Database documentation: seamount

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NIWA Internal Report
2006

Revised on 22 May 2007

Contents

List of Figures

1 Database documentation series

The National Institute of Water and Atmospheric Research (NIWA) currently carry out the role of Data Manager and Custodian for the fisheries research data owned by the Ministry of Fisheries (MFish).

This document provides an introduction to the trawl survey database **seamount**, and is a part of the database documentation series produced by NIWA.

All documents in this series include an introduction to the database design, a description of the main data structures accompanied by an Entity Relationship Diagram (ERD), and a listing of all the main tables. The ERD graphically shows how all the tables fit in together, and their relationships to other databases.

This document is intended as a guide for users and administrators of the **seamount** database.

2 Seamount database

2.1 Introduction

Seamounts have become a high-profile habitat type in recent years, as they have been increasingly recognised as important areas for biodiversity, sites of localised high biological productivity, and are often the focus of commercial fishing for valuable fish species (see review by Rogers 1994). The number of seamounts in the world's oceans is unknown because large areas of sea floor remain unmapped in sufficient detail to identify such features. However, the global number is likely to be very large as more than 30 000 seamounts are thought to exist in the Pacific Ocean alone (Smith & Jordon 1988). The physical, biological, and oceanographic characteristics of seamounts of the New Zealand region of the South Pacific Ocean are poorly known. The New Zealand region, because of its geological setting and history, has a complex seafloor relief. Tectonism and volcanism since 300 million years, and crucially within the last 80–100 million years have formed a sea-floor bathymetry in which isolated submarine rises feature prominently (CANZ 1997). The major physiographic features were known by the early 1970s (e.g., Brodie 1964; Wanoa & Lewis 1972; Thompson 1991), but with the advent of GPS satellite navigation, use of multibeam swath-mapping, and declassification of satellite altimetry data (Sandwell & Smith 1997), the last 10 years have seen a significant increase in knowledge of the distribution of seamounts around New Zealand (Ramillien & Wright 2000). Such data have produced detailed bathymetry of seamounts in some areas (e.g., Lewis et al. 1997), but most have not been mapped in detail. Biological research published in the primary literature on seamounts of the New Zealand region is limited, and reflects the fishery or fishing impact issues (Probert et al. 1997; Clark 1999; Clark & O'Driscoll 2003; Tracey et al. 2004). Only since 1999 has research been focused on assessing the diversity and ecology of seamount benthic macroinvertebrate fauna (Clark et al. 1999a). Determining the identities of species sampled from such previously unexplored habitats is very time-consuming and the results of such research effort have only recently begun to be published in preliminary/interim reports (Clark & O'Shea 2001; Rowden et al. 2002, 2003, 2004). Nonetheless, the importance of conserving seamount habitats (Probert 1999) in the New Zealand region has been recognised with the designation of 19 seamounts with “protected” status (closed to all trawl methods) following a management appraisal (Clark et al. 2000; Brodie & Clark 2004).

The **seamount** database presents a synopsis of the physical characteristics of seamounts within the “New Zealand region” (taken here as the area bounded by 24°S, 167°W, 57°S, and 157°E), which extends an earlier characterisation (Wright 1999).

2.2 Seamount, knoll, hill, or UTF?

It is important to clarify, in the present context, the term “seamount”. Three main types of submarine elevation, as defined by Eade & Carter (1975), are recognised in the New Zealand region: “seamount”—an isolated elevation rising 1000 m or more from the sea floor and of limited extent across the summit (not flat-topped as a “guyot”); “knoll”— an isolated elevation rising less than 1000 m from the sea floor, and of limited extent across the summit; “pinnacle”—a small pillar-like elevation of the sea floor. In recent years, the term seamount has been applied more generally to topographic “hill” elevations regardless of size and relief (e.g., Epp & Smoot 1989; Rogers 1994). Reports on seamounts in the New Zealand region have also used variable definitions, with a vertical extent of 250 m applied by Wright (1999), and 100 m by Clark et al. (1999b) and Clark & O’Driscoll (2003). MFish draft “Seamount Management Strategy” defines seamounts as “protruding irregularities or bottom features that rise greater than 100 m above the sea floor” (MFish 1999). For the purposes of this database, we have collated data on features with a vertical elevation of 250m or greater (thus, the term seamount is used here for discrete bathymetric features with ≥250 m of relief) with some features of 100 m or greater that are significant for the fishing industry being also included, but have presented these data in a way that accounts for differing interpretations of the terminology for undersea features of various sizes. MFish and the New Zealand fishing industry call this range of “seamounts” Underwater Topographical Features (UTF’s).

2.3 Data Methods

2.3.1 Physical Data

Physical data on seamounts were collated from existing sources used in the updating of regional bathymetry in 1997 (CANZ 1997), including data held by the NIWA, the New Zealand Hydrographic Office, Royal New Zealand Navy, National Geophysical Data Centre (United States), South Pacific Applied Geoscience Commission (Fiji), published scientific papers, and recent multibeam surveys funded by Institut Français de Recherche pour l’Exploitation de la Mer (IFREMER, France). This information was supplemented by detailed data on smaller features from University of Kiel (Germany), Seabed Mapping New Zealand Ltd, and research surveys carried out over the last 20 years by NIWA and MFish (including multibeam surveys in the last 5 years). Many of these surveys were for deep-water fish species such as orange roughy, which often form aggregations over small seamount features on the seabed.

The position, as identified by the fields “latitude” and “longitude”, of a seamount was based on the location of the summit, which was determined from actual bathymetric data wherever possible, or from the central point of the shallowest contour derived from NIWA’s regional bathymetric dataset. “Depth at top” is the shallowest depth record known from the seamount. The “depth at base” of the seamount was generally taken from the deepest most complete depth contour that encircled the entire seamount. In some instances, there was an appreciable difference between sectors of a seamount, where one side is, for example, up-slope of a broader feature like a rise. In these instances the mid-point between the shallow and deep basal depth was taken. "Elevation" was computed as the difference between depth at peak and depth at base. "Area" was estimated from the polygon of the basal depth contour. "Slope" was calculated in two ways. First, actual echo-sounding data from ship tracks over seamounts were analysed and maximum, minimum (usually zero at the peak), and mean slopes computed. For many seamounts, however, data were inadequate for this method, and hence slope was calculated from the seamount trigonometry using elevation and base radius to derive average slope angle. This method tends to underestimate the true slope on the flanks of seamounts, since most seamounts have broadly domed peak regions (i.e., the method tends to average the low gradients near the peak and higher gradients on the flanks).

2.3.2 Geological and Geomorphological Data

For the purposes of this database, the geological "association" of seamounts was broadly categorised as being associated either with the inner New Zealand continental margin (within the enclosing continuous 2000 m isobath) or with various types of ridge and rise systems on the surrounding oceanic sea floor. Most of the known seamounts have received little or no scientific study, and their geological "origin" is not definitive, but the seamounts included in this database are classified on the basis of geological composition or location, i.e., arc/mid-plate/oceanic plate/hotspot/rifted margin volcanoes, tectonic ridge, rifted continental block, or continental rise.

Less than 10 seamounts in the New Zealand region have any form of direct radiometric age dating (e.g., Wright 1994; Mortimer et al. 1998; Wright *unpubl. data*), thus most "age" determinations are based on interpretation of magnetic anomaly and plate reconstructions and a regional assessment of sea-floor volcanism (Sutherland 1999).

The methods to which the fields "volcanic_activity", "hydrothermal_activity", and "morphology" are described in detail in Appendix 2.

To date there are no regional studies of seamount "substrates" within the New Zealand region. The only regional compilation of substrate type is for sea-floor sediment composition (Mitchell et al. 1989), which is produced on a scale too coarse to realistically resolve sediment types for a seamount. At smaller spatial scales, modern swath imagery data (typically at an acquisition frequency of c. 12 kHz), although restricted to relatively small areas, can provide important information on general substrate compositions at scales of 100–1000 m. Such swath mapping imagery has been acquired from only a few areas where significant numbers of seamounts exist (southern Kermadec/Colville Ridges and Havre Trough, eastern North Island and Chatham Rise; Coffin et al. 1994; Blackmore & Wright 1995; Lewis et al. 1997, 1999; Barnes et al. 1998). These swath imagery data can differentiate broad areas of sediment and rock substrates (Orpin 2004) and the nature of large-scale degradation and mass-wasting of seamounts. More recently, as part of detailed geological investigations of specific seamounts along the southern Kermadec arc (Wright 1994, 1996, 2001; Wright & Gamble 1999), higher frequency and higher resolution multibeam systems (at 30 kHz) have been used (Wright et al. in press). From these detailed investigations it is possible to describe substrate heterogeneity at scales of tens to hundreds of metres through integrating data from swath mapping backscatter imagery, sea-floor photography, and/or sea-floor sampling (e.g., Wright et al. 2002). For this database, the presence of such swath imagery for a seamount is flagged by a Y/N in the "substrate" field.

Any mining activity, as shown by the field "mining", was based on current (at date of publication) mineral rights license areas as held by Crown Minerals at the Ministry of Economic Development.

2.3.3 Primary Productionl Data

Estimates of "chlorophyll *a*" (Chl. *a*) were derived from the mean of SeaWiFS (Hooker et al. 1992) observations (see Appendix 3). Remotely sensed Chl. *a* data are generally related to the relative occurrence of phytoplankton an surface waters, and given reasonable assumptions are proxies for phytoplankton biomass in the ocean above the seamount (Martin 2004). The amount of phytoplankton (or primary productivity) associated with seamounts is likely to influence the diversity of pelagic and subsequently the benthic faunal assemblages (Piepenburg & Müller 2004). The shortest "distance a seamount is from the continental shelf" was calculated using ArcGIS, where seamount distances from the 250 m depth contour (which approximates the continental shelf edge) were calculated at a resolution of ± 1 km, based on an azimuthal equidistant projection (Central Meridian 171°E, Latitude of Origin 41°S, Datum WGS84). The composition of faunal assemblages on seamounts (which are generally features of the slope or deep-sea) is expected to be in part influenced by the degree to which faunal colonisation has been possible from the shallow water of the shelf (Leal & Bouchet 1991; Gillet & Dauvin 2000). Thus, a measure of the shortest distance from the shelf edge is expected to be a reasonable proxy for the likely extent of seamount colonisation by shallow-water species. Distance from the shelf edge is also a reasonable proxy for the existence of localised, biologically meaningful, hydrodynamic processes. The intensity of the current flow field near a seamount decreases with distance from continental margins (Smith et al. 1989), which concomitantly impacts the development of hydrographic features (e.g., localised up welling, Taylor columns) that can influence primary productivity overlying seamounts (e.g., Comeau et al. 1995). Latitude and longitude can be used as proxies for the variable sea surface temperature and/or to establish position in relation to distinct water masses. In the present study, remotely-sensed data were available to directly measure sea surface temperature and derive data that gave temporally and spatially continuous variables that characterise different water masses. Data for sea surface temperature (SST) variables "wintertime SST", "annual amplitude of SST", "spatial SST gradient", and "summertime SST anomaly" were calculated from NIWA's archived SST climatology data set. Procedures for collecting satellite radiometer data, detecting cloud and retrieving SST data are described by Uddstrom & Oien (1999), and the calculation of the specified variables for the New Zealand region (at 1 km resolution) are detailed in Hadfield et al. (2002). Patterns in wintertime SST are a proxy for water mass (which is related to nutrient availability); variations in the annual amplitude of SST are owing to differences in stratification and wind mixing, that together produce the mixed layer across the region; spatial SST gradient recognises fronts in oceanic water masses (and is expected to correlate with variation in primary productivity); summertime SST anomaly is expected to recognise anomalies in temperature that are owing to hydrodynamic forcing, such as upwelling and vigorous mixing from eddies (areas with high values of this variable are expected to correlate with high primary productivity). All of these aforementioned parameters derived from SST data, possibly influence the composition of pelagic and benthic assemblages (see Longhurst 1998).

2.3.4 Fisheries Data

Extracts are carried out from the MFish research **trawl** database to produce by individual seamount feature lists of taxa comprising teleost fishes, elasmobranches (sharks, rays, chimaeras, and ghost sharks), squid, and octopi). These taxa are referred to as species in this document. A count of the occurrence of species have been made for a sub-sample (n=47) of seamounts occurring in the main geographic regions of the EEZ in depths between ~500 and 1700 m. Several of the seamounts from which data were extracted have had significant research effort and are important commercially. Examples of these are Graveyard, Mt Muck, Camerons, and Smiths. The number of times each fish and squid/octopi species was recorded in trawls on that seamount is provided in the "num_fish_research" and “num_squ_oct_research” fields. As a measure of effort, a count of the number of research trawls for each seamount is also provided in the “num_research_tows” field.

In addition to the research trawl data, extracts are carried from the MFish catch/effort database to produce individual seamount feature lists of: the number of tows, years fished, total catch weights, and fishing indices by key species; the number of tows and catch weights of all species by fishing year (1 October – 30 September); the year first fished; the total linear distance of trawls towed; and the number of trawls towed in each of the 4 compass directions in 90° quadrants.

Physical Data Model
Model: Seamounts_database
Package:
Diagram: PHYSICALDIAGRAM_1
Author: Kevin Mackay Date : 4/09/2006
Version : 2.0

t_seamounts	
reg_no	INTEGER
area_code	CHAR(15)
EEZ	CHAR(12)
FMA	CHAR(5)
fished	CHAR(1)
latitude	decimal(8,6)
longitude	decimal(9,6)
depth_top	INTEGER
depth_base	INTEGER
elevation	INTEGER
name	CHAR(60)
source	CHAR(50)
min_cont	INTEGER
max_cont	INTEGER
area_km2	longfloat
age	CHAR(10)
assoc	CHAR(30)
origin	CHAR(32)
volcanic_activity	CHAR(15)
hydrothermal_activity	CHAR(3)
mining	CHAR(1)
substrate	CHAR(1)
dist_shelf	decimal(5,1)
surf_water	CHAR(60)
chl_a	decimal(7,6)
chlor_mu	decimal(5,4)
chlor_sd	decimal(5,4)
chlor_cv	decimal(5,4)
c2_npp_mu	decimal(6,3)
c2_npp_sd	decimal(6,3)
c2_npp_cv	decimal(7,6)
vgpm_npp_mu	decimal(7,3)
vgpm_npp_sd	decimal(6,3)
vgpm_npp_cv	decimal(7,6)
biol_samp	CHAR(1)
matrix_coral	CHAR(1)
octocoral	CHAR(1)
sponge	CHAR(1)
protect_status	CHAR(30)
num_fish_research	INTEGER
num_squ_oct_research	INTEGER
num_research_tows	INTEGER
total_num_tows	INTEGER
total_fish_catch	decimal(10,3))
total_years_fished	INTEGER
FII_all	decimal(13,3)
year_first_fished	INTEGER
dist_towed	decimal(8,2)
num_tow_dir	INTEGER
num_N_tows	INTEGER
num_E_tows	INTEGER
num_S_tows	INTEGER
num_W_tows	INTEGER
FEI	decimal(12,6)
annual_amp_SST	decimal(7,6)
winter_SST	decimal(7,5)
summer_SST_anomaly	decimal(8,7)
spatial_SST_gradient	decimal(8,7)
curr_speed	decimal(10,9))
depth_thermocline	INTEGER
MEC_20	INTEGER
MEC_33	INTEGER
ann_mean_semi_diur_tide	longfloat
diurnal_tide	longfloat
prob_cap_meanflow	decimal(4,1)
prob_cap_diurnal	decimal(4,1))
min_slope	decimal(4,2)
max_slope	decimal(4,2)
mean_slope	decimal(4,2)
sd_slope	decimal(4,2)
calc_area	longfloat
perimeter	decimal(12,6)
comments	CHAR(120)

reg_no = reg_no

t_fish_spp_indices	
reg_no	INTEGER
species	CHAR(3)
num_tows	INTEGER
catch	decimal(9,3)
num_years	INTEGER
FII	decimal(13,3)

reg_no = reg_no

t_fish_year	
reg_no	INTEGER
yr	inter
catch	decimal(10,3)
num_tows	INTEGER

Figure 1: Entity Relationship Diagram (ERD) of the seamount database.

3 Data structures

3.1 Introduction

The seamount database was originally a spreadsheet and this is reflected in the schema with one large table with many attributes. The overriding factor when designing the schema was the need to transfer data easily between local copy spreadsheets (that individual researchers might have), the central database, and back again.

3.2 Database description

This database contains three tables. The ERD for **seamount** (Figure 1) shows the logical structure of the database and its entities (each entity is implemented as a database *table*) and relationships between these tables and tables in other databases. All of the table's attributes are shown in the ERD. The underlined attributes represent the table's primary key[1]. This schema is valid regardless of the database system chosen, and it can remain correct even if the Database Management System (DBMS) is changed.

Each table represents an object, event, or concept in the real world that has been selected to be represented in the database. Each *attribute* of a table is a defining property or quality of the table.

Note that one of the tables in the **seamount** database has an attribute, called a foreign key[2], which contains standard NIWA species codes. This attributes provide links to the **rdb** (research database) database, which contains the definitive list of standard codes.

Section 5 shows a listing of all the **seamount** tables as implemented by the Empress DBMS. As can be seen in the listing of the tables, a table's primary key has an unique index on it. Primary keys are generally listed using the format:

```
Indices:    UNIQUE index_name ON (attribute [, attributes ])
```

where the attribute(s) make up the primary key and the index name is the primary key name. This prevents records with duplicate key values from being inserted into the table, e.g., a trip with an existing trip code.

As reflected by the ERD, the central core of the database is centered on a seamount. Details for each seamount are held in the table *t_seamounts* (Table 1). Each seamount is uniquely identified by a registration number, stored as the attribute *reg_no*.

The fundamental relationship between tables that is repeated throughout the database is the *one-to-*

[1] A primary key is an attribute or a combination of attributes that contains an unique value to identify that record.
[2] A foreign key is any attribute, or a combination of attributes, in a table that is a primary key of another table. Tables are linked together through foreign keys.

many relationship[3]. This is shown in the ERD by connecting a single line (indicating 'many') from the child table (e.g., *t_fish_year*) to the parent table (e.g., *t_seamounts*) with an arrow-head (indicating 'one') pointing to the parent.

Every relationship has a mandatory or optional aspect to it. That is, if a relationship is mandatory, then it has to occur and least once, while an optional relationship might not occur at all. For example, in Figure 1, consider that relationship between the table *t_seamounts* and it's child table *t_fish_year*.

The symbol "O" by the child *t_fish_year* means that a seamount record can have zero or many fishing year records, while the bar by the parent *t_seamounts* means that for every fishing year record there must be a matching seamount record.

Fisheries related data on seamounts can be broken down into two types of relations.

The first fisheries relation is species. The table *t_fish_spp_indices*, for each combination of seamount and species, contains the total number of fishing tows targeting that species, the total catch of that species for all tow, the total number of years that that species has been caught on the seamount, and the Fishing Importance Index (FII) for that species on that seamount.

The second fisheries relation is year. The table *t_fish_year*, for each combination of seamount and year, contains the total catch weight and the total number of tows for all species.

These *t_fish_spp_indices* table contain foreign keys, which link these tables to tables in the **rdb** database. Links to the **rdb** database are enforced by referential constraints[4]. Constraints do not allow *orphans* to exist in any table, i.e., where a child record exists without a related parent record. This may happen when: a parent record is deleted; the parent record is altered so that the relationship is lost; or a child record is entered without a parent record. Constraints are shown in the table listings by the following format:

```
Referential:        error message (attribute) INSERT|REFER
                    parent table (attribute)
```

For example, consider the following constraint found in the table *t_fish_spp_indices*:

```
Referential: invalid reg no (reg_no) REFER t_seamounts (reg_no)
```

This means that the value of the attribute *reg_no* in a *t_fish_spp_indices* record must already exist in the parent table *t_seamounts* or the record will be rejected and the error message "invalid reg no" will be displayed.

All tables in this database are indexed. That is, attributes that are most likely to be used as a searching key have like values linked together to speed up searches. These indices are listed using the following format:

```
Indices:            NORMAL (2, 15) index_name ON (attribute[, attribute])
```

[3] A one-to-many relationship is where one record in a table (the *parent*) relates to one or many records in another table (the *child*).
[4] Also known as integrity checks.

Note that indices may be simple, pointing to one attribute or composite pointing to more than one attribute. The numbers "…(2, 15)…" in the syntax are Empress DBMS default values relating to the amount of space allocated for the index.

4 Table summaries

The **seamount** database has three tables containing seamount physical, oceanographic and fisheries related data.

The following is a listing and brief outline of the tables contained **seamount**:

1. **t_seamount :** contains physical, geological, chemical, oceanographic and fisheries information on all seamounts.
2. **t_fish_spp_indices :** contains species specific indices by seamount.
3. **t_fish_year :** contains year specific fisheries indices by seamount.

5 seamount tables

The following are listings of the tables in the **seamount** database, including attribute names, data types (and any range restrictions), and comments.

5.1 Table 1: t_seamounts

Comment: Profile information on seamounts.

Attributes	Data Type	Null?	Comment
reg_no	integer	No	Seamount unique number.
area_code	character(15,1)		Area code. Generally the NZOI Oceanic Series map name.
EEZ	character(12,1) smatch 'EEZ' or 'outside EEZ'		Inside the EEZ or not?
FMA	character(5,1)		Fisheries Management Area (FMA).
Fished	character(1,1) smatch '[YN]'		Has the seamount been fished at all?
latitude	decimal(8,6)		Latitude of seamount summit (dec. degrees).
longitude	decimal(9,6)		Longitude of seamount summit (dec. degrees).
depth_top	integer		Depth (metres) to seamount summit.
depth_base	integer		Depth (metres) to seamount base.
elevation	integer		Total seamount elevation (metres).
name	character(60,1)		Seamount name (if any).
source	character(50,1)		Brief description of the source for the first identification of the seamount.
min_cont	integer		Shallowest contour (at 50m intervals).
max_cont	integer		Deepest enclosing contour (at 50m intervals)
area_km2	double precision		Approx. area (km^2)
age	character(10,1)		Approx. geological age.
assoc	character(30,1)		Geological association.
origin	character(32,1)		Geological origin.

Attributes	Data Type	Null?	Comment
volcanic_activity	character(15,1) smatch 'Exinct|Dormant|Active'		Level of volcanic activity.
hydrothermal_activity	character(3,1) smatch 'Yes'		Is there any active hydrothermal activity?
mining	character(1,1) smatch '[YN]'		Is there any mining interest as determined by mineral-rights licenses lodged with Crown Minerals.
substrate	character(1,1) smatch '[YN]'		Is there any substrate data available (backscatter or sidescan)?
dist_shelf	decimal(5,1)		Distance (km) to the continental shelf.
surf_water	character(60,1)		Type of surface water.
chl_a	decimal(7,6)		Chlorophyll a biomass
chlor_mu	decimal(5,4)		Surface chlorophyll concentrations (mg m-3)
chlor_sd	decimal(5,4)		Standard deviation of the surface chlorophyll concentrations.
chlor_cv	decimal(5,4)		Coefficient of variance of the surface chlorophyll concentrations.
c2_npp_mu	decimal(6,3)		Carbon-based model calculations of net primary productivity
c2_npp_sd	decimal(6,3)		Standard deviation of the carbon-based model calculations of net primary productivity.
c2_npp_cv	decimal(7,6)		Coefficient of variance of the carbon-based model calculations of net primary productivity.
vgpm_npp_mu	decimal(7,3)		Vertically generalized production model calculations of net primary production (mean)
vgpm_npp_sd	decimal(6,3)		Standard deviation of the vertically generalized production model calculations of net primary production.
vgpm_npp_cv	decimal(7,6)		Coefficient of variance of the vertically generalized production model calculations of net primary production.
biol_samp	character(1,1)		Has there been any biological sampling?

	smatch ‘[YN]’	
matrix_coral	character(1,1) smatch ‘[YN]’	Is there any matrix-forming coral present?

Attributes	Data Type	Null?	Comment
octocoral	character(1,1) smatch '[YN]'		Are there any octocorals present?
sponge	character(1,1) smatch '[YN]'		Is there any sponge present?
protect_status	character(30,1) smatch 'Closed'		Is the seamount closed to fishing?
num_fish_research	integer		Number of research tows that contained fish species.
num_squ_oct_research	integer		Number of research tows that contained squids and/or octopi.
num_research_tows	integer		Total number of research tows.
total_num_tows	integer		Total number of all tows (research and commercial).
total_fish_catch	decimal(10,3)		Total catch weight of all fish (kg).
total_years_fished	integer		Total number of years seamount has been fished.
FII_all	decimal(13,3)		Overall fishing importance index. FII_all = FII_ORH + FII_OEO + FII_CDL + FII_BYX + FII_BNS + FII_RBY
year_first_fished	integer		First fishing year (1 October – 30 September, where 2002–03 fishing year is entered as 2003) in which there were 10 or more tows that fulfilled the following criteria: a) tow start position closer to the centre position of this seamount than to any other seamount in the database; b) tow start position within 10 km of the seamount centre; c) target species target species orange roughy, smooth, black, or unspecified oreos, black or unspecified cardinalfish, alfonsino, bluenose, or rubyfish.
dist_towed	decimal(8,2)		Summed tow length in kilometres of all tows in MFish catch-and-effort database up to 30 Sept 2003 that fulfilled the following criteria: a) tow start position closer to the centre position of this seamount than to any other seamount in the database; b) tow start position within 10 km of the seamount centre; c) target species orange roughy, smooth, black, or unspecified oreos,

			black or unspecified cardinalfish, alfonsino, bluenose, or rubyfish; d) tow length less than 3 n. miles (5.6 km).

Attributes	Data Type	Null?	Comment
num_tow_dir	integer range 0 to 4		Number of tow directions (in 90° quadrants, from 0-4), where there were more than 5 tows from 1 October 1989 (when tow finish position was first reported) to 30 September 2003 that fulfilled the following criteria: a) tow start position closer to the centre position of this seamount than to any other seamount in the database; b) tow start position within 10 km of the seamount centre; c) target species target species orange roughy, smooth, black, or unspecified oreos, black or unspecified cardinalfish, alfonsino, bluenose, or rubyfish; d) tow length between 0.5 n. miles (0.9 km) and 3 n. miles (5.6 km).
num_N_tows	integer		Number of tows from 1 October 1989 (when tow finish position was first reported) to 30 September 2003 that fulfilled the following criteria: a) tow start position closer to the centre position of this seamount than to any other seamount in the database; b) tow start position within 10 km of the seamount centre; c) target species target species orange roughy, smooth, black, or unspecified oreos, black or unspecified cardinalfish, alfonsino, bluenose, or rubyfish; d) tow length between 0.5 n. miles (0.9 km) and 3 n. miles (5.6 km); e) tow direction to the north (315°-45°).
num_E_tows	integer		As above except tow direction to the east (45°-135°).
num_S_tows	integer		As above except tow direction to the south (135°-225°).
num_W_tows	integer		As above except tow direction to the west (225°-315°).
FEI	decimal(12,6)		Fishing effects index up to 30 September 2003 as defined by O'Driscoll & Clark (2005). FEI = (dist_towed / seamount area) * (n_directions / 4)

annual_amp_SST	decimal(7,6)		Annual amp. sea surface temp. (°C).
winter_SST	decimal(7,5)		Winter sea surface temp. (°C).
summer_SST_anomaly	decimal(8,7)		Summer sea surface temp. anomaly (°C).

Attributes	**Data Type**	**Null?**	**Comment**
spatial_SST_gradient	decimal(8,7)		Spatial sea surface temp. gradient.
curr_speed	decimal(10,9)		Average current speed (m/s).
depth_thermocline	integer		Depth (m) to the thermocline.
MEC_20	integer		MEC 20-class classification.
MEC_33	integer		MEC 33-class classication.
ann_mean_semi_diur_tide	double precision		Annual mean semi diurnal tide (m).
diurnal_tide	double precision		Diurnal tide (m).
prob_cap_meanflow	decimal(4,1)		Probability of Taylor Cap from Mean Flow.
prob_cap_diurnal	decimal(4,1)		Probability of strong resonant cap generation due to diurnal tides.
min_slope	decimal(4,2)		Minimum calculated slope (°).
max_slope	decimal(4,2)		Maximum calculated slope (°).
mean_slope	decimal(4,2)		Mean calculated slope (°).
sd_slope	decimal(4,2)		Standard deviation of slope.
calc_area	double precision		Calculated area (m^2).
perimeter	decimal(12,6)		Perimeter of the seamount base.
comments	character(100,1)		

```
Creator:     dba
Referential: (reg_no) REFERRED t_fish_year (reg_no)
             (reg_no) REFERRED t_fish_spp_indices (reg_no)
Indices:     PRIMARY KEY BTREE ON (reg_no)
```

5.2 Table 2: t_fish_spp_indices

Comment: Fish species indices by species and seamount.

Attributes	Data Type	Null?	Comment
reg_no	integer	No	Seamount unique number.
species	character(3,1)		3-char. Species code. Refer to rdb:curr_spp
num_tows	integer		Number of tows in MFish catch-and-effort database up to 30 September 2003 that fulfilled the following criteria: a) tow start position closer to the centre position of this seamount than to any other seamount in the database; b) tow start position within 10 km of the seamount centre; c) target species.
catch	decimal(9,3)		Total catch weight (tonnes) of species in MFish catch-and-effort database up to 30 September 2003 from tows that fulfilled the following criteria: a) tow start position closer to the centre position of this seamount than to any other seamount in the database; b) tow start position within 10 km of the seamount centre. from all tows.
num_years	integer		Number of fishing years up to 30 September 2003 in which there were 10 or more tows that fulfilled the following criteria: a) tow start position closer to the centre position of this seamount than to any other seamount in the database; b) tow start position within 10 km of the seamount centre; c) target species.
FII	decimal(13,3)		Fishing importance index for species up to 30 September 2003 as defined by Clark & O'Driscoll (2003). FII_ORH = ntows_ORH * c_ORH * nyrs_ORH

Creator: dba
Referential: (reg_no) REFER t_seamounts (reg_no)
Indices: FOREIGN KEY BTREE ON (reg_no)

5.3 Table 3: t_fish_year

Comment: Fish catch data by year and seamount.

Attributes	Data Type	Null?	Comment
reg_no	integer	No	Seamount unique number.
yr	integer		Year (1979 to 2003).
catch	decimal(10,3)		Annual summed catch in tonnes of orange roughy, smooth, black, and unspecified oreos, black and unspecified cardinalfish, alfonsino, bluenose, and rubyfish in each fishing year from 1 October 1978 - 30 September 1979 (1979) to 1 October 2002 - 30 September 2003 (2003) that from tows that fulfilled the following criteria: a) tow start position closer to the centre position of this seamount than to any other seamount in the database; b) tow start position within 10 km of the seamount centre.
num_tows	integer		Number of tows in MFish catch-and-effort database up to 30 September 2003 that fulfilled the following criteria: a) tow start position closer to the centre position of this seamount than to any other seamount in the database; b) tow start position within 10 km of the seamount centre; c) target species orange roughy, smooth, black, or unspecified oreos, black or unspecified cardinalfish, alfonsino, bluenose, or rubyfish. .

Creator: dba
Referential: (reg_no) REFER t_seamounts (reg_no)
Indices: FOREIGN KEY BTREE ON (reg_no)

6 seamount business rules

6.1 Introduction to business rules

The following are a list of business rules pertaining to the **seamount** database. A business rule is a written statement specifying what the information system (i.e., any system that is designed to handle trawl survey data) must do or how it must be structured.

There are three recognized types of business rules:

Fact	Certainty or an existence in the information system
Formula	Calculation employed in the information system
Validation	Constraint on a value in the information system

Fact rules are shown on the ERD by the cardinality (e.g., one-to-many) of table relationships. Formula and Validation rules are implemented by referential constraints, range checks, and algorithms both in the database and during validation.

Validation rules may be part of the preloading checks on the data as opposed to constraints or checks imposed by the database. These rules sometimes state that a value should be within a certain range. All such rules containing the word 'should' are conducted by preloading software. The use of the word 'should' in relation to these validation checks means that a warning message is generated when a value falls outside this range and the data are then checked further in relation to this value.

6.2 Summary of rules

Seamount details (t_seamount)

reg_no Seamount registration number, must be unique.

area_code Area code. Generally the NZOI Oceanic Series map name (see Figure 2 for map names), but can be free text.

EEZ Must be either "EEZ"' or "outside EEZ"

FMA Must be either null or a valid Fisheries Management Area (see Figure 3).

fished Must be either a "Y" or "N".

latitude Should be a number between -20 and -57.5.

longitude Should be a number between 150 and 200.

depth_top Must be an integer greater than zero.

depth_base Must be an integer greater than zero and greater than depth_top.

elevation Must be an integer and should be the result of depth_base minus depth_top.

min_cont Must be an integer greater than zero and less than or equal to depth_top.

max_cont Must be an integer greater than zero, greater than min_cont, and less than or equal to depth_base.

area_km2 Must be a number greater than zero.

assoc Should be one of the following:
- Continental
- Elevated oceanic ridge
- Elevated Ridge
- Oceanic

volcanic_activity Must be either null or one of "Extinct", "Dormant", or "Active".

hydrothermal_activity Must be either null or "Yes".

mining Must be either null or "Y" or "N".

substrate Must be either null or "Y" or "N".

dist_shelf Must be a number greater than zero.

surf_water Should be one of the following:
- Circumpolar Surface Water
- Subantarctic Front
- Subantarctic Water
- Subtropical Convergence
- Subtropical Water
- Tasman Front

chl_a Must be either a null, or a number greater than zero that should be within
the

range 0.05 to 2.0.

chlor_mu Must be either a null, or a number greater than zero that should be within
the

range 0.08 to 0.85.

chlor_sd Must be either a null, or a number greater than zero that should be within
the

range 0.07 to 0.7.

chlor_cv Must be either a null, or a number greater than zero that should be within the range 0.01 to 1.3.

c2_npp_mu Must be either a null, or a number greater than zero that should be within the range 60 to 700.

c2_npp_sd Must be either a null, or a number greater than zero that should be within the range 40 to 580.

c2_npp_cv Must be either a null, or a number greater than zero that should be within the range 0.1 to 2.

vgpm_npp_mu Must be either a null, or a number greater than zero that should be within the range 150 to 1020.

vgpm_npp_sd Must be either a null, or a number greater than zero that should be within the range 50 to 420.

vgpm_npp_cv Must be either a null, or a number greater than zero that should be within the range 0.1 to 0.7.

biol_samp Must be either null or "Y" or "N".

matrix_coral Must be either null or "Y" or "N".

sponge Must be either null or "Y" or "N".

protect_status Must be either null or "Closed".

num_fish_research Must be an integer greater than or equal to zero and less than or equal to num_research_tows.

num_squ_oct_research Must be an integer greater than or equal to zero and less than or equal to num_research_tows.

num_research_tows Must be an integer greater than or equal to zero and less than or equal to total_num_tows.

total_num_tows Must be an integer greater than or equal to zero.

total_fish_catch Must be zero or, if total_num_tows is greater than zero, a number greater than zero.

total_years_fished Must be either a null or an integer between 0 and 23.

FII_all	Must be either a null or a number greater than zero and that number is: FII_all = FII_ORH + FII_OEO + FII_CDL + FII_BYX + FII_BNS + FII_RBY
year_first_fished	Must be either null or an integer that must be between 1979 and 2003.
dist_towed	Must be either a null or an number between 0 and 10600.
num_tow_dir	Must be either a null or an number between 0 and 4 where that number is the sum of the times that the corresponding values in num_N_tows, num_E_tows, num_S_tows, and num_W_tows are greater than zero.
num_N_tows	Must be either a null or a number between 0 and 1700.
num_E_tows	Must be either a null or a number between 0 and 1700.
num_S_tows	Must be either a null or a number between 0 and 1700.
num_W_tows	Must be either a null or a number between 0 and 1700.
FEI	Must be either a null or a number that is: FEI = (dist_towed / seamount area) * (n_directions / 4)
annual_amp_SST	Must be either a null or a number between 0.05 and 3.5.
winter_SST	Must be either a null or a number between 3.0 and 25.0.
summer_SST_anomaly	Must be either a null or a number between -1.5 and 0.7.
spatial_SST_gradient	Must be either a null or a number between 0.002 and 0.075.
curr_speed	Must be either a null or a number between 0.0001 and 0.35. A value of -999 maybe be used to denote “unknown”.
depth_thermocline	Must be either a null or a number between 5 and 1000. A value of -999 maybe be used to denote “unknown”.
MEC_20	Must be either a null or a number between 1 and 204.
MEC_33	Must be either a null or a number between 1 and 204.

ann_mean_semi_diur_tide Must be either a null or a number between 0.005 and 0.5.
A value of -999 maybe be used to denote “unknown”.

diurnal_tide Must be either a null or a number between 0.001 and 0.1.

prob_cap_meanflow Must be either a null or a number between 0 and 100.

prob_cap_diurnal Must be either a null or a number between 0 and 100.

min_slope Must be either a null or a number between 0 and 10.

max_slope Must be either a null or a number between 0.05 and 80 and must be greater than or equal to min_slope.

mean_slope Must be either a null or a number between 0.01 and 60 and must be greater than or equal to min_slope and less than or equal to max_slope.

sd_slope Must be either a null or a number between 0.01 and 25.

calc_area Must be either a null or a number greater then 9000.

perimeter Must be either a null or a number greater than 1000.

Fish species indices (t_fish_spp_indices)

reg_no Seamount registration number, must contained in the t_seamounts table.

species Must be a valid species code as listed in the *curr_spp* table in the **rdb** database.

num_tows Must be either null or an integer greater than zero.

catch Must either be null or a number greater than or equal zero and less than or equal to the value in total_fish_catch in the *t_seamounts* table.

num_years Must either be null or an integer greater than or equal zero and less than or equal to the value in total_years_fished in the *t_seamounts* table

FII Must either be null or a number greater than or equal zero and less than or equal to the value in FII_all in the *t_seamounts* table

Fish catch by year details (t_fish_year)

reg_no Seamount registration number, must contained in the t_seamounts table.

yr Must be either null or an integer that must be between 1979 and 2003.

catch Must either be null or a number greater than or equal zero and less than or equal to the value in total_fish_catch in the *t_seamounts* table.

num_tows Must be either a null or a number between 0 and 1000.

~~7~~Acknowledgements
The author would like to thank Megan Oliver, Ashley Rowden, Ian Wright, Graham Rickard, Di Tracey, Richard O'Driscoll, and Ken Richardson for their contributions to the Appendices.

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Appendix 1 – Reference Code Tables

area_code

See Figure 2 for the Oceanic Series Areas.

FMA

See Figure 3 for the Fisheries Management Areas.

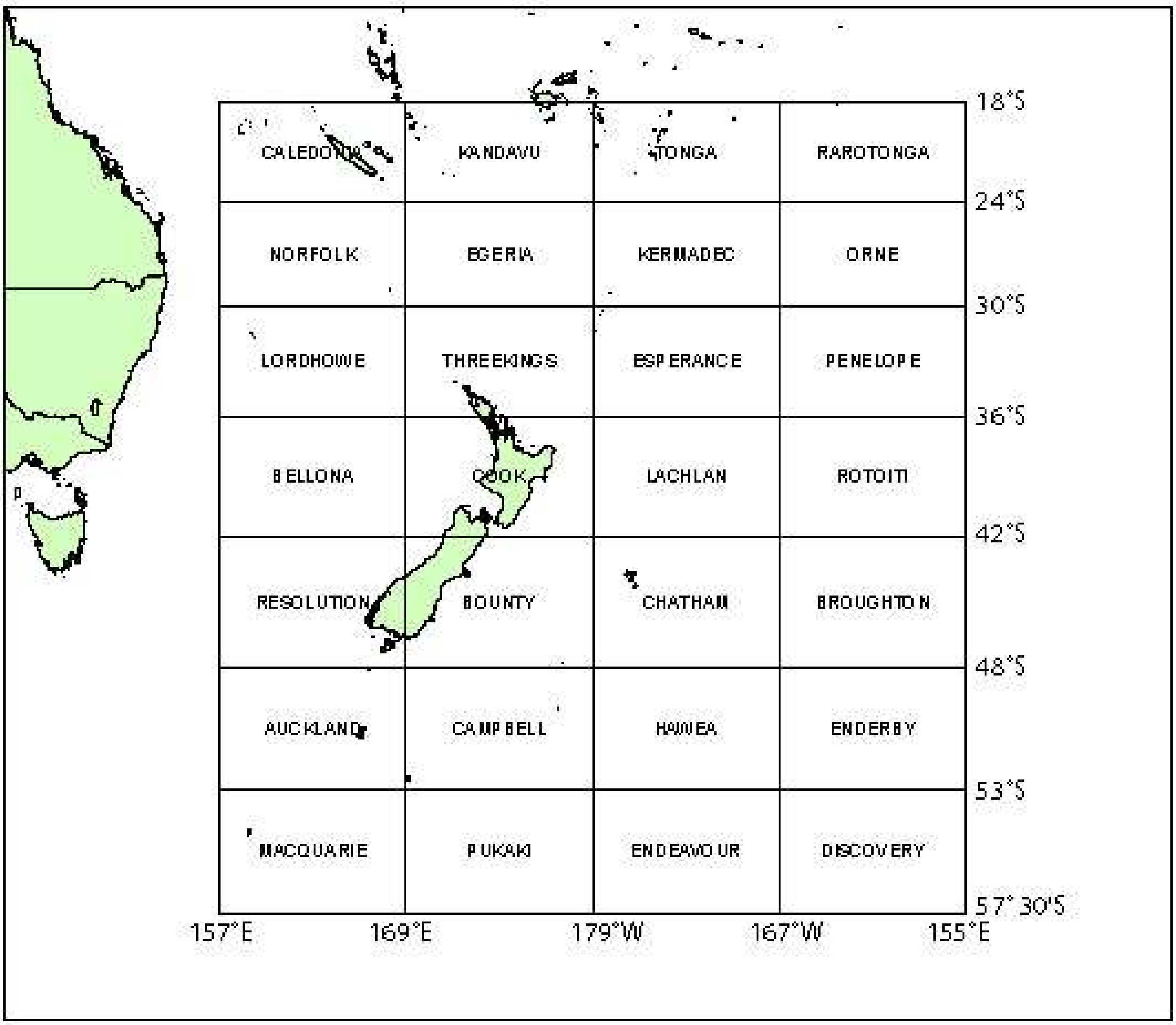

Figure 2: Oceanic Series Areas

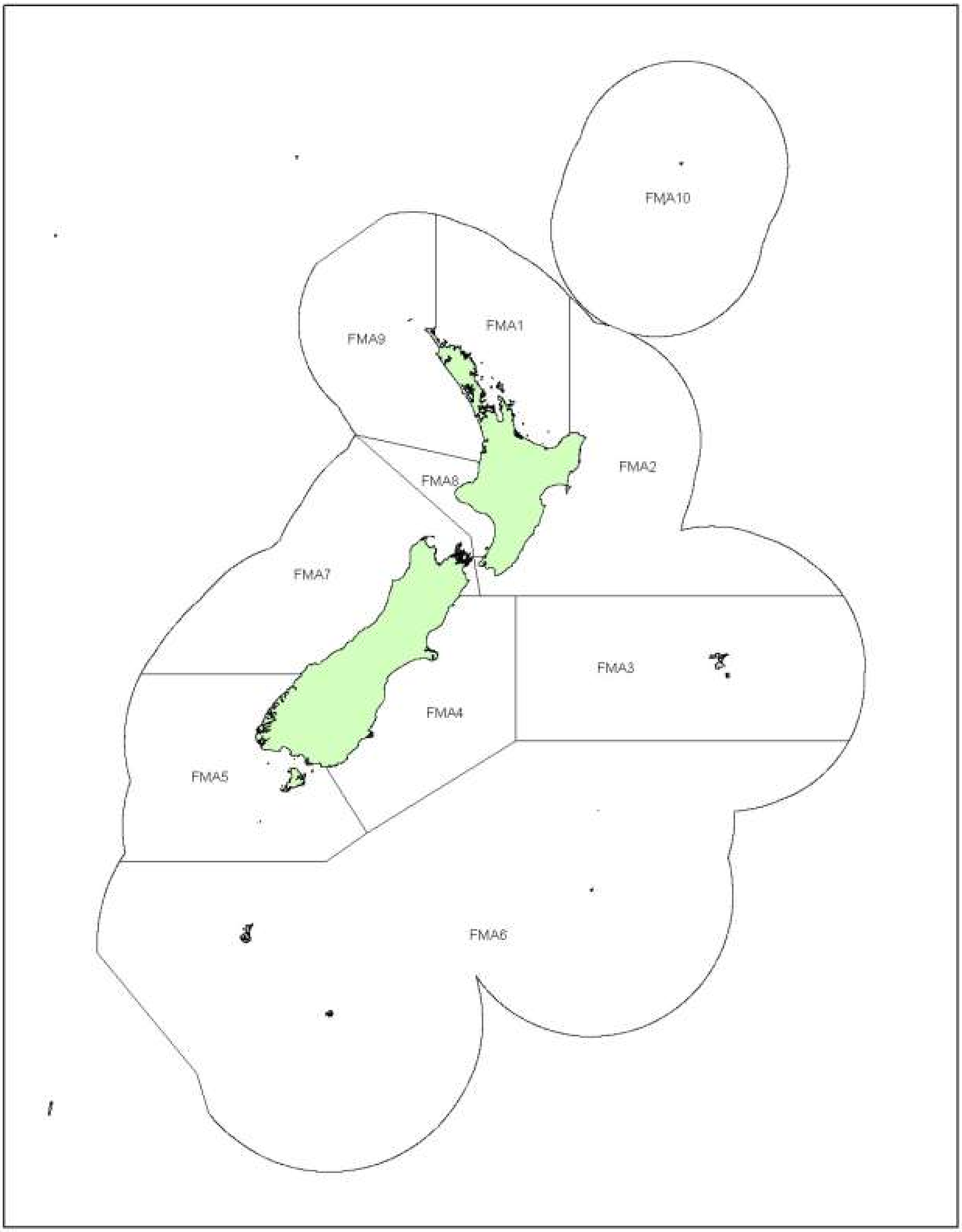

Figure 3: Fisheries Management Areas

Appendix 2 – Volcanism, hydrothermal activity and morphology

Volcanism and Venting

Submarine volcanic eruptions, though inherently difficult to record, can be interpreted from indirect hydroacoustic *T*-wave data, eruptive manifestations at the sea-surface, and even the emergence of ephemeral island volcanoes. For the New Zealand region such recordings (although almost certainly under-reported) are restricted to seamounts along the Kermadec Ridge. Such reports are taken from the work of Kibblewhite (1967), Davey (1980), Latter et al. (1992), Lloyd et al. (1996), and Wright et al. (2006).

Similarly, the discovery of hydrothermal venting at depths of 500 – 2000 m below the sea-surface is difficult. However, more recent and systematic surveys of seamounts along the Kermadec Ridge using towed sensor arrays measuring water-chemistry and optical properties have established the incidence of the more significant submarine hydrothermal venting. Such reports are taken from the work of de Ronde et al. (2001); Baker et al. (2003), and de Ronde et al. (submitted).

Morphology Classification

A morphometric analysis / classification of New Zealand "seamounts" has not been undertaken in this present work due to project time constraints. Standard hydrographic classifications based on subjective interpretation of "seamount" morphology and elevation (e.g., seamount, knoll, guyot) can be applied using the standard International Hydrographic Classification. However, such classifications are subjective and time consuming, requiring "analysis" of each feature.

Algorithm and / or GIS based morphometric analysis which could undertake a component analysis of "footprint area", degree of elongation, elevation, slope, aspect, volume, and corresponding ratios of these parameters, would provide a more quantitative and robust analysis of "seamount" morphology. Such an analysis may well provide insight into relationships of seamount morphology and biological importance.

A limitation though to such work is the highly variable quality of the bathymetry data. Much of the existing "seamount" bathymetry is based on limited, poorly navigated, single-beam echo-sounding profiles, though more recent mapping has used modern multi-beam systems to provide 100% coverage of the seafloor. Newly compiled and updated bathymetry datasets for could be used for a morphometric analysis of New Zealand region seamounts.

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Appendix 3 – Satellite Primary Productivity and Chlorophyll Biomass Products

Net Primary Productivity (NPP)

Mike Behrenfeld and collaborators (see Behrenfeld *et* al., 2005 and references therein) generate estimates of primary productivity based on two main depth integrated models (DIMs)[5].

Vertically Generalised Production Model (VGPM)

The VGPM (Behrenfeld and Falkowski 1997) is a chlorophyll-based depth-integrated algorithm which uses the algorithm NPP = Chl x Z_{eu} x $f(I_0)$ x DL x P^b_{opt}. For the NPP data provided to the seamounts project, Chl is SeaWiFS chlorophyll (from the GSM01 algorithm: see Siegel *et al*., 2002), Z_{eu} is the depth of the photosynthetically active surface layer (computed as a function of chlorophyll), DL is day length, P^b_{opt} is a physiological variability parameter (an empirical function of sea surface temperature), and $f(I_0)$ is a function of incident light that attempts to account for the depth of light saturation.

The NPP product uses coincident SeaWiFS cloud-corrected surface PAR (I_0: moles photons m^{-2} h^{-1}), Advanced Very High Resolution Radiometer (AVHRR) sea surface temperature (SST) data, and monthly mean mixed layer depth (MLD) data (see Behrenfeld *et al*., 2005 for SST and MLD data sources).These data are available at monthly time scales and have a spatial resolution of ~ 9km.

Carbon-based model (carbon2)

This novel approach uses the algorithm NPP = C x μ x Z_{eu} x $h(I_0)$ where C is phytoplankton carbon biomass (mg m^{-3}) derived from estimates of SeaWiFS backscatter (b_{bp}: m^{-1}- see Behrenfeld *et* al., 2005 and Siegel *et al*., 2002), and μ is phytoplankton growth rate (divisions d^{-1}) estimated from SeaWiFS Chl:C ratios and median mixed layer light levels $I_g = I_0 \exp(-k_d x MLD/2)$. The affect of changes in surface light (I_0) on the depth-dependent profile of carbon fixation are modelled by the function $h(I_0)$ (as does $f(I_0)$ in the VGPM). These data are also available at monthly time scales and have a spatial resolution of ~ 9km.

Climatology generation and comments on NPP algorithms

Climatology for September 1997 to December 2004 was generated by computing the mean, standard deviation, and CV of NPP predictions based on monthly composited estimates of NPP from the above algorithms. The inaccuracies of computing these statistics from monthly composites is unlikely to be significant given the differences between PP algorithms (see Figure 4). Data from these climatologies at pixels nearest to the seamount locations were extracted into the NIWA seamount database.

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[5] Some but not all of the NPP products that Beherenfeld and co-workers have made available can be found at http://web.science.oregonstate.edu/ocean.productivity/.

Note that both the development of satellite NPP algorithms and the validation of products based on

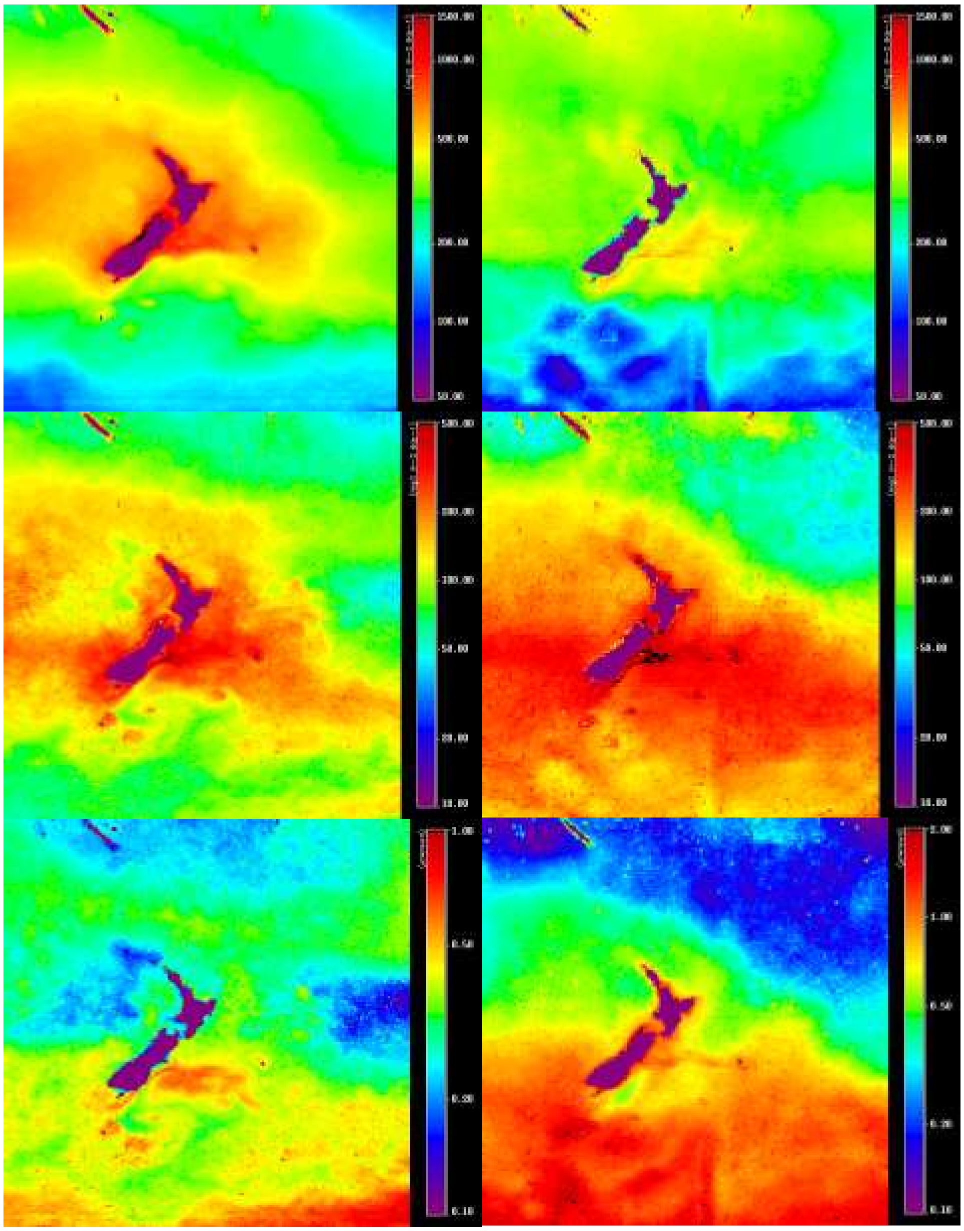

Figure 4. Left hand column: Mean (top), standard deviation (middle) and CV (bottom) from the VGPM model. Right hand column is the same for the carbon2 model.

these algorithms are areas of active research in New Zealand and overseas. Given the lack of published validation results and the substantial differences between current algorithms in New Zealand waters (see Figure 4), the NPP data provided should be regarded as preliminary. We are not yet in a position to advise which is ‘best’. Behrenfeld (pers. comm., 2006) favours the carbon2 algorithm but expects further improvement from a depth-resolved and wavelength-resolved model which is currently under development.

Surface Chlorophyll Biomass

Behrenfeld (pers. comm., 2006) favours the carbon2 algorithm but expects further improvement from a depth-resolved and wavelength-resolved model which is currently under development. Once that the error characteristics of these NPP products are better understood it would be useful to use the data reduction method of Uddstrom and Oien, 1999 to generate additional useful statistics from these data.

SeaWiFS 4km L1A daily radiances for 1998-2002 has been processed using the OC4v4 algorithm (see e.g., Pinkerton *et al*., 2005) to derive surface chlorophyll concentrations (mg m^{-3}). The resulting daily chlorophyll products were then further processed using the Fourier decomposition and objective

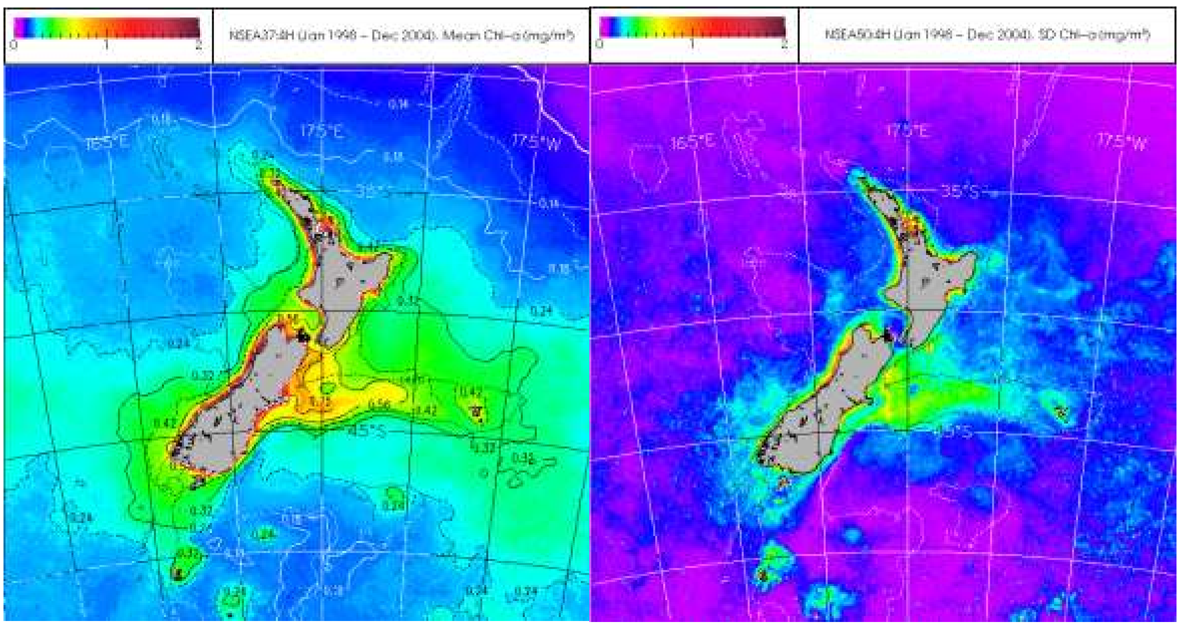

Figure 5: Mean (left) and temporal standard deviations (right) for SeaWiFS chlorophyll

analysis methodology of Uddstrom & Oien, 1999 to generate a chlorophyll climatology of means and (temporal) standard deviations (see Figure 5). The spatial resolution of these climatologies is approximately 8km.

Data from these climatological products at pixels nearest to the seamount locations were extracted into the NIWA seamount database.

Comments on product accuracy and climatology generation and

Research undertaken at NIWA (Pinkerton *et al*., 2005; Richardson *et al*., 2004) suggests that while the ‘end-to-end’ accuracy of the OC4v4 chlorophyll product in open ocean waters is within the SeaWiFS mission target of 30%, there are small regional biases. The uncertainty of the climatology will therefore be less than this in the open ocean, but constrained by the bias.

The more complex method used to generate chlorophyll climatologies has been preferred over a simple mean over the mission lifetime since it has the advantage of reducing noise inherent in the rather short SeaWiFS time series. Other statistics (e.g., gradients, spatial standard deviations) are also easily computed

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Appendix 4 - Report on Oceanographic Components of Seamount Database

Introduction

As part of a seamount ecological risk assessment program, a seamount database is being collated at NIWA comprising indicators and parameters relevant to quantifying potential risks to seamounts. This part of the work reports on the oceanographic factors influencing circulation at seamounts, in order to build up a picture of the likely distribution of flows impacting the biology around seamounts.

The nature of the flow solution at a seamount depends on where the seamount is, and its physical geometry in terms of height, width etc. The seamount location is important in terms of its latitude (thus determining the value of the Coriolis parameter f at the seamount), the structure of the average 'undisturbed' water column around the seamount, and the 'background' flows impinging on the seamount. The terms in quotes are taken from the point of view that most of the average data we have is representative of the water surrounding the seamount, rather than at the seamount itself, since (of course) the aim is to find how the background flow is perturbed by the presence of the seamount. For the present study, the data used is on scales much larger than that of most individual seamounts, so this approximate view is valid. However, we will have to be more careful about this interpretation as more site-specific data begins to be collected.

The background flow impinging on the seamount will be composed of a 'mean' flow, and tidal flow. Here, mean flows are driven by pressure gradients in the ocean and will have structure in the vertical, while the tidal flows are uniform throughout the water column ('barotropic'). Tidal flows are 'predictable' in that the external forcing for them is astronomical and 'regular'. However, mean flows can be much more 'unpredictable' due to natural variability in the ocean as a result of atmospheric forcing, instabilities, eddy propagation etc.

Theoretically, seamounts exhibit characteristic responses to each of these background flows. However, each of the responses are 'similar', and because most seamounts are embedded in mean *and* tidal flows, and each with its own characteristic variability, the difficulty of attributing observed seamount effects to a particular forcing becomes apparent. Nevertheless, because the responses are 'similar' it should be possible to conclude that a seamount does induce a measurable response, and that the response may be strong enough to 'significantly' impact on the biology.

In general, flow impinging on a seamount is forced initially to try to go either up and over the seamount, or around the sides. Flow going up eventually has to descend on the downstream side of the seamount, and then separate to rejoin the background flow. The process of forcing water up and down induces vertical motions in the water, and these vertical motions have a character dependent on the shape of the seamount and the ambient structure of the undisturbed water column. The nature of the response is thus determined by a series of time and length scales related to the speed of the forcing flow and that of the perturbed water column. Thus there will be a characteristic time scale for the background flow to traverse the dimensions of the seamount. Vertical motions induced in the water will depend on the vertical structure of the water (the 'stratification') and will have their own timescale. There is also a geophysical timescale allowing for Coriolis effects (dependent on f) to play a significant role as the water flows around or up and over the seamount. Throw in the different nature of the flows, instabilities leading to significant turbulent mixing (especially in the boundary layer close to the seamount), and it is apparent that the problem is particularly complex.

In a weak mean flow, two counter-rotating cells are set-up around the seamount summit in the horizontal plane, and these cells rotate anti-cyclonically (anti-clockwise in our hemisphere) about the summit. In the vertical plane through the seamount, there is a secondary closed circulation pattern consisting of upward flow on one side of the seamount, which then passes over the seamount quite a distance up the water column from the peak, and then returns by descending on the far side, and then passing back across the peak of the seamount. This secondary circulation is a response to the counter-rotating cells. The upward/downward flows lead to raising/lowering of the density surfaces (isopycnals) either side of the seamount.

For tidal forcing at frequency w, say, then a similar pattern to that for weak mean flow arises for sub-inertial frequencies w, i.e. $w < f$, and in this range so-called seamount trapped waves are formed (as opposed to freely propagating waves in the form of internal tides for $w > f$).

If the mean flow is 'strong', then a *Taylor column* results in which in the horizontal plane there is a single cell rotating anti-cyclonically and centred on the seamount. In the vertical plane, the secondary circulation consists of a pair of cells. Each of these cells feeds flow in towards the peak of the seamount, and then upwells from the seamount peak; these cells are closed by flow separation higher above the peak feeding water away from the seamount, and then eventually descending to complete the circulation pattern. This 'classical' pattern becomes a so-called *Taylor cap* when dissipation and turbulence are taken into account; nevertheless, the basic structure of the cap (or column) persists. In these cases, the upwelling at the peak leads to doming of the isopycnal surfaces above and over the summit of the seamount, with dips in the surfaces where the secondary return flow descends.

This Taylor cap structure also arises in tidal flow that drives large amplitude trapped waves; in this instance a process called non-linear rectification can occur that is a resonant interaction between the forcing from the tides and the natural modes in the seawater around the seamount. This resonance can lead to significant (many hundreds of times) amplification of the background currents, so that the secondary circulation is much stronger, leading to the non-linear feedback. Furthermore, the likelihood for enhancement of turbulent activity is increased, and has been seen in terms of vertical mixing over seamounts being many orders of magnitude larger than that in the surrounding ocean. Despite the different forcing here, the basic isopycnal doming of a Taylor cap is still expected.

The variables chosen to go into the oceanographic part of the database reflect the general features of seamount-flow interaction just described. Many are simply measures of the seamount geometry, and the background properties of the water column. However, theory and numerical models have pointed towards specific dimensionless numbers that may indicate the expected strength of response of a seamount, and some of these have been included in order to improve the ability to assess 'likelihood' and hence 'risk factors'.

A useful reference for this work is Beckmann (2004) where a number of the issues discussed here are addressed.

Oceanographic Seamount Database Components

(1) **Depth-averaged current speed (m/s) per seamount;**

This has been taken from a 1/6° regional ocean model run at NIWA (Rickard et al, 2005). The mean flow field from the model has a vertical structure, but the depth-averaged value, u_b say, provides an indication of the flow relative to tidal flows.

(2) **Annual mean tidal semi-diurnal and diurnal current speeds (m/s) per seamount;**

These are from the NIWA tide model. An annual mean has been used to give a feel for the average speed over many tidal cycles. Only the diurnal current speed will allow for trapped seamount waves ($w < f$), but the presence of the semi-diurnal amplitude is relevant for internal tide generation.

(3) **Mean depth of permanent thermocline per seamount (m);**

The vertical temperature structure of the water column is part of the determination of the vertical column response. Here the mean depth of the thermocline is being assessed relative to where the peak of the seamount is. The mean thermocline depth is here defined to be the average of the depth of the winter mixed layer depth, and the depth of the base of the thermocline itself; the former is relatively easy to get, but the latter is a little trickier as it relies on finding where the temperature gradient reaches a minimum.

(4) **Average seamount radius (r_o) and seamount slope scale (l_o) (m);**

It is observed that many seamounts have two distinctive horizontal scales: a shorter scale representing the steepest ascent towards the summit (the slope scale), and a broader scale (the radius) associated with a rather broad but flat summit plus the side slopes. Each scale length is relevant since the steepness in terms of l_o represents how rapidly water is made to ascend/descend over the seamount, whereas the broader r_o represents a characteristic distance for water to traverse the seamount horizontally. To get these numbers, existing data in the database has been used, namely the elevation of the seamount (elev), and the two slope angles meanslop, measuring the average slope across the seamount, and maxslop the maximum slope. Simple geometry then suggests,

$r_o = \tan(\text{meanslop})/\text{elev}, \qquad l_o = \tan(\text{maxslop})/\text{elev}.$

(5) **Buoyancy frequency at seamount peak (s^{-1});**

No measures the frequency at which natural vertical displacements in the water column arise. It is an important measure of how the seamount will respond as water flows up and over the seamount, and gives a feel for the vertical timescale expected. This is calculated from climatological ocean data, and is interpolated to give a value around the peak of each seamount.

(6) **Seamount fractional height;**

Using the height of the seamount (elev) and the total water depth (dbase) from the database, the fractional height is simply

frac = elev/dbase.

(7) **Rossby number for the mean flow;**

A dimensionless number measuring the average time to cross l_o relative to the timescale for Coriolis effects to be important, and is

$Ro = u_b/(f\ l_o)$.

(8) **Burger numbers for the seamount;**

These numbers measure ratios of characteristic vertical speeds to horizontal speeds, and give a feel for how strong the vertical responses are compared to equivalent horizontal processes. The Burger numbers are typically quoted in the form,

$Bu = (No\ dbase)/(f\ \ L)$,

where No is a characteristic buoyancy frequency, and L is a horizontal scale length. However, in this form it is difficult to know what number to chose for No, as the buoyancy frequency depends on the depth; for example, some have chosen to use the average No over the depth, others the value of No at the seamount peak etc. The uncertainty reflects the complexity associated with the processes involved. A possible resolution is to note that the Burger number can be written as,

$Bu = r_d/L,\qquad r_d = (No\ dbase)/f$,

where r_d is called the 'Rossby deformation radius'. The deformation radius is a horizontal scale associated with vertical eigenmode responses in the ocean, and has been solved for using climatological information for the global ocean, and its evaluation takes into account the full vertical structure in the ocean at each point, and seems a relevant way to circumvent the rather 'arbitrary' choices for No. will be the number used to get Bu in the seamount database. Of course, the seamount has two horizontal scales, so the database has them both viz,

$Bul = r_d/l_o,\qquad Bur = r_d/r_o$.

(9) **Likelihood for Taylor cap formation in mean flow;**

Chapman and Haidvogel (1992) performed a series of numerical experiments to assess whether or not a Gaussian seamount placed in a stratified medium with a mean flow imposed generated a Taylor cap. Their results are summarized in Figure 1. By plotting the Rossby number against the seamount fractional height they found Taylor cap formation to occur to the right of the diagonal bold line, and below the horizontal solid line. They also found a smaller region where these lines cross (which they called 'TT'), where temporary Taylor caps formed, i.e., they saw the Taylor cap emerge but then get swept off by the mean flow field, a process that would repeat.

Also plotted on Figure 1 are the seamount values in this domain given by the dots and using the database elements (6) and (7) above. If the position of the dot is in the major Taylor cap formation region, then a value of 90% likelihood of cap formation has been assigned in the database, if in TT then 30%, otherwise 0. These values are arbitrary but indicative; more detailed studies will be required to give a more consistent scaling.

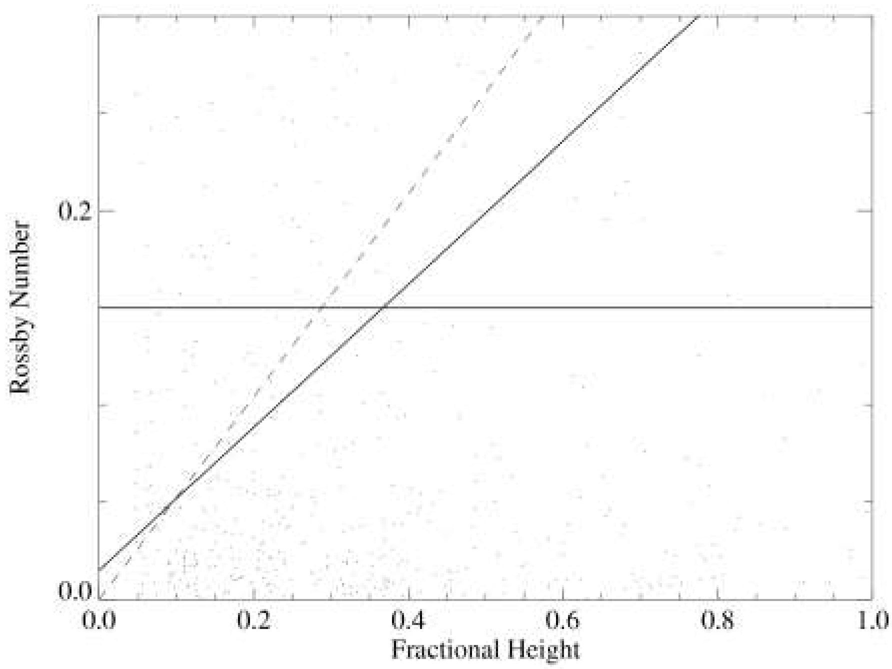

Figure 6 Approximate regimes for Taylor cap formation for steady, stratified flow over Gaussian seamounts from Chapman and Haidvogel (1992). Taylor cap formation is most likely for points lying to the right of the solid diagonal line, and below the solid horizontal line. The diagonal dashed line is a cut-off from analytic quasigeostrophic theory. Chapman and Haidvogel (1992) also show a zone 'TT' around where the solid lines intersect; in this zone temporary trapping occurs. The location in this domain of each seamount is given by the dots.

(10) **Likelihood for tidal rectification from tidal flows forcing;**

This measure is the equivalent to (9) but for the subinertial ($w < f$) tidal flows. Again, numerical experiments (Beckmann, 1995) suggested resonances at the seamount could be found for a range of the Burger numbers, but that a particularly strong resonance (in the form of a more than twenty fold amplification of the background tidal current speed over the seamount, leading to Taylor cap formation) occurred when Bul = 1.0 and Bur = 0.5.

However, consider Figure 2 showing the distribution of Bur and Bul for the seamounts in the database. It is clear that the range of values we get spreads well beyond the optimum resonance numbers of around 1 suggested by Beckmann (1995). This could be a true reflection of the state of seamounts around New Zealand, in which case strong tidal rectification is only then likely at very few of our seamounts. Given that the Rossby deformation radius comes from an external reference, the other likely errors are due to our estimates of r_o and l_o, which are themselves dependent on earlier estimates of the slope parameters. The discrepancies could also be due to

Beckmann's (1995) assumptions about the average shape of seamounts being characterized by r_o and l_o in a particular way. It is difficult to believe that the number of seamounts in our region satisfying Beckmann's maximal resonance condition is so small (only one or two of the whole set around a Burger number of 1).

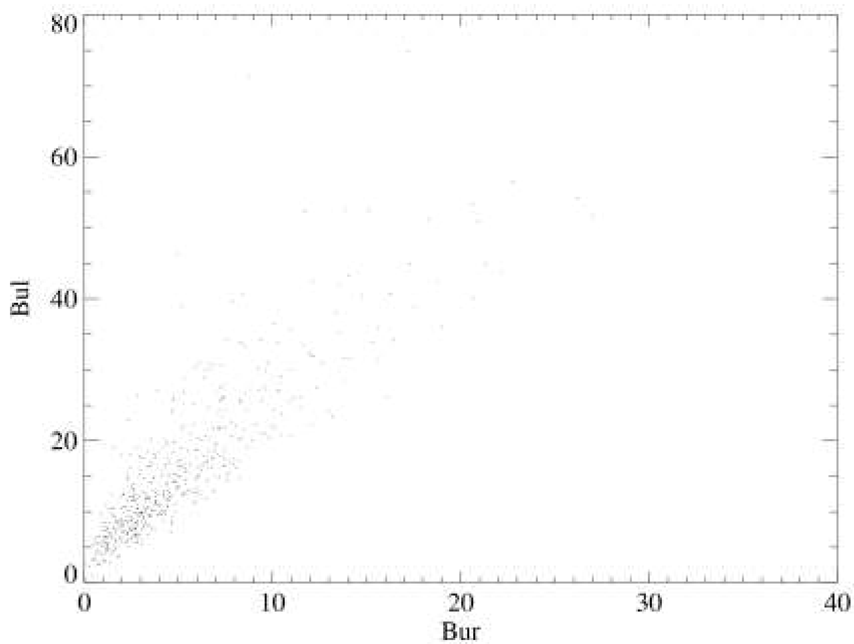

Figure 7 Seamount Bur against Bul Burger number distribution from the database.

To provide a first go at a statistic representing likelihood of Taylor cap formation from tidal rectification -- especially given the relative uncertainties in the Bur and Bul distributions – a normalization of the distribution is proposed in terms of an rms distance in Bur against Bul space for the seamounts, viz

$rr = sqrt(Bur^2 + Bul^2)$, $rrms = sqrt(Sum_n(rr^2)/n)$,

where 'n' is the number of seamounts, and 'Sum_n' represents a summation over all seamounts. The probability for Taylor cap formation is then assessed simply on a normal distribution related to the distance in Bur against Bul space in the form,

$Prob(rr) = 90.0exp(-(rr/rrms)^2)$.

This form assumes that the distribution of points is correct, but that there is a consistent bias in the estimates. This is *unscientific* as we don't as yet have any evidence to back this assertion up, so we have to be a little careful. Nevertheless, there is a feeling in the literature that tidal rectification should be fairly widespread, hence the assumption of a 'normal distribution' of sorts. A final filter on the data is applied for all seamounts lying to the north of 30ºS; here subinertial tidal forcing is unlikely to apply due to the variation in *f* itself.

From the database, rrms = 30.39. Using this number we can assign Prob(rr) at each point, and this is shown in Figure 3 as the contours, with the individual seamount locations as before.

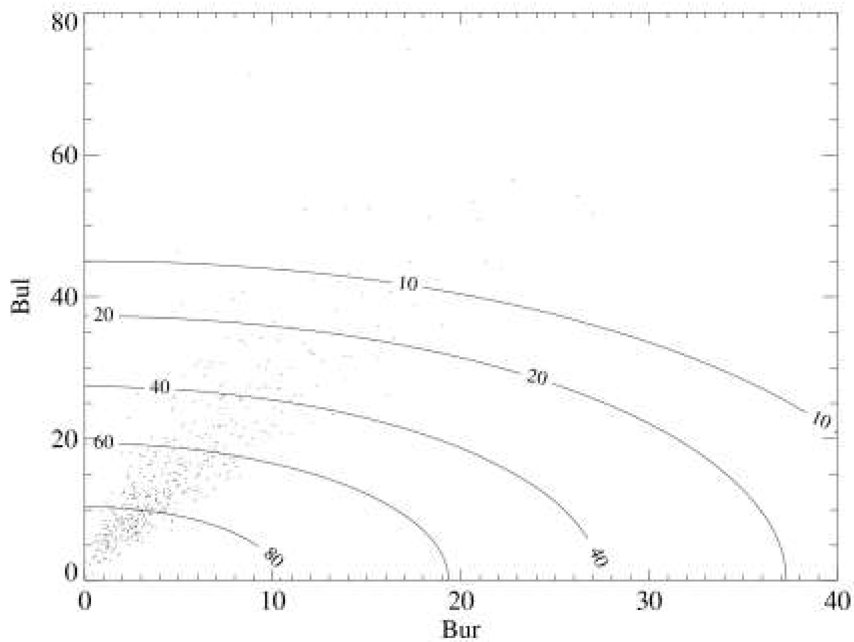

Figure 8 **Contours of likelihood estimates of Taylor cap formation due to diurnal tide rectification. Labels show percentage likelihood based on a normal distribution applied to the raw seamount data (see text).**

Summary

Using a combination of data from the seamount database, temperature and salinity climatologies, and model output, a series of parameters relevant to the assessment of the likelihood for Taylor cap formation at seamounts has been produced. Items (1) to (8) above will remain relevant as our level of understanding improves through continued observation and modelling. Items (9) and (10) represent best numerical estimates of likelihood of cap formation from steady and subinertial tidal flow, respectively. Item (9) seems more robust, in that the numbers arising from the seamount database seem to lie reasonably within the domain. Item (10) seems to be the most sensitive, and the raw data suggests few of the seamounts will actually feel significant tidal rectification. This may be true; however, the data has been rescaled to give a 'normal distribution', reflecting the uncertainties (perhaps!) in this parameter.

Future work will have to give more weight to any underlying errors in the raw parameters. We are certainly being hopeful that so few numbers can be used to determine the full complexity of the flows in the real ocean. Nevertheless, we have to start somewhere…

References

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