian Islands 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., in New Zealand 19 seamounts have been closed since May 2001, and new regulations have been in force since November 2007 (http://www.fish.govt.nz/en-nz/Environmental/Seabed+Protection+and+Research/Benthic+Protection+Areas.htm). In New Caledonia, at least 9 seamounts have been closed since April 2004 (ftp://ftp.juridoc.gouv.nc/jonc/7777.pdf). On a regional scale, however, seamounts, like most shallow marine habitats, remain poorly protected (Alder and Wood, 2004; Mora et al., 2006).

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By providing an updated list of seamounts, this study will help Pacific Island Countries and Territories (PICTs) and Regional Fisheries Management Organizations such as the Western and Central Pacific Fisheries Commission (WCPFC) or the South Pacific Regional Fisheries Management Organization (SPRFMO) to identify seamounts for protection and management in national waters and in the high seas of the WCPO. According to our study, 3369 underwater features are located in EEZs, i.e., under national jurisdiction (Fig. 1). Of these, 2187 are in the EEZs of the PICTs (Table 4). A total of 654 potential seamounts have been validated in the adjacent high seas (Fig. 1). These seamounts are thus located beyond national jurisdiction and their management will require the cooperation of the different existing legal instruments at the global and regional levels and possibly the development of new legal mechanisms and tools (Kimball, 2005).

5. Conclusion

Cross-checking of available seamount and bathymetry datasets provided a much needed enhanced list of seamounts and other underwater features in the WCPO. The study emphasized that only large seamounts could be detected with existing altimetry data. When they were correctly identified, their characteristics (geomorphology, position and summit depth) often remained poorly estimated. This exercise highlights the need for higher-resolution bathymetry and to further conduct a worldwide review and geomorphological classification of underwater features. These improvements would greatly enhance existing databases, especially by accurately incorporating all the small and narrow underwater features currently undetectable. 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. The updated list (see Online Supplementary Material) is still imperfect but it provides a substantial enhancement of previous databases.

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Appendix A. Supplementary materials

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.dsr.2008.04.004.

References

Alder, J., Wood, L., 2004. Managing and protecting seamounts ecosystems. Fisheries Centre Research Reports 12 (5), 67–73.

Andréfouët, S., Muller-Karger, F.E., Robinson, J.A., Kranenburg, C.J., Torres-Pulliza, D., Spraggins, S.A., Murch, B., 2006. Global assessment of modern coral reef extent and diversity for regional science and management applications: a view from space. In: Proceedings of the 10th International Coral Reef Symposium, pp. 1732–1745.

Batiza, R., 1982. Abundances, distribution and sizes of volcanoes in the Pacific Ocean and implications for the origin of non-hotspot volcanoes. Earth and Planetary Science Letters 60 (2), 195–206.

Baudry, N., 1991. 3-D modelling of seamount topography from satellite altimetry. Geophysical Research Letters 18 (6), 1143–1146.

Bett, B.J., 2001. UK Atlantic Margin Environmental Survey: introduction and overview of bathyal benthic ecology. Continental Shelf Research 21 (8–10), 917–956.

Beverly, S., Robinson, E., Itano, D., 2004. Trial setting of deep longline techniques to reduce bycatch and increase targeting of deep-swimming tunas. In: 17th Meeting of the Standing Committee on Tuna and Billfish, SCTB17, Majuro, Marshall Islands, 9–18 August 2004, FTWG-7a, pp. 1–28.

Bonneville, A., Sichoix, L., 1998. Topographie des fonds océaniques de la Polynésie française: synthèse et analyse. Géologie de la France 3, 15–28.

Campbell, R., Hobday, A.J., 2003. Swordfish–Environment–Seamount–Fishery interactions off eastern Australia. Report of the Australian Fisheries Management Authority, 597.780994, pp. 1–97.

Canessa, R.R., Conley, K.W., Smiley, B.D., 2003. Bowie seamount pilot marine protected area: an ecosystem overview report. Canadian Technical Report of Fisheries and Aquatic Sciences 2461, 1–85.

Clark, M.R., 1999. Fisheries for orange roughy (*Hoplostethus atlanticus*) on seamounts in New Zealand. Oceanologica Acta 22 (6), 593–602.

Clark, M.R., O'Driscoll, R., 2003. Deepwater fisheries and aspects of their impact on seamount habitat in New Zealand. Journal of Northwest Atlantic Fishery Science 31, 441–458.

Convention on Biological Diversity, 2003. Management of risks to the biodiversity of seamounts and cold-water corals communities beyond national jurisdiction UNEP/CBD/COP/7/INF/25, pp. 1–11.

Davies, A.J., Roberts, J.M., Hall-Spencer, J., 2007. Preserving deep-sea natural heritage: emerging issues in offshore conservation and management. Biological Conservation 138 (3–4), 299–312.

Etnoyer, P., 2005. Seamount resolution in satellite-derived bathymetry. G3 Geochemistry Geophysics Geosystems an Electronic Journal of the Earth Sciences 6 (3), 1–8.

Fonteneau, A., 1991. Monts sous-marins et thons dans l'Atlantique tropical est. Aquatic Living Resources 4, 13–25.

Gianni, M., 2004. High Seas Bottom Trawl Fisheries and Their Impacts on the Biodiversity of Vulnerable Deep-sea Ecosystems: Options for International Action. IUCN, Gland, Switzerland, 88pp.

Gjerde, K.M., 2006. Ecosystems and biodiversity in deep waters and high seas. UNEP Regional Seas Report and Studies 178, 1–60.

Hall-Spencer, J., Allain, V., Fosså, J.H., 2002. Trawling damage to Northeast Atlantic ancient coral reefs. Proceedings of the Royal Society of London B 269, 507–511.

Hillier, J.K., Watts, A.B., 2007. Global distribution of seamounts from ship-track bathymetry data. Geophysical Research Letters 34 (L13304).

International Hydrographic Organization, Intergovernmental Oceanographic Commission, 2001. Standardization of Undersea Feature Names. Guidelines Proposal Form Terminology. Bathymetric Publication No. 6. International Hydrographic Bureau, Monaco, 40pp.

Itano, D., Holland, K.N., 2000. Movement and vulnerability of bigeye (*Thunnus obesus*) and yellowfin (*Thunnus albacares*) in relation to FADs and natural aggregation points. Aquatic Living Resources 13, 213–223.

Johnston, P.A., Santillo, D., 2004. Conservation of seamount ecosystems: application of a marine protected areas concept. Archive of Fishery and Marine Research 51 (1–3), 305–319.

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Kimball, L.A., 2005. The international legal regime of the high seas and the seabed beyond the limits of national jurisdiction and options for cooperation for the establishment of marine protected areas (MPAs) in marine areas beyond the limits of national jurisdiction. Secretariat of the Convention on Biological Diversity Technical Series 19, 1–64.

Kirkwood, G.P., 1999. Management Strategies for New or Lightly Exploited Fisheries Final Technical Report. MRAG Ltd, London, 45pp.

Kitchingman, A., Lai, S., 2004. Inferences on potential seamount locations from mid-resolution bathymetric data. Fisheries Centre Research Reports 12 (5), 7–12.

Kojima, K., 1999. Report on the cobalt-rich manganese crust resources in the waters of the Republic of the Marshall Islands: Based on the results of the cooperation study project on the deepsea mineral resources in selected offshore areas of the SOPAC Region. SOPAC Technical Report 293, 1–9.

Koslow, J., Boehlert, G.W., Gordon, J.D.M., Haedrich, R.L., Lorance, P., Parin, N., 2000. Continental slope and deep-sea fisheries: implications for a fragile ecosystem. ICES Journal of Marine Science 87, 548–557.

Marks, K.M., Smith, W.H.F., 2006. An evaluation of publicly available global bathymetry grid. Marine Geophysical Researches 27 (1), 19–34.

Marova, N.A., 2002. Seamounts of the World Ocean: features of their distribution by height and space. Oceanology 42 (3), 409–413.

Mofjeld, H.O., Titov, V.V., González, F.I., Newman, J.C., 2001. Tsunami scattering provinces in the Pacific Ocean. Geophysical Research Letters 28 (2), 335–337.

Mora, C., Andréfouët, S., Costello, M., Kranenburg, C., Rollo, A., Veron, J., Gaston, K., Myers, R., 2006. Coral reefs and the global network of marine protected areas. Science 312, 1750–1751.

Muhlia Melo, A., Klimley, P., González Armas, R., Trasviña Castro, A., Rodríguez Romero, J., Amador Buenrostro, A., 2003. Pelagic fish assemblages at the Espíritu Santo seamount in the Gulf of California during El Niño 1997–1998 and non-El Niño conditions. Geofísica Internacional 42 (3), 473–481.

Ponsonnet, C., 2004. Les paru. Bilan des connaissances acquises et perspectives d'exploitation en Polynésie Française. Document et travaux du programme ZEPOLYF 3, 1–214.

Richer de Forges, B., Koslow, J.A., Poore, G.B.C., 2000. Diversity and endemism of the benthic seamount fauna in the southwest Pacific. Nature 405, 944–947.

Roberts, C.M., 2002. Deep impact: the rising toll of fishing in the deep sea. Trends in Ecology and Evolution 17 (5), 242–245.

Rogers, A.D., 1994. The biology of seamounts. Advances in Marine Biology 13, 305–350.

Rowden, A.A., Clark, M.R., Wright, I.C., 2005. Physical characterisation and a biologically focused classification of "seamounts" in the New Zealand region. New Zealand Journal of Marine and Freshwater Research 39, 1039–1059.

Sandwell, D.T., Smith, W.H.F., Gille, S., Kappel, E., Jayne, S., Khalid, S., Coakley, B., Géli, L., 2006. Bathymetry from space: rationale and requirements for a new, high-resolution altimetric mission. Comptes-Rendus de Geoscience 338 (14–15), 1049–1062.

Schmidt, S., Christiansen, S., 2004. The Offshore MPA Toolbox: Implementing Marine Protected Areas in the North-east Atlantic Offshore: Seamounts—A Case Study. OASIS and WWF Germany, Hamburg, Frankfurt am Main, 56pp.

Scovazzi, T., 2004. Marine protected areas on the high seas: some legal and policy considerations. The International Journal of Marine and Coastal Law 19 (1), 1–17.

Seki, M.P., Tagami, D.T., 1986. Review and present status of handline fisheries for alfonsino. NOAA Technical Report NMFS 43, 31–35.

Sichoix, L., Bonneville, A., 1996. Prediction of bathymetry in French Polynesia constrained by shipboard data. Geophysical Research Letters 23, 2469–2472.

Smith, D.K., Jordan, T.H., 1988. Seamount statistics in the Pacific Ocean. Journal of Geophysical Research 93 (B4), 2899–2918.

Smith, W.H.F., Sandwell, D.T., 1994. Bathymetry prediction from dense satellite altimetry and sparse shipboard bathymetry. Journal of Geophysical Research 99 (B11), 21803–21824.

Smith, W.H.F., Sandwell, D.T., 1997. Global sea floor topography from satellite altimetry and ship depth soundings. Science 277 (5334), 1956–1962.

Smith, W.H.F., Sandwell, D.T., 2004. Conventional bathymetry, bathymetry from space, and geodetic altimetry. Oceanography 17 (1), 8–23.

Stocks, K., 2005. Seamounts Online: An Online Information System for Seamount Biology Version 2005-1. World Wide Web Electronic Publication 〈http://seamounts.sdsc.edu〉.

Watts, A.B., Sandwell, D.T., Smith, W.H.F., Wessel, P., 2006. Global gravity, bathymetry, and the distribution of submarine volcanism through space and time. Journal of Geophysical Research 111 (B08408), 1–26.

Wessel, P., 2001. Global distribution of seamounts inferred from gridded Geosat/ERS-1 altimetry. Journal of Geophysical Research 106 (B9), 19431–19441.

Wessel, P., Lyons, S., 1997. Distribution of large Pacific seamounts from Geosat/ERS-1: implications for the history of intraplate volcanism. Journal of Geophysical Research 102 (B10), 22459–22475.

White, M., Bashmachchnikov, I., Arístegui, J., Martins, A., 2007. Physical processes and seamount productivity. In: Pitcher, T.J., Morato, T., Hart, P.J.B., Clark, M.R., Haggan, N., Santos, R.S. (Eds.), Seamounts: Ecology, Fisheries & Conservation. Blackwell Publishing Ltd., Oxford, pp. 65–84.

Williams, P.G., Reid, C., 2007. Overview of tuna fisheries in the Western and Central Pacific Ocean, including economic conditions—2006. In: 3rd Regular Session of the Scientific Committee of the Western and Central Pacific Fisheries Commission, WCPFC-SC3, Honolulu, Hawaii, USA, 13–24 August 2007, GN WP-1, pp. 1–43.

Worm, B., Lotze, H.K., Myers, R.A., 2003. Predator diversity hotspots in the blue ocean. Proceedings of the National Academy of Sciences 100 (17), 9884–9888.

Wright, D.J., Bloomer, S.H., MacLeod, C.J., Taylor, B., Goodlife, A.M., 2000. Bathymetry of the Tonga Trench and Forearc: a map series. Marine Geophysical Researches 21, 489–511.

Yasui, M., 1986. Albacore, *Thunnus alalunga*, pole-and-line fishery around the Emperor Seamounts. NOAA Technical Report NMFS 43, 37–40.