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The estimation of catch levels for new orange roughy fisheries on seamounts: a meta-analysis of seamount data

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EXECUTIVE SUMMARY

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Physical attributes and catch data of deepwater fisheries were compiled for 77 seamounts in the New Zealand region. Characteristics of location, depth, size, elevation above the seafloor, age, continental association, geological origin, distance offshore and from surrounding seamounts, and degree of spawning were defined. These were then analysed as independent variables against the minimum orange roughy population size estimated from the historical level of catch taken from seamounts to investigate whether they could be useful predictors of likely safe catch from newly found seamounts.

Multiple regression procedures were used to model the effects of the physical variables on orange roughy stock size. There were two stages in the analysis. First, biomass was modelled on individual seamounts grouped in regions (as a categorical variable) and including predictors specific to individual seamounts. This analysis showed region, depth of the peak, and slope of the seamount to be significant. A second analysis was carried out where the region effects were modelled, using predictors related to entire regions. This showed latitude and association (continental/oceanic) to be important. The predictive power of the models was tested by cross validation, and compared with simpler models to assess their informative value.

It is concluded that data on the physical features of a seamount can be informative in predicting possible stock size. Formulae for predicting orange roughy biomass on a "new" seamount are given, with worked examples of the application of the model. It is stressed that these predictions are approximate only, as the data show a wide scatter, but they can be useful in helping guide initial management of a developing fishery on a seamount.

1. BACKGROUND

Exploratory fishing for deepwater commercial species around New Zealand is to a large extent focused on seamounts and other seabed topographic features, where orange roughy (*Hoplostethus atlanticus*) and oreos (black oreo, *Allocyttus niger*, and smooth oreo, *Pseudocyttus maculatus*) often aggregate. It is estimated that over 70% of orange roughy catch, and 40% of oreo catch is now taken off seamount features (Clark 1999a, Clark et al. 1999). Considerable effort has been applied by the New Zealand deepwater fishing industry in recent years to areas of the Macquarie Ridge, Campbell Plateau, and northern-central North Island with bathymetric surveys (e.g., swath-mapping) followed up by fishing trips to test features identified. This activity peaked in the mid 1990s when about 25 "new" seamounts were being found and fished each year, although this rate has now decreased to 5–10 each year (Clark & O'Driscoll, unpublished results).

Seamounts have supported major orange roughy and oreo fisheries in New Zealand through the 1980s and into the 1990s, but in some areas stocks have been rapidly depleted and fisheries have declined (Clark 1999a). Seamounts are widely regarded as being fragile habitat (Rogers 1994), and susceptible to overfishing, meaning that careful management is required in the initial stages of fishery development to reduce the risks of rapid expansion in effort and possible overexploitation.

The task of designing and carrying out appropriate abundance surveys on seamounts can be a lengthy, expensive, and complicated task. However, stocks may be small and localised, which raises the question of whether a research programme is warranted or cost-effective. It is appropriate, therefore, to examine whether trends in existing and historical seamount fisheries around New Zealand, together with information on their physical characteristics, can serve as a guide to setting initial catch levels until more is known about the nature of the fishery and the seamount stocks.

In late 1999 NIWA was contracted by The Orange Roughy Management Company Limited (ORMC) to carry out an exploratory analysis of trends in deepwater fisheries catch and some physical features of seamounts. Physical attributes and catch data of deepwater fisheries were compiled for 74 seamounts in the New Zealand region (Clark 1999b). Characteristics of location, depth, size, elevation above the seafloor, age, continental association, geological origin, overlying surface water mass, and degree of spawning were analysed as independent variables against estimated sustainable catch of orange roughy and oreo from seamounts to investigate whether they could be useful predictors of likely safe catch. Multiple regression procedures were used to model the effects of the physical variables on orange roughy and oreo yield. The level of orange roughy spawning (high-medium-low) had the most important effect on orange roughy yield. Longitude and depth of peak were also found to be useful predictor variables. Oreo yield was very strongly related to latitude (or surface water mass), and other variables, although statistically significant, had little effect on the estimated yield level. It was concluded that information on the physical and biological features of a seamount and its fish fauna may be useful in helping guide initial management of a developing fishery on a seamount.

These results were presented to the Deepwater Working Group in 2000, and during discussions on the work various suggestions were made for improvement to the analyses. NIWA was requested to extend the initial work, under ORH2000/02 (Ministry of Fisheries project "Orange roughy stock assessment") for the 2000–01 year.

1.1 Objectives

The specified objectives were as follows.

1. To analyse time series of commercial catch and effort data for orange roughy and oreo fisheries on selected seamount features around the New Zealand EEZ.
2. To describe physical characteristics of these seamount features, such as size, depth, and physical composition.
3. To determine if physical characteristics of a seamount combined with catch and effort data can provide a guide to approximate levels of sustainable yield and appropriate initial levels of catch.

This report considers the third of these, as the first two have been largely covered by Clark (1999b).

2. METHODS

2.1 Seamount selection

There are many seamounts and other seabed topographic features in the New Zealand region. NIWA has identified about 800 as part of a PGSF study on the ecology of seamounts (Clark et al. 1999, Wright 1999), although it is certain that this is not an exhaustive listing, as uncharted seamount-type features with low relief (under about 250 m) are frequently located during exploratory commercial fishing. For the present study, a number of seamounts were selected that satisfied the following criteria:

- reliable data on physical attributes existed
- vertical elevation of at least 100 m
- had been fished for at least 3 years with sufficient effort (10 or more trawls per year) to be able to interpret catch-effort data to estimate biomass
- were separated from adjacent seamounts sufficiently (2–3 n.miles) to be able to estimate catch from the single seamount

Efforts were also made to ensure the selected seamounts spanned a wide geographical range through the New Zealand region This set of conditions resulted in 77 seamounts being chosen, for which complete data were available (Appendix 1). The location of the seamounts is shown in Figure 1.

2.2 Variables considered

Twelve physical variables were included.

1) Latitude (continuous) of the seamount (to nearest 100 m)
2) Depth at peak (i.e., minimum depth of seamount) (continuous, Figure 2). This ranged from just over 200 m to 1100 m.
3) Elevation (continuous, Figure 2). This is defined as the depth range between the peak and base of the seamount. The base depth was determined by the most complete depth contour which encircled the seamount from detailed bathymetric data.
4) Area (continuous, Figure 3). This was calculated in the horizontal plane with the base depth circumference defining the boundaries. This ranged from 0.5 to over 4000 km^2.
5) Slope index (continuous, Figure 4). This was approximated as $\text{Elevation}/\sqrt{\text{Area}}$. This represents the average steepness of the flanks of the seamount.

6) Association (categorical): The location of a seamount has an association with a number of broad physical characteristics of the New Zealand region. Seamount association with two types was defined; continental, oceanic. Continental classification indicated the seamounts were close to the continental shelf around New Zealand or its associated rises and plateau; an oceanic association meant a seamount was more isolated.
7) Origin (categorical). The way in which the seamount was formed has been classified, as volcanic or non-volcanic (I. Wright, NIWA, pers. comm.). This was included as a variable that might indicate a difference in benthic fauna as volcanic substrate and stability of the environment differ from non-volcanic seamounts.
8) Distance to nearest adjacent seamount (continuous, Figure 5). This shows most of the selected seamounts were close to other features (under 50 km), with only a few being highly isolated.
9) Distance to mainland (continuous, Table 2)
10) Distance to centre of defined region (continuous, Figure 6). The centre of the region is defined as the mean latitude and longitude of all the included hills in the region.
11) Distance to seamount with highest orange roughy biomass in region (continuous, Figure 7). If a seamount has the highest biomass in its region, we instead use the distance to the next highest.
12) Index of distances to nearby seamounts (continuous, Figure 8). The index is defined as $\sum(1/dij)$ where d is distance of seamount i from seamounts j in the same region. The index is 0 for a lone seamount, and increases as the number of hills in the region increases, and as they get closer to this hill, so a high value indicates there are other hills close by.

A single biological variable was also included.

13) Orange roughy spawning level (continuous, Figure 9). This was included because whether a seamount is a major spawning site, and is the focus of fish migration for spawning, might affect long-term yield. Actual levels of spawning were derived from research trawl records covering mid June to mid July. Criteria used in extracting the reproductive data from the database were limited to those surveys conducted during June and July and to tows with an acceptable gear performance. Dates for each research survey voyage from which reproductive data were sourced are presented in Appendix 2. The selection of the reproductive data during this time ensured the relevant timing of peak spawning for orange roughy (usually consistent for all regions) was covered. All reproductive stage data were selected and proportions were formed covering the ripe, running ripe, partially spent, and spent females. For the regional analysis, regions were classified as having "low" (under 30%), "medium" (typically 30–70%), or "high" (over 70%) typical spawning levels (Table 3), based on the percentages for individual seamounts. Regions for which sufficient percentage spawning data were not obtained were assigned a typical spawning level based on Clark (1999b) and the experience of the authors on the grounds. Reproductive data collected by MFish scientific observers were examined, but were found to add little to the research survey information. A few seamounts fell in different bands from the typical level for their region and were designated as having 'higher' or 'lower' spawning levels (Table 3).

2.3 Commercial catch data

Information on trawl location and catch were obtained from MFish Trawl Catch Effort Processing Returns. These data up to and including the 1999–2000 fishing year are held on a relational database. Data were extracted for seamount regions from this database, or from other data which had been extensively checked for errors during the course of other catch-effort analyses. Tow records were further checked for errors by comparing trawl time and location-distance data, and corrected where possible.

Start and finish positions had been plotted by Clark (1999b) to establish which seamounts had been regularly trawled, and the coordinates that should be specified to isolate the catch from a particular seamount. Checks were made on recent data to ensure these boundaries were still appropriate.

2.4 Stock size

The dependent abundance variable was an estimate of the minimum stock size ($B_{\min}$) on a seamount based on the commercial catch history. The model of Francis (1992) was used, with biological parameters for the Chatham Rise (see Annala et al. 2001). The catch history for each seamount was derived from the commercial catch records using the coordinate boundaries given in Appendix 3. The model was run to find the minimum biomass to enable the catch history to be taken, with the provision that the maximum exploitation rate in any single year would not exceed 0.67. The biomass estimate was rounded to the nearest 50 t (Figure 10).

2.5 Regression analysis

The regression analysis was carried out in two stages. The first stage was to model orange roughy biomass of individual seamounts using 'region' as a categorical effect and including predictors specific to individual seamounts. The second stage was to model the region effects, using predictors relating to entire regions. So, in the first stage, one data point represented one seamount; in the second stage, one data point represented one region.

The advantage of this method, as compared to a single regression of seamount biomass on all predictors, is that the categorical 'region' effect allows for differences between regions, over and above those explainable by the recorded physical and biological variables. Two seamount complexes at similar latitudes, with similar geological characteristics, and similar orange roughy spawning levels, can nonetheless have quite different orange roughy abundances. The second stage of the analysis allows us to attempt to explain these differences between regions in terms of the observed variables.

The seamounts in this study were divided into the following 19 regions (Figure 1):

Auckland Islands
Bay of Plenty
Challenger Plateau
East Coast North Island
East Chatham Rise
East Cape
Louisville North
Louisville South
Macquarie Ridge
North Chatham Rise
Northeast Chatham Rise
Northwest Challenger
Northwest Chatham Rise
Puysegur
South Chatham Rise
Southeast Chatham Rise
Southwest Chatham Rise
Snares
West Northland

Some of the predictor variables relate to entire regions, and some to individual seamounts.

Predictors by region
- Latitude
- Origin (volcanic / non-volcanic)
- Association (continental / oceanic)
- Typical orange roughy spawning level (low / medium / high)
- Distance between centre of region and mainland.

Predictors by individual seamount

- Area
- Depth of top
- Depth of base
- Elevation
- Slope index
- Spawning level relative to rest of region (lower / same or unknown / higher)
- Distance to nearest seamount
- Distance from centre of region
- Distance from seamount with highest orange roughy biomass in region (or the next highest, if this seamount has the highest)
- Index of distance from other seamounts in the region (sum of inverse distances).

The regressions were carried out with a generalised additive model (GAM) using smoothing splines (Hastie & Tibshirani 1990, Venables & Ripley 1999, p. 285). This model allows nonlinear relationships between the response and predictor variables. The log-link function was used, resulting in a multiplicative model in which the combined effect of two predictors is the product of the individual effects. Interactions between predictors were not considered. Gamma errors were used (McCullagh & Nelder 1989), which imply a constant coefficient of variation of the response variable, given the predictors. The model was hence

$$\text{response}_j \sim \text{Gamma}\begin{pmatrix} \log(\text{mean}) = \sum_{\text{predictors } i} \beta_i s(x_{ij}) \\ \text{c.v. constant} \end{pmatrix}$$

where s denotes a smoothing spline.

In the first stage of the analysis, the response variable was B_{min}: in the second stage of the analysis, the response variable was the region effect from the first stage.

Predictors were selected using a forwards stepwise fitting method, using the 'step.gam' method in S+ (Venables & Ripley 1999). At each step, this method selects the predictor which improves the AIC (Akaike's information criterion; see Hastie & Tibshirani (1990, p. 158) for the definition of AIC under the GAM). Continuous terms were offered as smoothing splines with 2 or 4 degrees of freedom (so, if 2 d.f. did not allow enough flexibility to model a nonlinear relationship, 4 d.f. would be used).

The dispersion parameter of the gamma distribution was estimated using the moments estimator of McCullagh & Nelder (1989) on the model fitted with all terms included and 4 d.f. for all continuous terms, i.e., the most full model available. This dispersion parameter was then held fixed during the stepwise process so that the AIC would be comparable between models.

2.6 Cross-validation analysis

The predictive power of our models was estimated by cross-validation, and compared with simpler models to assess the informative value of the predictor variables.

The model of individual seamount biomass was compared with a simpler model in which the only predictor was the region effect. In this simple model, the predicted biomass of any new seamount is simply the average biomass of the other seamounts in the same region, and none of the physical and biological variables are used. The 'average' used is the geometric mean, due to the gamma error structure. The informative value of the biological and physical variables was measured by the difference in predictive power between our regression model and this simple model. The simple model, in turn, was compared with a "trivial" model with no predictors at all.

The model of region effects was compared with a trivial model with no predictors. In this model, the predicted region effect for any new region is simply the average of the effects for all the other regions. Again, the informative value of the biological and physical variables was measured by the difference in predictive power between our regression model and this trivial model.

Predictive power was estimated for each model by the following cross-validation technique:

1. remove one point from the dataset
2. refit the model with the reduced dataset
3. predict the response at the removed point
4. repeat steps 1–3 for every point in the dataset
5. compare the predictions with the actual responses: measure the prediction error in terms of the mean squared error on the log scale,

$$MSE = \sum\left([\log(\text{actual}) - \log(\text{predicted})]^2\right).$$

Small biomass estimates (below 100 t) were rounded up to 100 t in the calculation of MSE, to prevent them from having an excessive influence on the result. Similarly, in the second model, small region effects below 0.3 were rounded up to 0.3.

3. RESULTS

3.1 Individual seamount model

The predictors of orange roughy biomass on individual seamounts were region, depth of top, and slope.

These variables were selected as statistically significant by the stepwise fit. Their effects are shown in Figures 11, 12, and 13. The effect value indicates the relative importance of the variable, with a larger effect meaning greater importance.

All else being equal, the regions in which orange roughy are (or were) most abundant are the East Chatham Rise and the Challenger Plateau. They are least abundant on the Southwest Chatham Rise, the Macquarie Ridge and Snares, and the Northwest Challenger Plateau.

Orange roughy are more abundant on seamounts with peaks closer to the surface, although this result holds only for the depth range of the seamounts covered in this study, i.e., 600–1000 m. Orange roughy do not occur shallower than about 700 m in New Zealand waters, and if more shallow seamounts with no orange roughy (because the base depth would be less than 700–800) were included, the depth effect would move towards a dome shape, with the peak at the optimal depth.

Abundance is higher on gently sloping seamounts than on steep seamounts.

A plot of predictions versus actual values is given in Figure 14. Outliers for which the actual biomass was substantially higher than the prediction include Ritchie Hill, MegaBrick, Mt. Kiso, Big Chief, Main Hill, and Goomzy. These are seamounts that stand out as having a substantially higher biomass than others in their regions, which cannot be fully explained by the regression model.

The cross-validation predictive error of this model is MSE = 1.42 which is a 22% improvement on MSE = 1.82 for the naive model (i.e., the model where the only predictor is the region effect) and a 46% improvement on MSE = 2.63 for the trivial model (i.e., the model with no predictors).

The 'depth of top', 'slope index', and 'region' variables therefore have predictive power and could improve predictions of yield on new seamounts in the same regions.

3.2 Region model

The predictors of region effects were latitude, and association.

These variables account for some of the differences between regions. They were selected as statistically significant by the stepwise fit. Their effects are shown in Figures 15 and 16. Orange roughy were found to have relatively lower abundance in regions north of 39° S and south of 45° S. The most "productive" seamounts were at latitudes of 41° – 43° S. Abundance on seamounts with a continental association (near the New Zealand shelf or on major plateaux and rises) was much higher than on oceanic seamounts.

A plot of predictions versus actual values is given in Figure 17. Outliers for which the actual region effect was substantially higher than the prediction include the Challenger Plateau, East Coast North Island, the East Chatham Rise, and Louisville South. Outliers for which the prediction was too high include the Southwest Chatham Rise and Northwest Challenger Plateau.

Spawning levels appeared to have little effect on regional orange roughy abundance. In the region with the highest effect – the East Chatham Rise – the typical spawning level was low. The Southeast Chatham Rise also had a high region effect but low spawning levels; whereas the Bay of Plenty had a relatively low region effect but high spawning levels. Consequently, typical spawning level was not selected as a significant predictor.

The cross-validation predictive error of this model is MSE = 0.92, a small improvement of 13% on MSE = 1.06 for the trivial model with no predictors. The 'latitude' and 'association' variables therefore have predictive power and could improve predictions of yield on seamounts in new regions.

3.3 Making predictions

Predictions using these models should ideally be carried out using the fitted regression equations. However, the spline terms in the regressions are complex, so we provide approximating formulae here.

For the individual seamount model, the approximating formula is

Predicted biomass = exp(intercept + region effect + depth of top effect + slope effect) where the intercept is 6.89 and the region, depth of top, and slope effects are given below. (Note that these effects are used on the log-scale here, whereas they have been converted to the linear scale in Figures 10–12.) For a new region, use the region effect predicted by the Region regression model.

Region	Effect
Auckland Islands	0.00
Bay of Plenty	–0.07
Challenger Plateau	1.72
East Cape	0.14
East Chatham Rise	1.82
East Coast North Island	1.38
Louisville North	–0.35
Louisville South	0.83
Macquarie Ridge	–1.60
North Chatham Rise	0.77
Northeast Chatham Rise	1.00
Northwest Challenger	–0.88
Northwest Chatham Rise	1.24
Puysegur	0.75
Snares	–1.17
South Chatham Rise	0.58
Southeast Chatham Rise	1.13
Southwest Chatham Rise	–3.83
West Northland	0.06

Depth of top (m)	Effect
<600	0.95
600–649	0.76
650–699	0.65
700–749	0.39
750–799	0.19
800–849	0.02
850–899	–0.19
900–949	–0.41
950+	–0.64

Slope	Effect
<0.1	0.46
0.1–0.2	0.08
0.2–0.25	–0.22
0.25–0.3	–0.41
0.3–0.4	–0.62
0.4–0.5	–0.84
0.5+	–1.00

This formula is used where a new seamount is found within an existing region. For example, the approximate prediction for Mt. Ghost (if it was a new feature on the southern Louisville Ridge) would be:

Biomass = exp(6.89 + 0.83 (Louisville South) + 0.76 (top depth is 620 m) + 0.08 (slope is 0.14))
= 5200 t.

We also provide an approximating formula for the region model. The result has little meaning in absolute terms but can be compared with that of other complexes, and also can be applied to the individual seamount formula to estimate ORH abundance on a seamount in a new region. The formula is:

predicted region effect = exp(intercept + latitude effect + association effect) where the intercept is 0.73 and the region, depth of top, and slope effects are given below. (Note that these effects are used on the log-scale here, whereas they have been converted to the linear scale in Figures 14–15.)

Latitude	Effect
north of 37°S	–0.45
39°S – 37°S	–0.01
42°S – 39°S	0.33
44°S – 42°S	0.39
45°S – 44°S	0.23
49°S – 45°S	–0.30
south of 49°S	–0.77

Association	Effect
continental	0.00
oceanic	–1.00

4. DISCUSSION

The distribution of seamounts around New Zealand that are fished for orange roughy has concentrations in certain areas, such as the Chatham Rise, Challenger Plateau, and Macquarie Ridge. This means that correlation between some physical variables can be expected to occur. Clark (1999b) described the problem of surface water mass (as a hydrological factor) and latitude, where across the latitudinal band, where surface water changes from Subantarctic through the Subtropical Front to Subtropical, all the fished seamounts are on the Chatham Rise, and the two variables cannot be separated. The inclusion of more seamounts is limited by available physical data, and could not at this stage solve the problems, given that there are definite patterns in the distribution of seamounts and deepwater fishing. Our approach of dividing seamounts into geographical areas attempted to reduce this uneven distribution rather than allow too many variables which can become confounded. Nevertheless, this study has shown that of the 12 variables studied the 3 most important predictors of seamount orange roughy associations and biomass are latitude (region), depth of top, and slope.

For almost all seamounts in the New Zealand region there are no fisheries-independent estimates of biomass and sustainable yield. The approach taken here using minimum biomass consistent with the reported catch history is not ideal, but is potentially a conservative approach as long as the conditions of the population model under which biomass is estimated are appropriate. In addition, catch might not relate directly to stock size, but in some areas may simply reflect a fishing pattern geared at maintaining good catch rates by fishing a number of seamounts in sequence, avoiding disturbance to the aggregations. For orange roughy stocks in New Zealand sustainable yield is estimated at about 30% of virgin biomass (long-term MSY) (Annala et al. 2001). It is uncertain how the biomass measure used in this study (B_{min}) relates to virgin biomass and hence MSY. However, several stock assessments of orange roughy in seamount fisheries have calculated stock size to be at a level very close to B_{min}, even when based on research survey or detailed CPUE analyses (e.g., Bay of Plenty (Clark et al. 2001), Challenger Plateau (Field & Francis 2001), East Cape (Anderson 2000), Puysegur Bank (Annala et al. 2001)).

Spawning level was unimportant in this analysis, in contrast to the findings of Clark (1999b). This was a surprising result at first glance as many orange roughy fisheries take a large amount of catch from the winter spawning aggregations which can occur on seamounts. It was expected that this variable would be an important factor, as the seamount can host migratory fish that spend much of the year elsewhere, but move onto a seamount (and are vulnerable to capture) during the spawning season. However, although seamounts in some areas function as important spawning sites (e.g., Ritchie Hill, Main Hill at East Cape), others appear to function as feeding grounds. For example, the East Chatham Rise seamounts generally have low levels of spawning. The area is heavily fished at certain times of the year. It is assumed (e.g., Annala et al. 2001) that these seamounts host fish from the Northeast

Chatham "stock", which is believed to spawn primarily in the areas of the Spawning Box and Northeast seamounts, with spawning migrations being reported (Coburn & Doonan 1997).

This study treated each seamount independently. However, they are often clustered, with only a few miles separating them. Several could also be interpreted as a single larger seamount with multiple peaks (e.g., Big Chief). It has been implicitly assumed that each seamount has its own population, which may not be true. It is likely that orange roughy move around between seamounts, and hence the catch on one could affect the catch on its neighbours. This has been investigated here, using the distance to neighbouring seamounts, but was not a significant factor.

There are no estimates of error or variance associated with the predicted values of catch for a new seamount. Normally a bootstrapping procedure would have been applied, but this was not possible given the two-stage approach taken in this study. However, the plots of predicted versus actual biomass (Figures 14 and 17) give an indication of variability in the results.

The individual seamount model appears to work reasonably well for many seamounts. However, fisheries managers need to be concerned about the likelihood of any prediction being substantially wrong, and for this the outliers in the model result are important. In particular, the seamounts in Figure 14 that are to the left of the line are critical. This is where the model prediction is that a much larger biomass exists than the actual B_{min} estimate from the catch history. The model could therefore lead to an overestimate of biomass, and catch levels set on that basis would be too high, with a risk of overexploiting the population. The values to the left of the dashed line are seamounts where the actual B_{min} estimate is relatively low, typically less than about 4000 t. Although the size of B_{min} can to an extent be affected by the length of time the seamount has been fished (more years, more catch, higher B_{min}), it appears that most seamounts discovered in recent years have relatively small stock sizes (Figure 18). This plot shows the estimate of B_{min} and year of first fishing of a seamount. There is a declining trend in biomass with year, which may indicate that the seamounts with large populations were found and fished in the earlier years of orange roughy fishing. Since 1994, the populations on new seamounts are estimated to be small. Managers could therefore be wary of a new seamount where the predicted biomass was high, and apply a more conservative catch level.

The completeness and quality of physical data is continually being improved with active seamount research programmes in New Zealand. However, some potentially important variables could not be included in this study. Clark (1999b) considered the age of seamounts, which could determine the structure and complexity of benthic fauna (e.g., coral and sponge communities) which might in turn affect the composition and abundance of associated fish species. However, ageing of rock samples is often imprecise, and may be affected by iceberg melt over parts of the EEZ which deposits rocks that are not related to the actual seamount origin.

This study indicates there is predictive information in physical and biological "conditions" of a seamount that can be useful in setting initial catch levels. The regression formulae presented here are not precise, and the plots of predicted against actual biomass show a wide spread, with some important outliers. The analysis could be improved with the addition of more seamounts with a developing catch history, where new physical data are acquired, and the application of more advanced regression methods (such as MARS-multiple adaptive regression splines (Hastie et al. 2001)). Nevertheless, we expect that the analysis can provide some guidance to help solve the difficult problem of how to manage new and vulnerable resources in the absence of detailed information.

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Table 1: Divisions of regions into continental / oceanic, volcanic / non-volcanic (after Wright 1999, Wright, pers. comm.).

	Origin	
Association	Volcanic	Non-volcanic
Continental	Auckland Islands	Bay of Plenty
	Chatham Rise (all regions)	East Cape
	Challenger Plateau	East Coast North Island
	West Northland	Puysegur
Oceanic	Louisville South & North	Macquarie Ridge
		Snares

Table 2: Distances of regions from the mainland. Distance is calculated from the mean latitude and longitude of seamounts in the region to the nearest point on the coast of the mainland.

Region	Position of centre	Distance from mainland (km)
Auckland Islands	50° 06′ S 165° 54′ E	415
Bay of Plenty	36° 23′ S 176° 48′ E	78
Challenger	40° 00′ S 167° 41′ E	370
East Cape	37° 42′ S 179° 05′ E	53
East Chatham Rise	44° 06′ S 174° 24′ W	834
East Coast North Island	39° 23′ S 178° 24′ E	51
Louisville North	38° 23′ S 168° 18′ W	1157
Louisville South	40° 47′ S 165° 11′ W	1437
Macquarie Ridge	49° 36 S′ 164° 00′ E	425
North Chatham Rise	42° 47′ S 176° 54′ W	590
Northeast Chatham Rise	43° 06′ S 174° 18′ W	781
Northwest Challenger	37° 23′ S 167° 41′ E	541
Northwest Chatham Rise	42° 42′ S 179° 54′ W	382
Puysegur	47° 06′ S 165° 35′ E	130
Snares	48° 00′ S 165° 05′ E	236
South Chatham Rise	44° 36′ S 177° 41′ W	638
Southeast Chatham Rise	44° 42′ S 175° 18′ W	806
Southwest Chatham Rise	44° 47′ S 175° 35′ E	226
West Northland	34° 47′ S 171° 41′ E	96

Table 3: Typical spawning levels assigned to each region. Percent spawning data for individual seamounts are listed; seamounts with substantially higher or lower spawning levels than the rest of the region are marked (+) or (–).

Region	Typical spawning level	Percent spawning data
Auckland Islands	Medium	DSW 39
Bay of Plenty	High	Colville Knolls 82, Mercury Knoll 83, Ohena Knoll 82
Challenger	High	MegaBrick 91, TwinTits 92
East Cape	High	Hill3 95, Hill7 63 (–), Main Hill 88
East Chatham Rise	Low	Cathy 35 (+), Cotopaxi 8, Not Till Sunday 41 (+), Possum 2, Sir Michael 8
East Coast North Island	Medium	North Hill 47, Ritchie Hill 68
Louisville North	Medium	None
Louisville South	Medium	None
Macquarie Ridge	Low	None
North Chatham Rise	High	Mt. Muck 96
Northeast Chatham Rise	High	Camerons 72, Erebus 22 (–), Smiths 70
Northwest Challenger	Medium	None
Northwest Chatham Rise	Medium	Dead Ringer 42, Graveyard 74 (+), Morgue 47
Puysegur	Medium	Godiva 59, Goomzy 69, Malcolms Mont. 69
Snares	Medium	Bobs Gun 54
South Chatham Rise	Low	None
Southeast Chatham Rise	Low	Big Chief 2, Charlie 1, Condoms 6, Teepee 4, Tomahawk 0
Southwest Chatham Rise	Low	None
West Northland	Medium	Tauroa Knoll 67

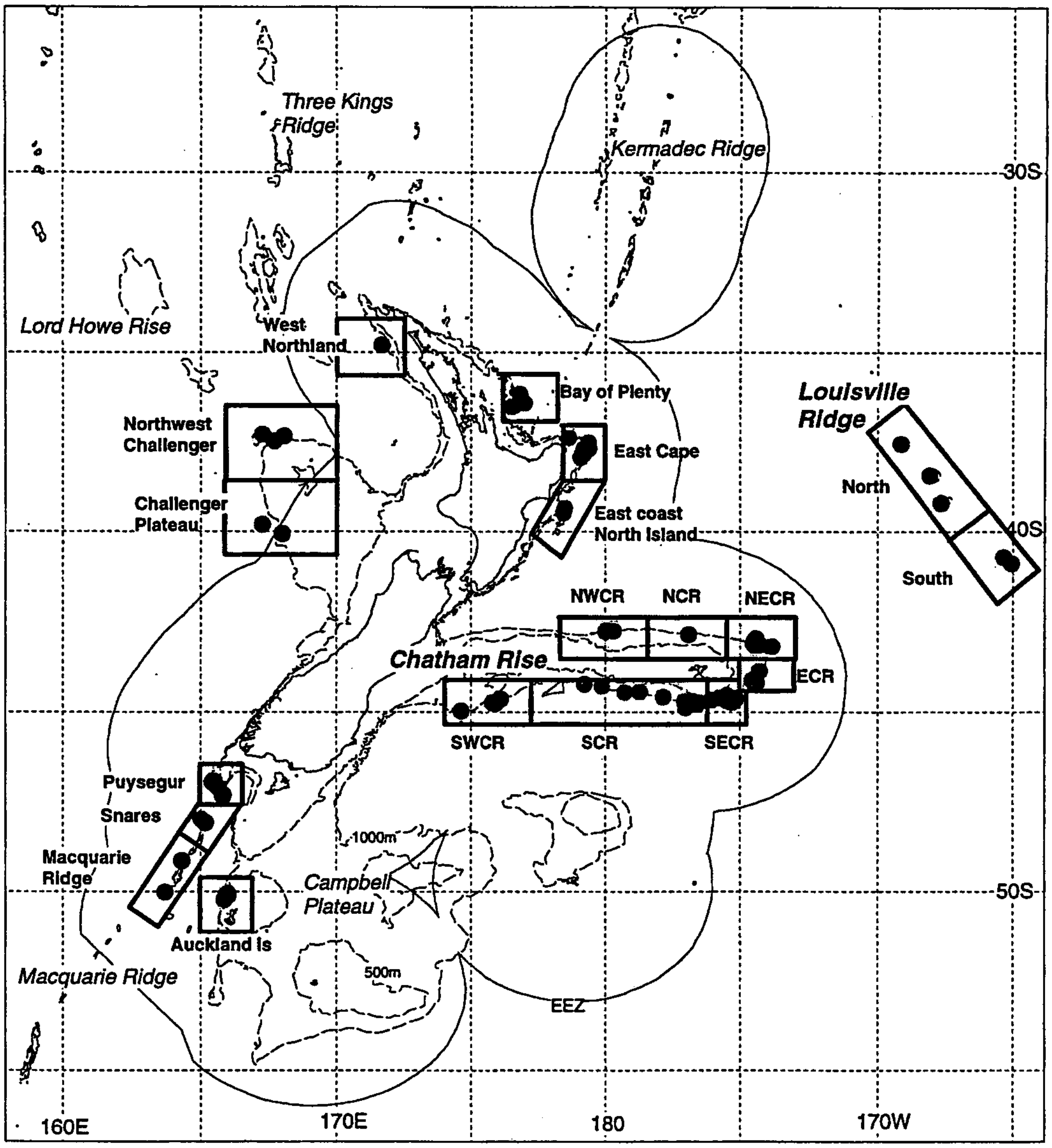

Figure 1: The regions and seamounts included in this study. The Chatham Rise regions are abbreviated to CR. Refer text for details.

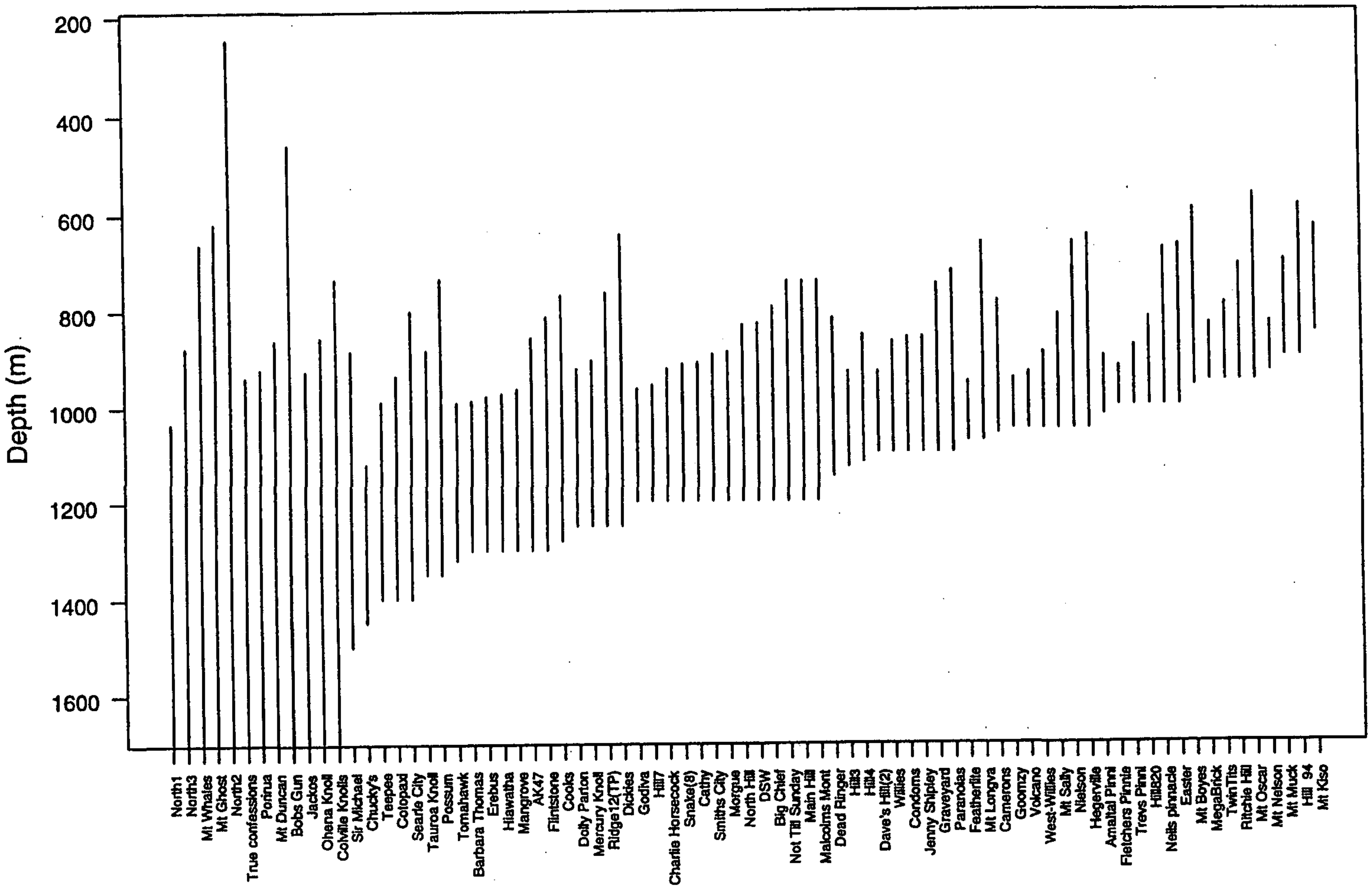

Figure 2: Base and top depths of each seamount. Elevation is indicated by the length of the line. The depth axis is truncated: in fact some of these seamounts have base depths of more than 4500 m.

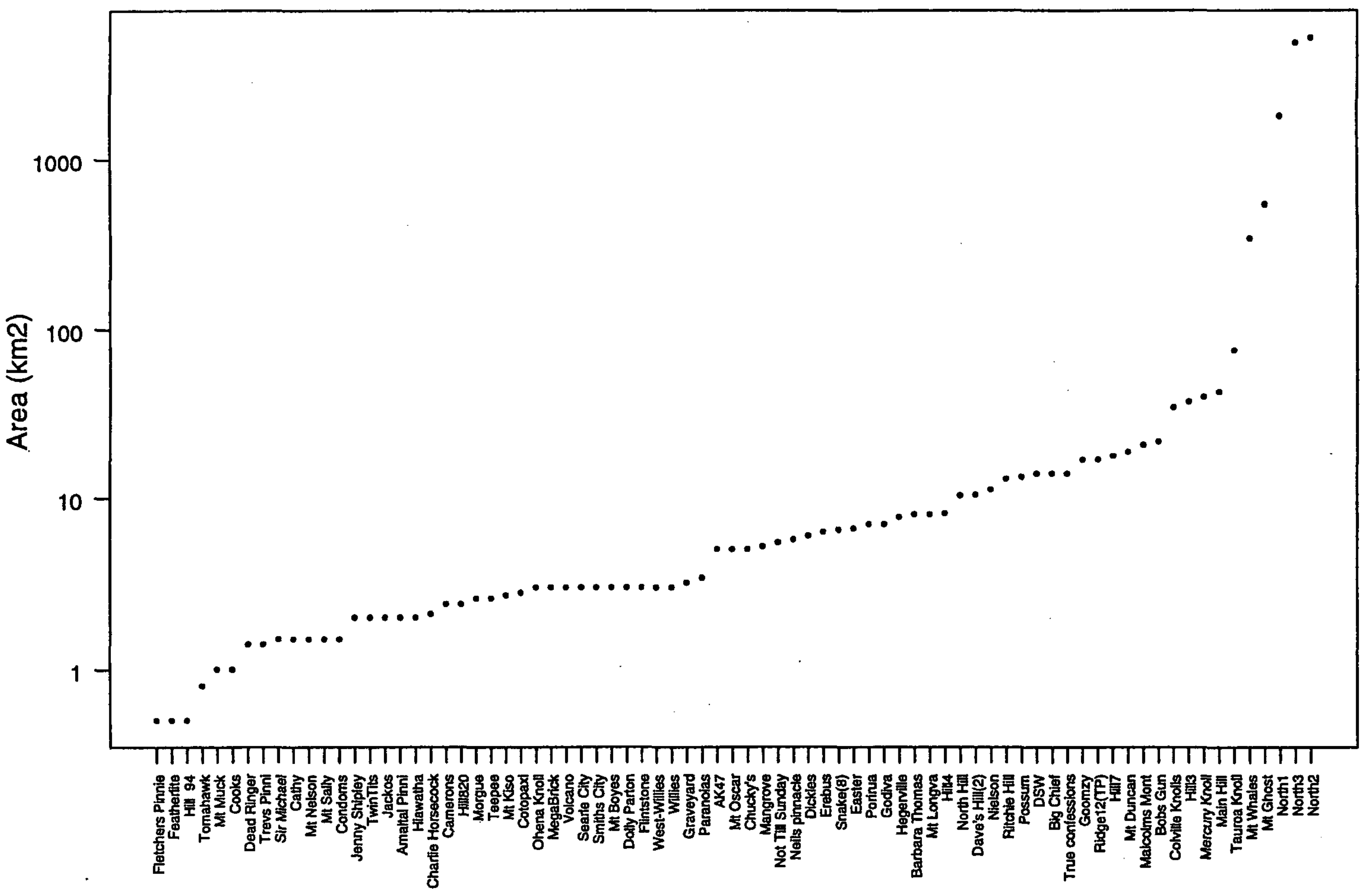

Figure 3: Area of each seamount.

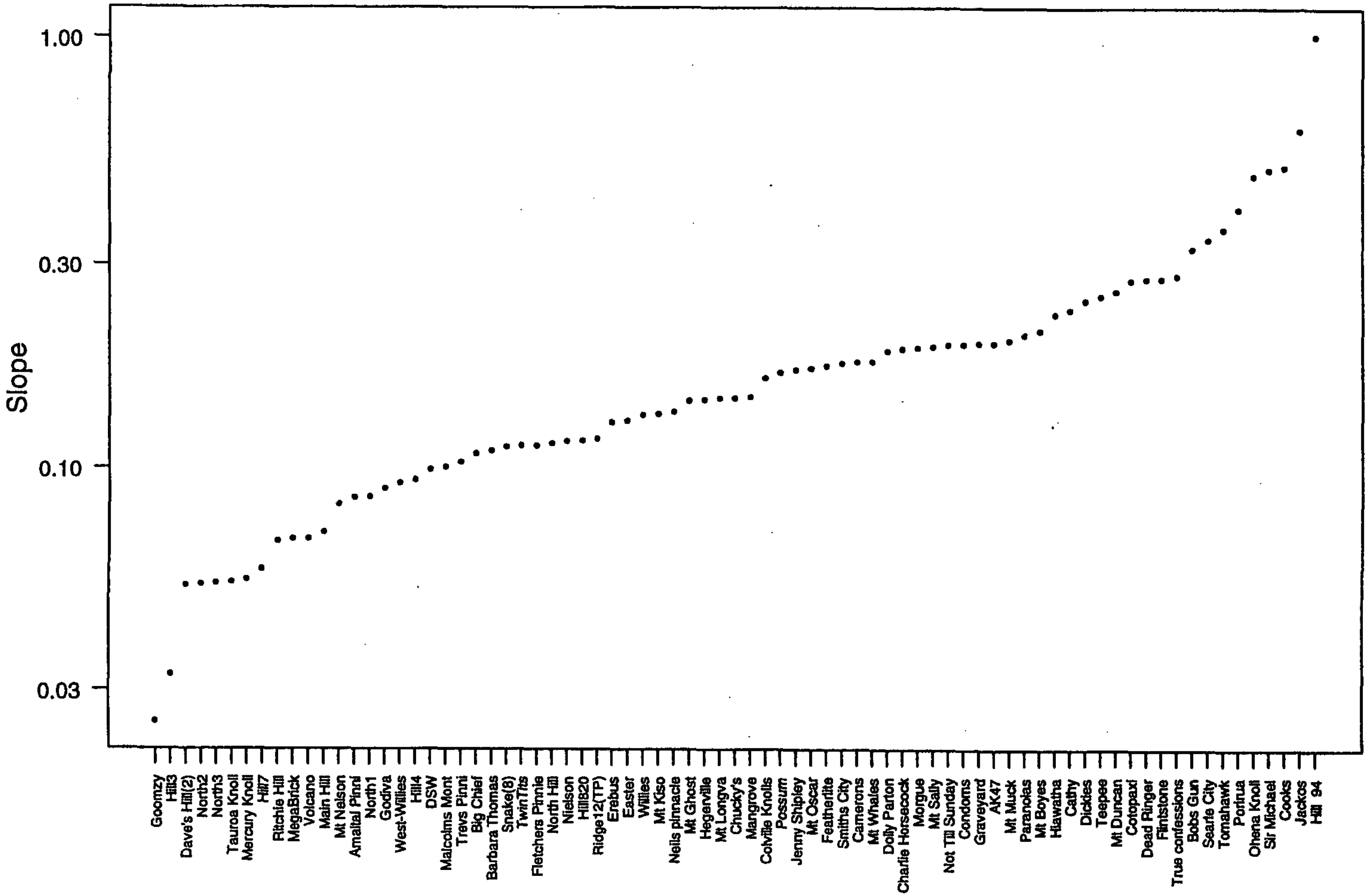

Figure 4: Slope index of each seamount (calculated as elevation / sqrt(area)).

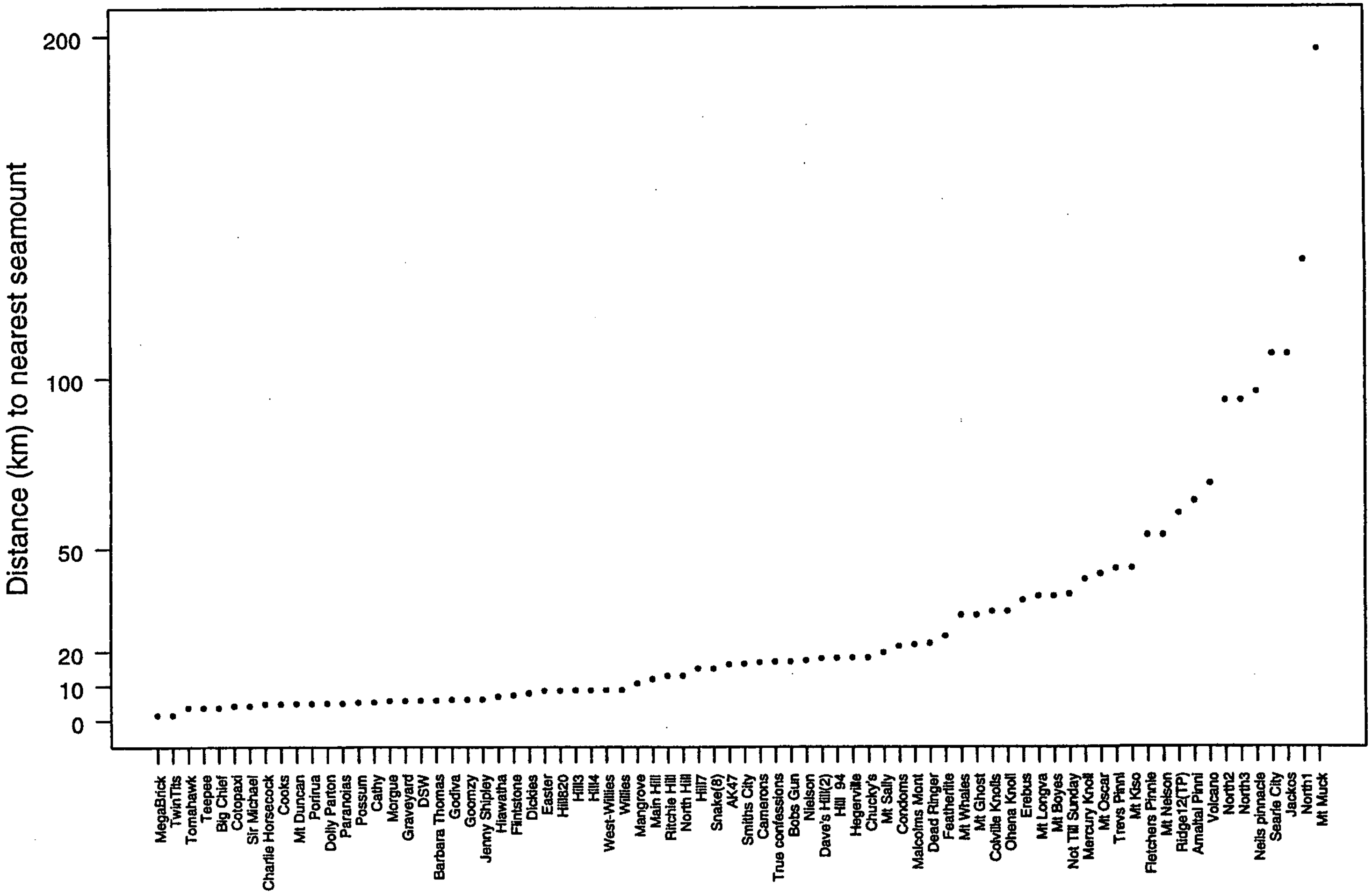

Figure 5: Distance (km) from each seamount to its nearest neighbour. Tauroa Knoll is excluded since it is over 400 km from the nearest seamount included in the dataset.

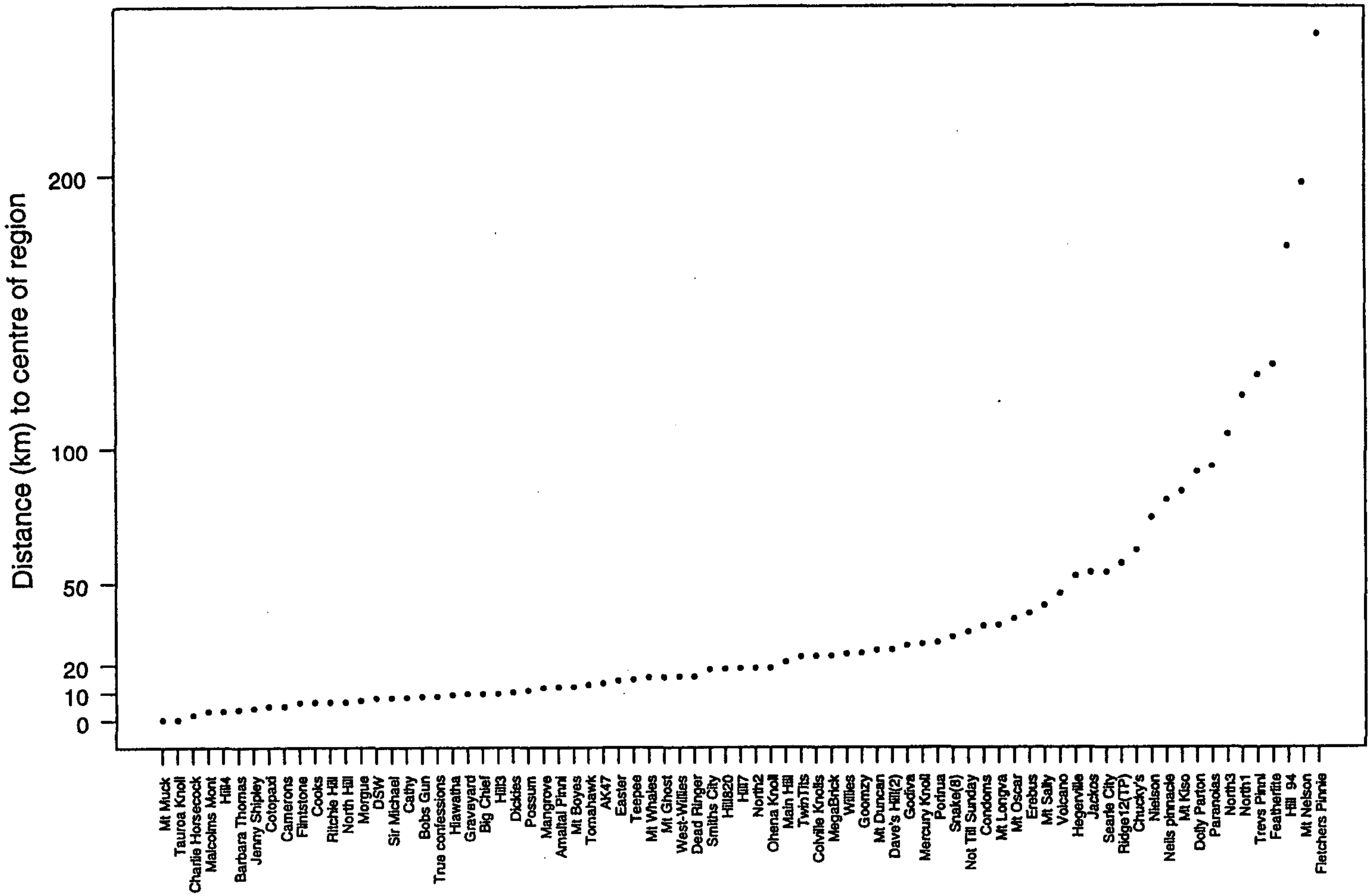

Figure 6: Distance (km) from each seamount to the centre of its region. The centre is calculated as the mean longitude and mean latitude of all included seamounts in the region.

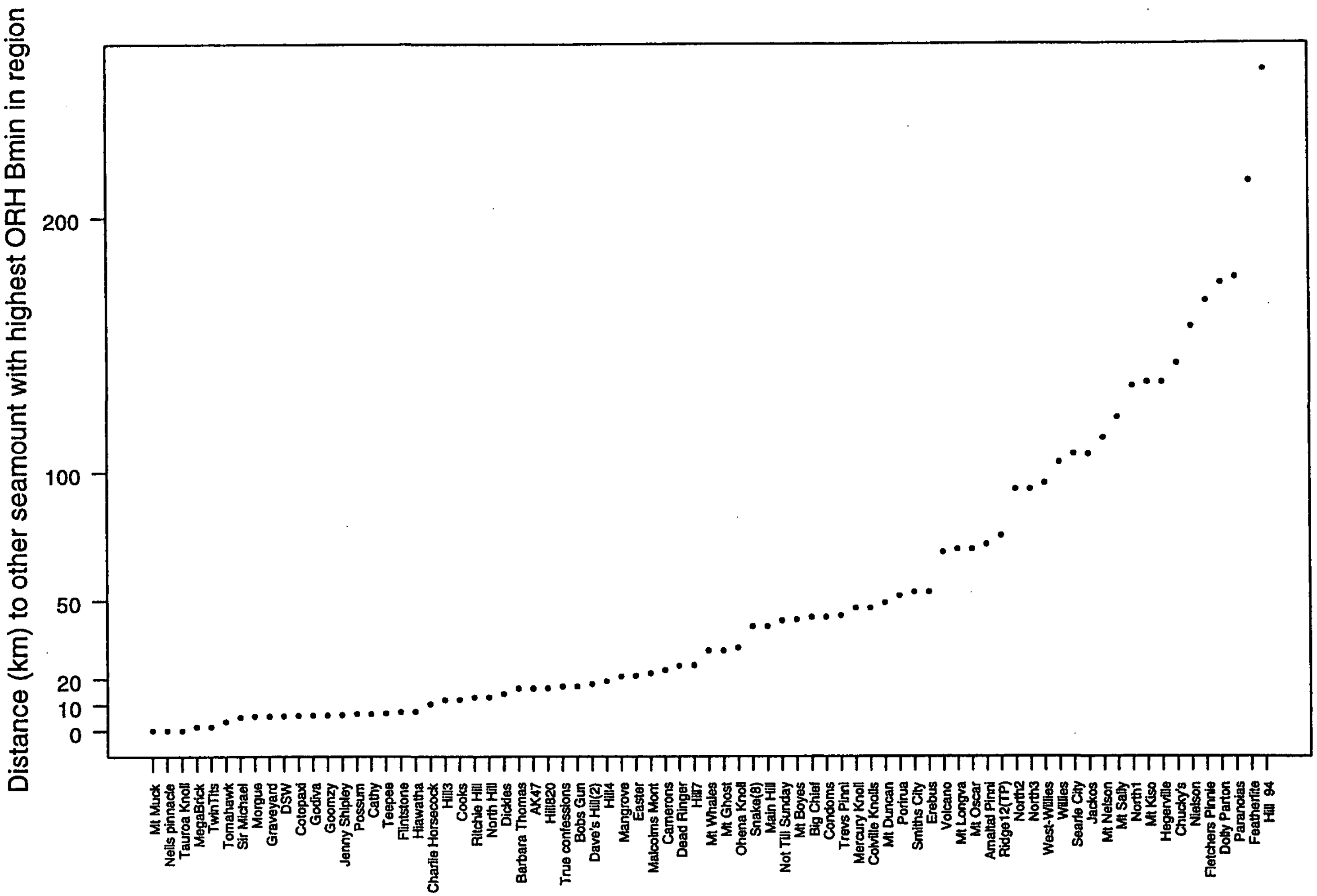

Figure 7: Distance (km) from each seamount to the seamount with the highest orange roughy biomass in the region. If a seamount has the highest B_{min} in its region, we instead use the distance to the next highest.

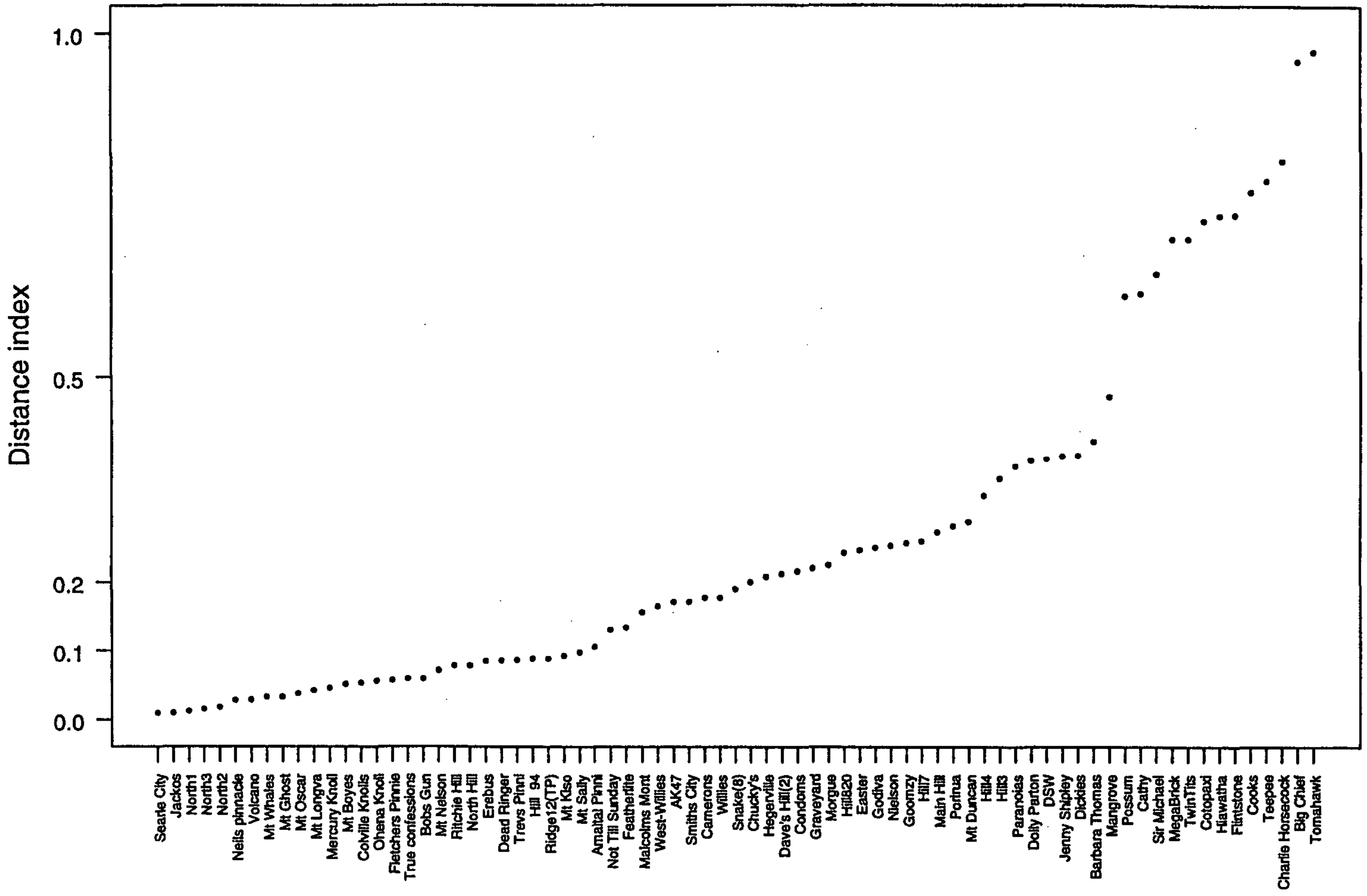

Figure 8: Index of distances to nearby seamounts, defined as $\sum(1/\text{distance})$ for seamounts in the same region. The index is 0 for a lone seamount, and increases as the number of hills in the region increases, and as they get closer to this hill. So, a high value indicates there are other hills close by.

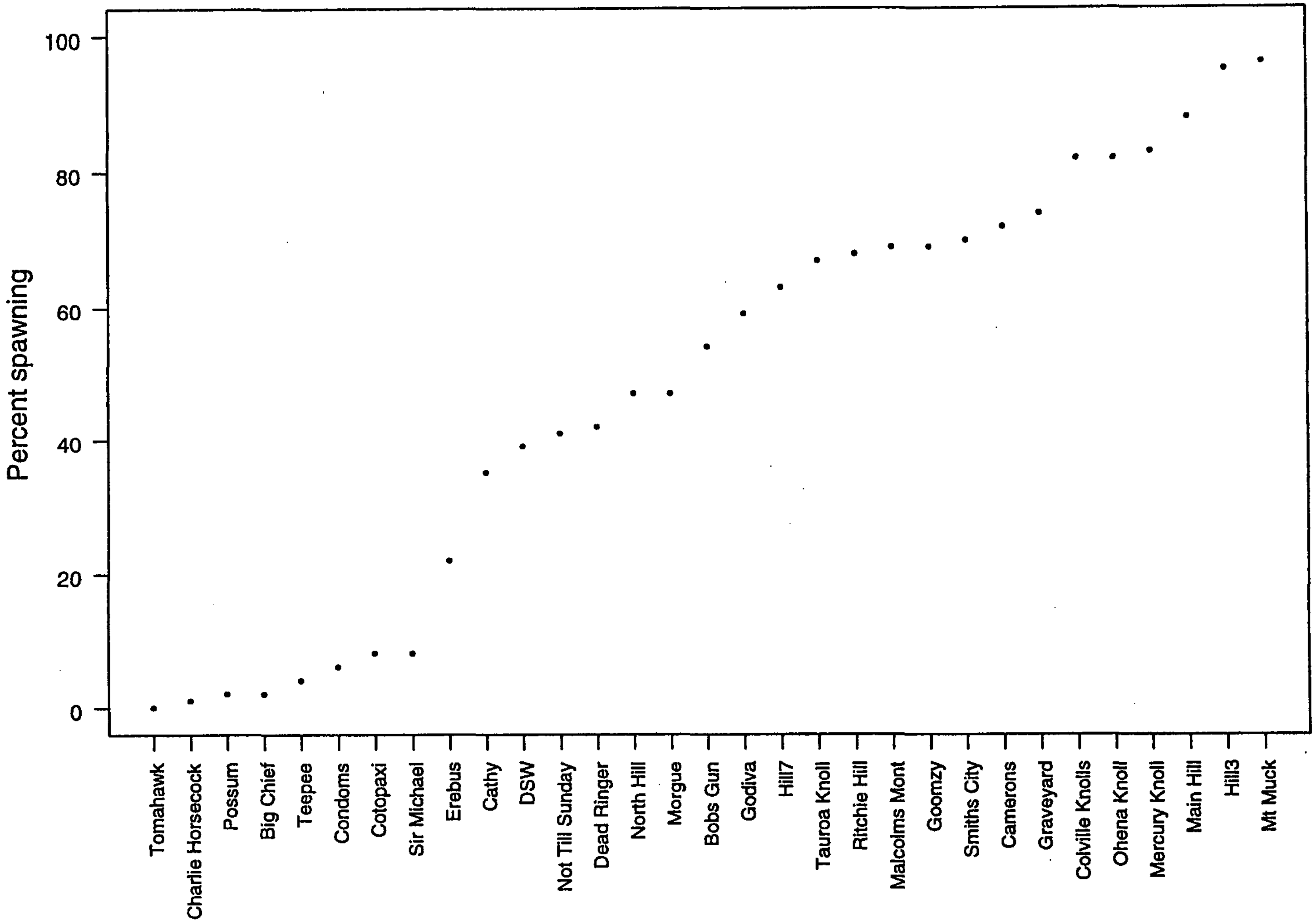

Figure 9: Percent spawning for each seamount for which it is available.

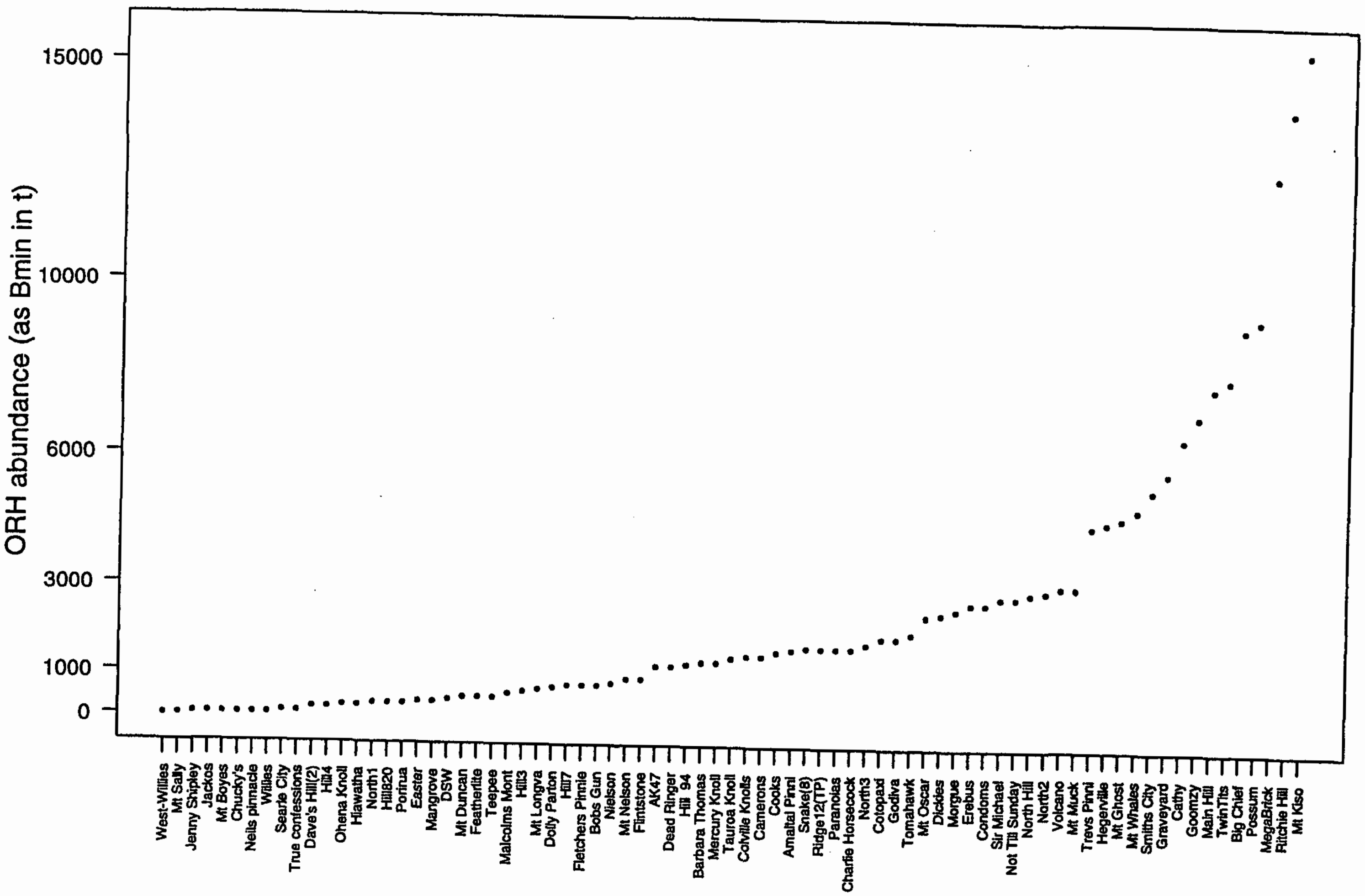

Figure 10: Orange roughy biomass by seamount.

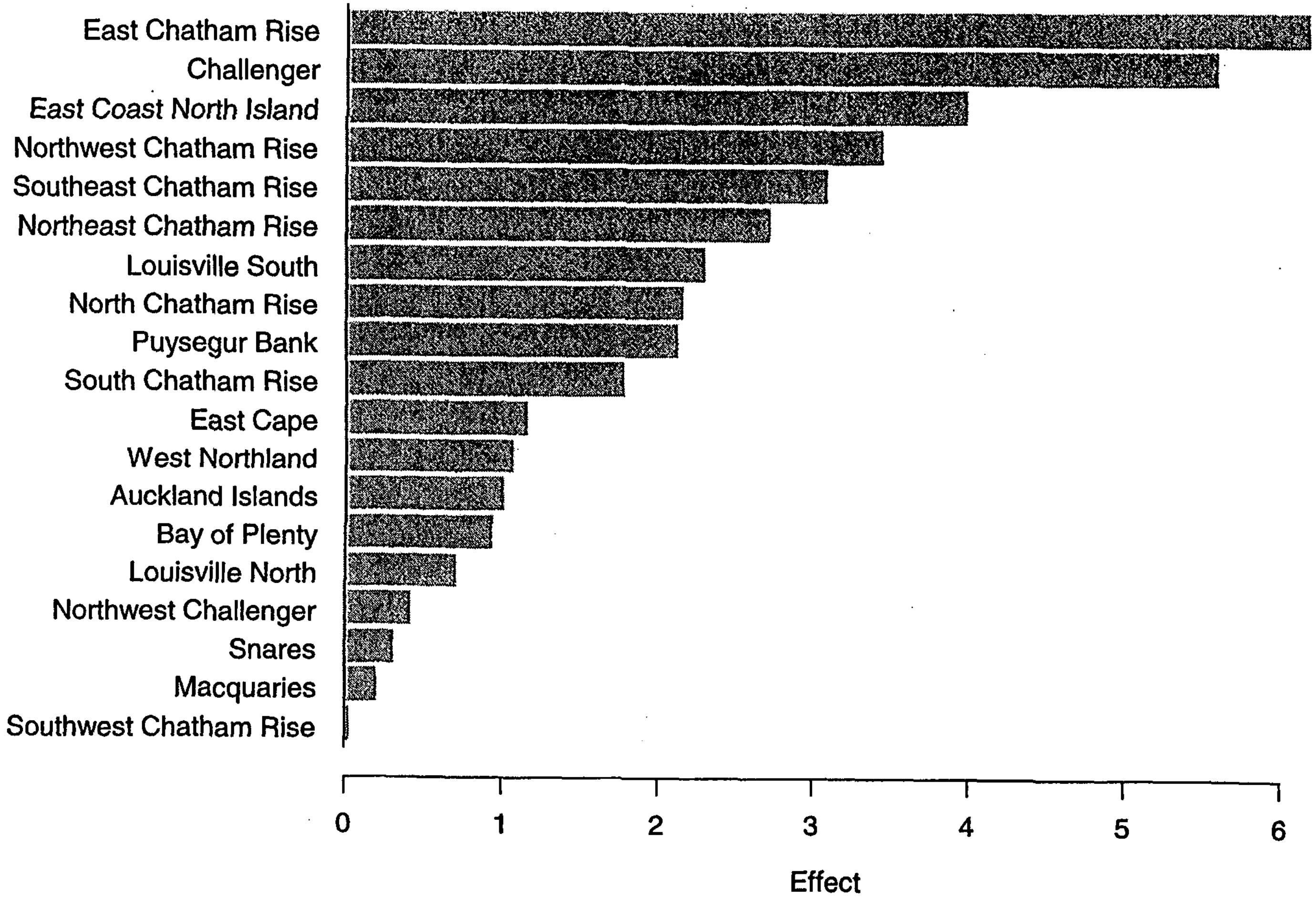

Figure 11: Region effects on seamount biomass. The length of each bar indicates the average relative abundance of orange roughy on seamounts in the region (once the effects of the 'slope' and 'depth of top' predictors have been removed).

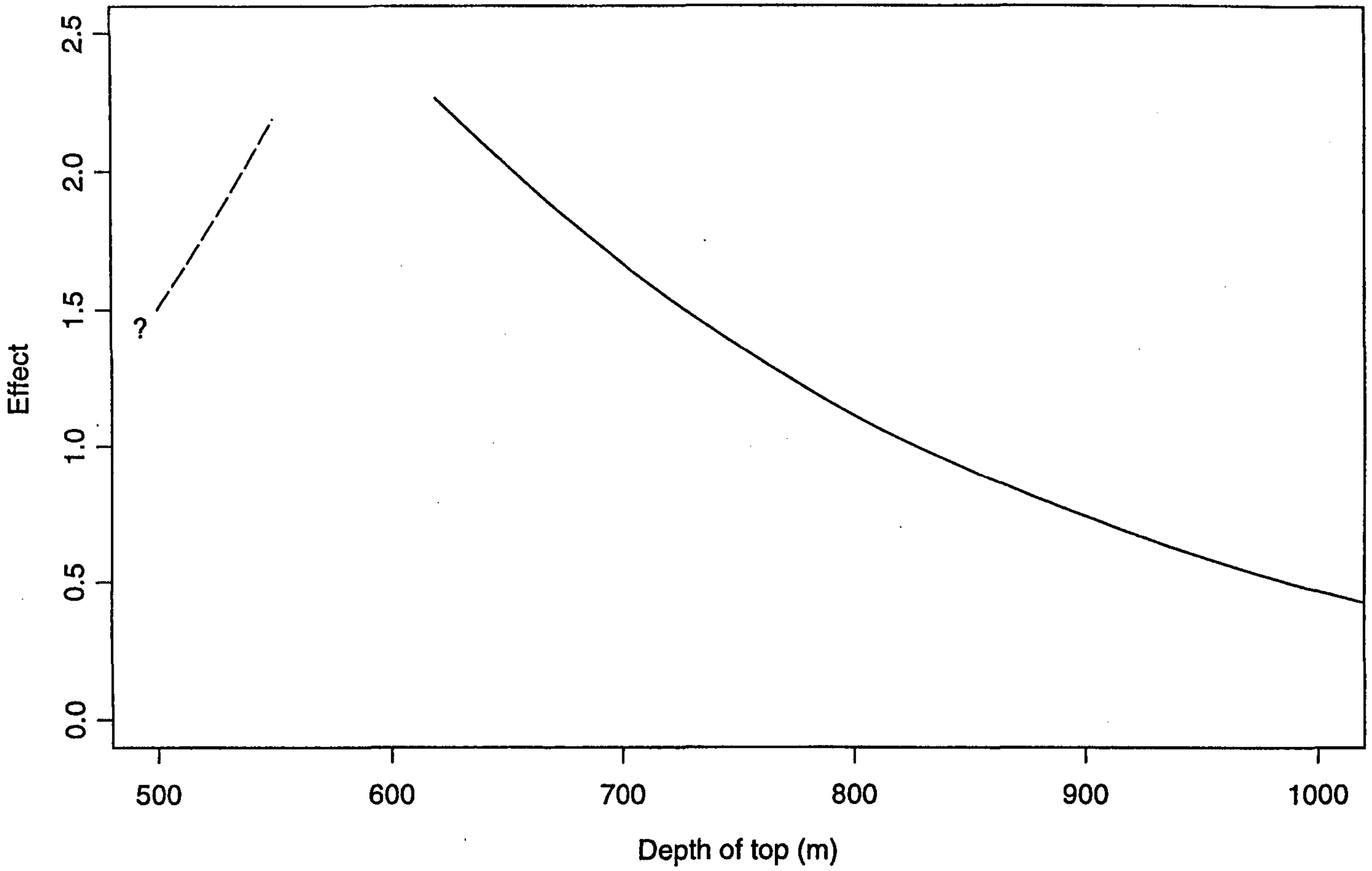

Figure 12: Effect of the depth of the top of a seamount on biomass. The value of the curve indicates the relative abundance of orange roughy on seamounts of that depth, all else being equal. The dataset includes few hills with shallow tops, so the curve does not decline at the left hand end as could be expected; we have added the dotted line to reflect this.

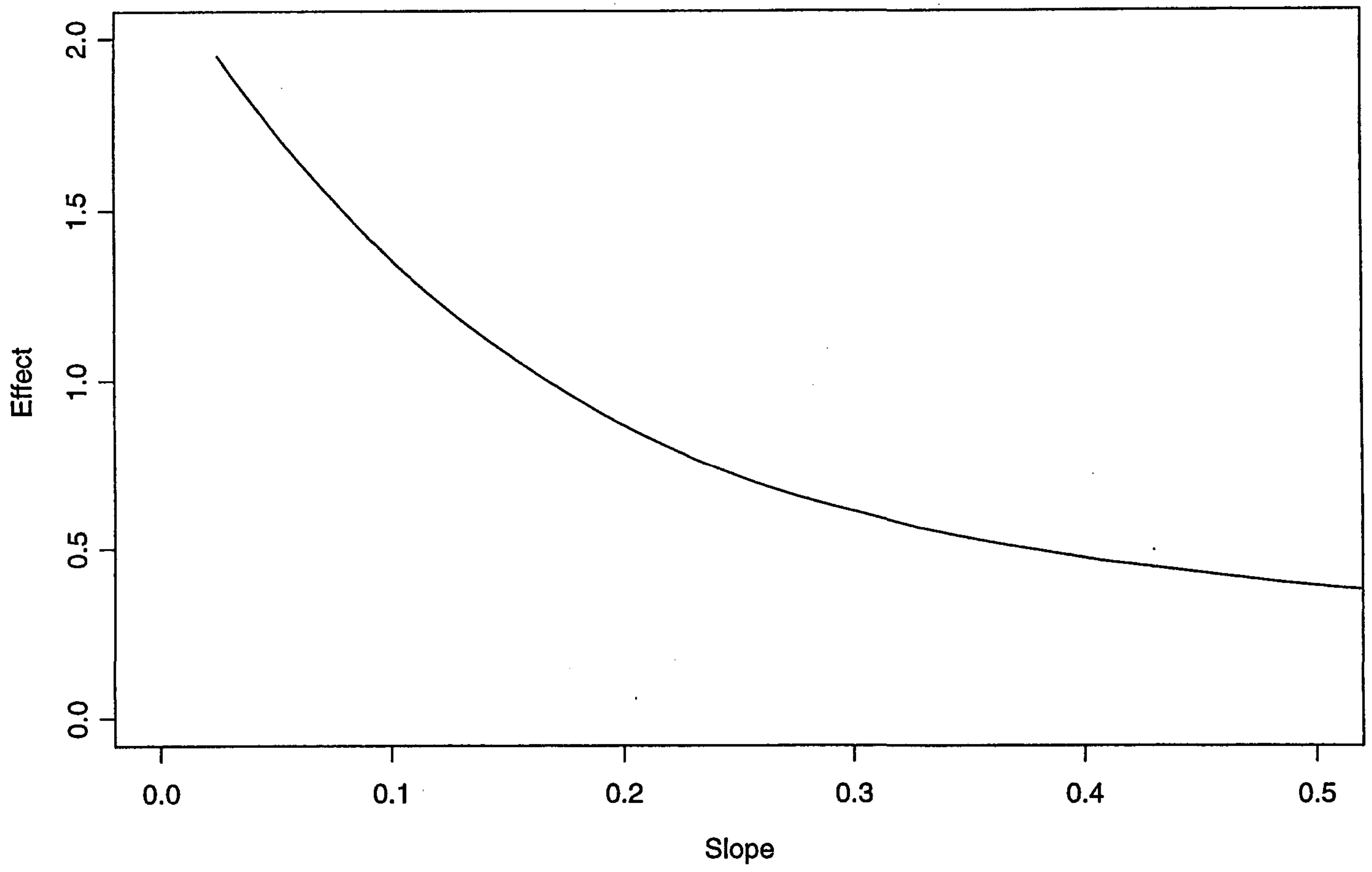

Figure 13: Effect of the slope of a seamount on biomass. The value of the curve indicates the relative abundance of orange roughy on seamounts of that slope, all else being equal. The x-axis is restricted to the range of slopes in which most of the dataset lies. Note that a "slope index" of 0.1 is about 6°, and 0.5 is 27°.

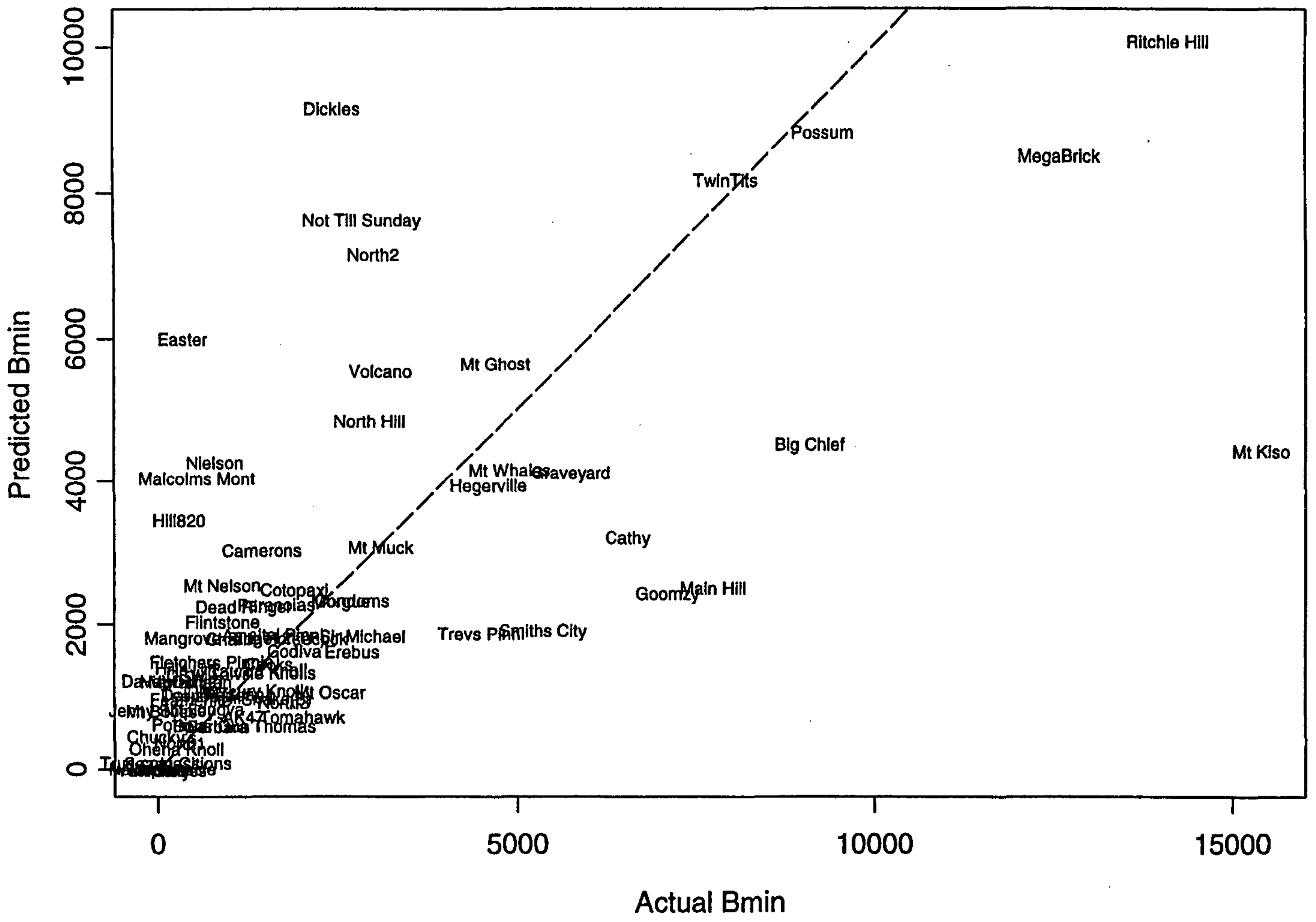

Figure 14: Predictions vs. actual values in the individual seamounts model. The dashed line indicates accurate predictions: points to the right of the line are underestimates, typically hills with biomass substantially above those of the other seamounts in their region. Points to the left are overestimates.

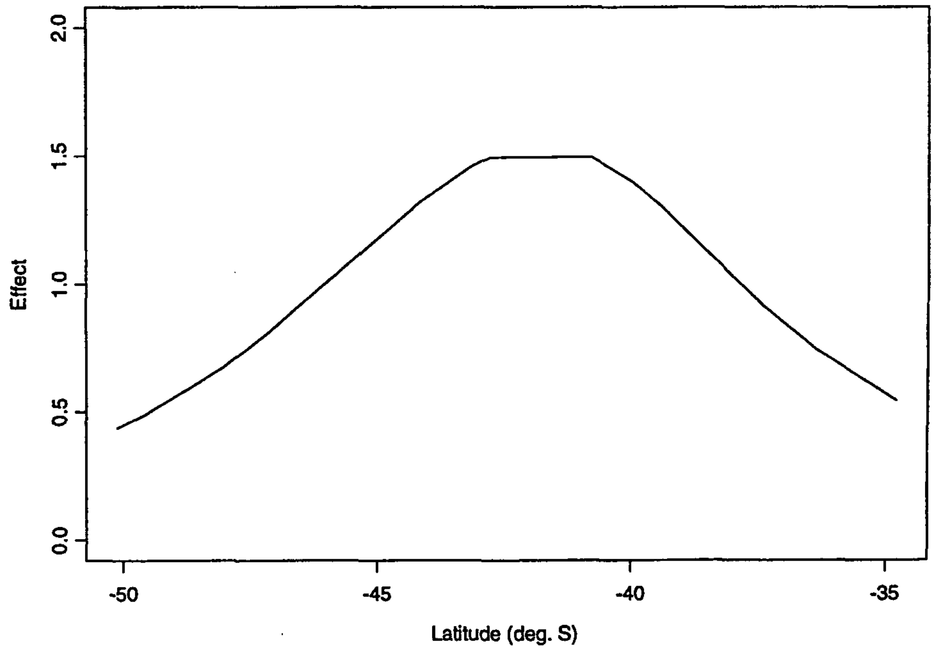

Figure 15: Effect of latitude on orange roughy abundance by region. The value of the curve indicates the relative abundance of orange roughy at that latitude, all else being equal. The x-axis is restricted to the range of latitudes in which most of the dataset lies.

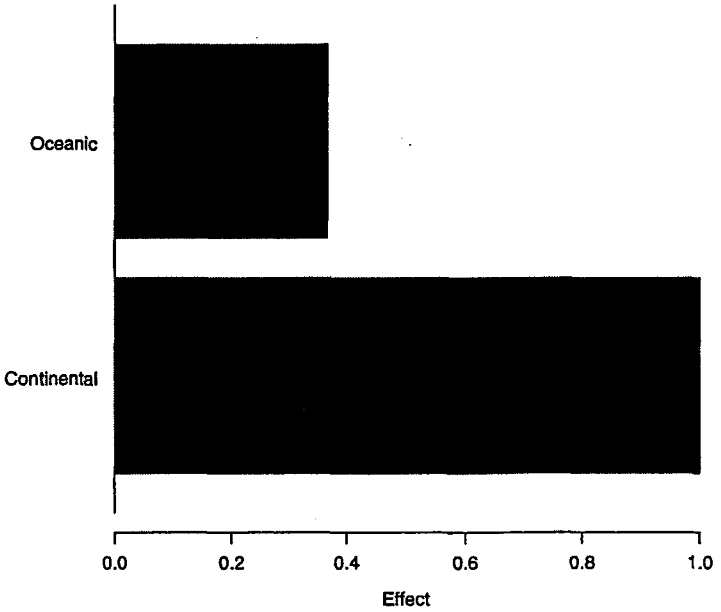

Figure 16: Effect of association on orange roughy abundance by region. The length of the bar indicates the relative abundance of orange roughy, all else being equal.

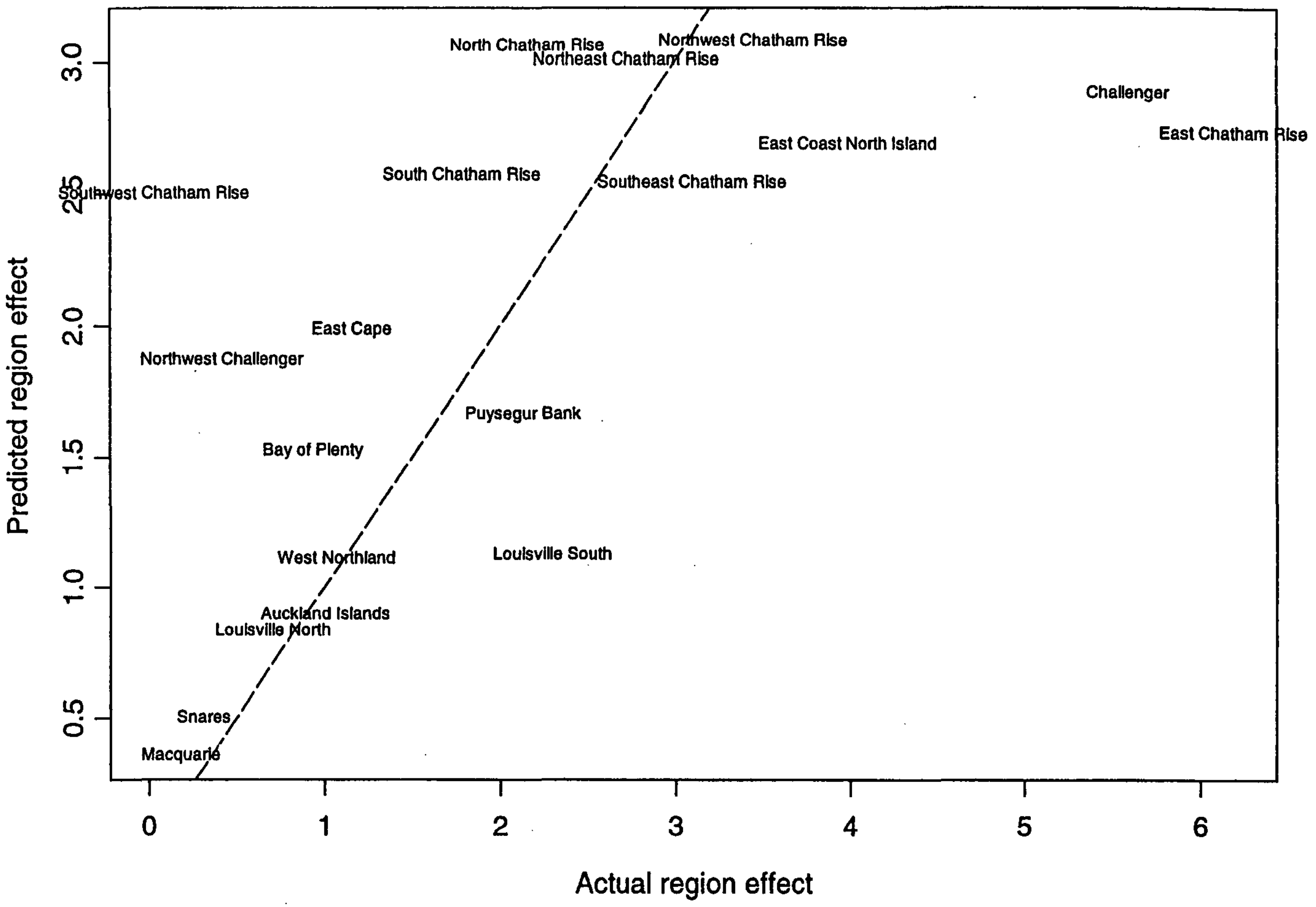

Figure 17: Predictions vs. actual values in the regions model. The dashed line indicates accurate predictions: points to the right of the line are underestimates, to the left overestimates.

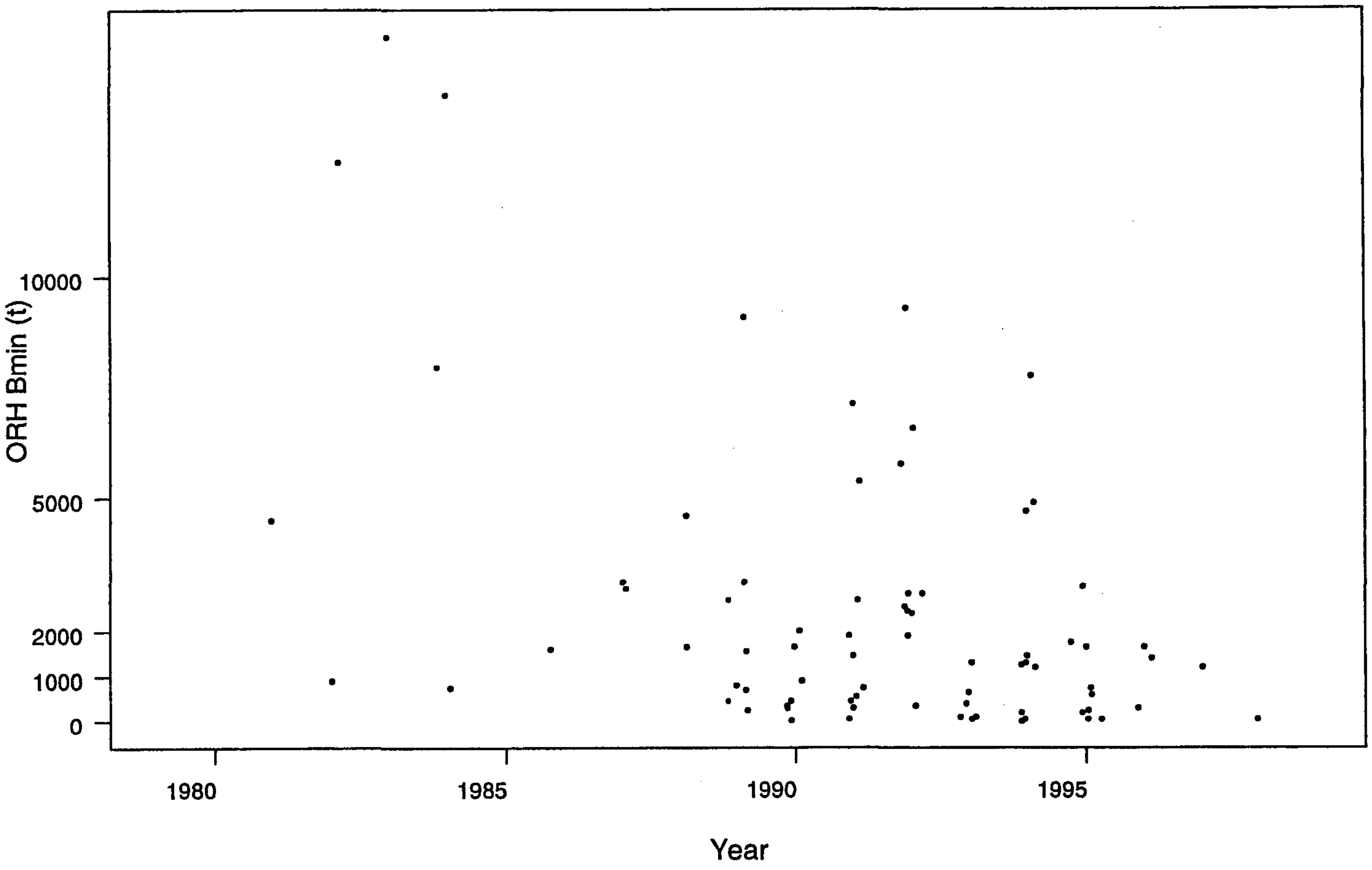

Figure 18: Plot of estimated Bmin against year of first fishing of seamounts.

Appendix 1: Dataset used in this study.

		ORH			area	depths (m)		elevation			spawning level		
Region	**name**	**Biomass**	**lat**	**long**	**(km2)**	**top**	**base**	**(m)**	**association**	**origin**	**Percent**	**region**	**seamount**
Aucklands	DSW	400	-50.050	165.974	14	830	1200	370	continental	volcanic	39	medium	
Aucklands	Barbara Thomas	1300	-50.083	165.914	8	989	1300	311	continental	volcanic		medium	
Aucklands	Jenny Shipley	50	-50.107	165.989	2	859	1100	241	continental	volcanic		medium	
Aucklands	AK47	1200	-50.222	165.850	5	859	1300	441	continental	volcanic		medium	
Bay of Plenty	Mercury Knoll	1300	-36.522	176.516	40	906	1250	344	continental	non-volcanic	83	high	
Bay of Plenty	Colville Knolls	1450	-36.164	176.793	35	735	1700	965	continental	non-volcanic	82	high	
Bay of Plenty	Ohena Knoll	250	-36.417	176.953	3	858	1700	842	continental	volcanic	82	high	
Challenger	MegaBrick	12600	-40.068	167.980	3	833	950	117	continental	volcanic	91	high	
Challenger	TwinTits	7950	-40.055	167.982	2	790	950	160	continental	volcanic	92	high	
Challenger	Volcano	3100	-39.807	167.247	3	933	1050	117	continental	volcanic		high	
East Cape	Dave's Hill(2)	200	-37.524	179.359	10.4	930	1100	170	continental	non-volcanic		high	
East Cape	Hill3	600	-37.661	179.255	37.7	930	1130	200	continental	non-volcanic	95	high	
East Cape	Hill4	200	-37.700	179.172	8.1	854	1120	266	continental	non-volcanic		high	
East Cape	Hill7	750	-37.842	179.185	18	956	1200	244	continental	non-volcanic	63	high	lower
East Cape	Snake(8)	1650	-37.940	179.071	6.5	914	1200	286	continental	non-volcanic		high	
East Cape	Ridge12(TP)	1650	-37.391	178.615	17.1	765	1250	485	continental	non-volcanic		high	
East Cape	Main Hill	7750	-37.683	179.386	42.8	742	1200	458	continental	non-volcanic	88	high	
East Chatham Rise	Possum	9300	-44.217	185.552	13.4	735	1350	615	continental	volcanic	2	low	
East Chatham Rise	Cotopaxi	1900	-44.165	185.555	2.8	937	1400	463	continental	volcanic	8	low	
East Chatham Rise	Sir Michael	2850	-44.185	185.598	1.5	885	1500	615	continental	volcanic	8	low	
East Chatham Rise	Dickies	2450	-44.125	185.430	6	643	1250	607	continental	volcanic		low	
East Chatham Rise	Cathy	6550	-44.178	185.493	1.5	911	1200	289	continental	volcanic	35	low	higher
East Chatham Rise	Not Till Sunday	2850	-43.854	185.700	5.5	742	1200	458	continental	volcanic	41	low	higher
East Coast North Island	Ritchie Hill	14100	-39.469	178.413	13	709	950	241	continental	non-volcanic	68	medium	
East Coast North Island	North Hill	2950	-39.358	178.452	10.3	833	1200	367	continental	non-volcanic	47	medium	
Louisville North	North2	3000	-38.441	191.905	5000	247	4000	3753	oceanic	volcanic		medium	
Louisville North	North3	1750	-39.212	192.329	4682.8	878	4530	3652	oceanic	volcanic		medium	
Louisville North	North1	300	-37.564	190.853	1800	1035	4648	3613	oceanic	volcanic		medium	

Appendix 1: *(cont'd)*

Louisville South	Mt Whales	4900	-40.872	194.935	350	662	4000	3338	oceanic	volcanic		medium	
Louisville South	Mt Ghost	4700	-40.700	194.654	550	620	4000	3380	oceanic	volcanic		medium	
Macquaries	Searle City	100	-49.148	164.313	3	802	1400	598	oceanic	non-volcanic		low	
Macquaries	Jackos	50	-50.024	163.700	2	927	1800	873	oceanic	non-volcanic		low	
North Chatham Rise	Mt Muck	3100	-42.844	183.094	1	700	900	200	continental	volcanic	96	high	
Northeast Chatham Rise	Smiths City	5350	-42.960	185.580	3	894	1200	306	continental	volcanic	70	medium	
Northeast Chatham Rise	Camerons	1450	-43.133	185.737	2.4	784	1060	276	continental	volcanic	72	medium	
Northeast Chatham Rise	Erebus	2700	-43.178	186.160	6.3	979	1300	321	continental	volcanic	22	medium	lower
Northeast Chatham Rise	Easter	350	-43.145	185.533	6.6	668	1000	332	continental	volcanic		medium	
Northeast Chatham Rise	Hill820	300	-43.083	185.472	2.4	820	1000	180	continental	volcanic		medium	
Northwest Challenger	Mt Longva	650	-37.346	168.051	8	662	1075	413	continental	volcanic		medium	
Northwest Challenger	Mt Boyes	50	-37.484	167.684	3	595	960	365	continental	volcanic		medium	
Northwest Challenger	Mt Oscar	2400	-37.304	167.262	5	566	950	384	continental	volcanic		medium	
Northwest Chatham Rise	Dead Ringer	1200	-42.738	180.310	1.4	820	1150	330	continental	volcanic	42	medium	
Northwest Chatham Rise	Morgue	2550	-42.717	180.040	2.6	890	1200	310	continental	volcanic	47	medium	
Northwest Chatham Rise	Graveyard	5750	-42.762	180.010	3.2	748	1100	352	continental	volcanic	74	medium	higher
Puysegur	Mt Duncan	450	-47.310	165.814	19	864	2000	1136	continental	non-volcanic		medium	
Puysegur	Porirua	300	-47.350	165.792	7	922	2000	1078	continental	non-volcanic		medium	
Puysegur	Godiva	1900	-46.916	165.450	7	964	1200	236	continental	non-volcanic	59	medium	
Puysegur	Malcolms Mont	550	-47.100	165.621	21	740	1200	460	continental	non-volcanic	69	medium	
Puysegur	Goomzy	7100	-46.963	165.415	17	946	1050	104	continental	non-volcanic	69	medium	
South Chatham Rise	Fletchers Pinnie	750	-44.229	179.204	0.5	920	1000	80	continental	volcanic		low	
South Chatham Rise	Mt Nelson	900	-44.282	179.871	1.5	830	930	100	continental	volcanic		low	
South Chatham Rise	Trevs Pinni	4500	-44.450	180.728	1.4	878	1000	122	continental	volcanic		low	
South Chatham Rise	Mt Kiso	15400	-44.432	181.280	2.7	630	850	220	continental	volcanic	0	low	
South Chatham Rise	Amaltal Pinni	1600	-44.580	182.160	2	900	1020	120	continental	volcanic		low	
South Chatham Rise	Hegerville	4600	-44.709	182.942	7.7	648	1050	402	continental	volcanic		low	
South Chatham Rise	Nielson	800	-44.725	183.216	11.2	662	1050	388	continental	volcanic		low	
South Chatham Rise	Dolly Parton	700	-44.773	183.423	3	923	1250	327	continental	volcanic		low	
South Chatham Rise	Paranoias	1650	-44.738	183.460	3.4	720	1100	380	continental	volcanic		low	

Appendix 1: *(cont'd)*

South Chatham Rise	Featherlite	450	-44.662	183.948	0.5	952	1075	123	continental	volcanic		low
South Chatham Rise	Chucky's	50	-44.870	182.973	5	1123	1450	327	continental	volcanic		low
South Chatham Rise	Hill 94	1250	-44.537	184.497	0.5	588	900	715.503	continental	volcanic		low
Southeast Chatham Rise	Big Chief	9100	-44.662	184.785	14	795	1200	405	continental	volcanic	2	low
Southeast Chatham Rise	Tomahawk	2000	-44.645	184.823	0.8	993	1320	327	continental	volcanic	0	low
Southeast Chatham Rise	Hiawatha Charlie	250	-44.722	184.745	2	974	1300	326	continental	volcanic		low
Southeast Chatham Rise	Horsecock	1650	-44.678	184.658	2.1	923	1200	277	continental	volcanic	1	low
Southeast Chatham Rise	Flintstone	900	-44.620	184.717	3	816	1300	484	continental	volcanic		low
Southeast Chatham Rise	Mangrove	350	-44.697	184.528	5.2	964	1300	336	continental	volcanic		low
Southeast Chatham Rise	Cooks	1550	-44.720	184.660	1	770	1280	510	continental	volcanic		low
Southeast Chatham Rise	Teepee	450	-44.615	184.837	2.6	990	1400	410	continental	volcanic	4	low
Southeast Chatham Rise	Condoms	2700	-44.606	184.245	1.5	860	1100	240	continental	volcanic	6	low
Snares	True confessions	100	-47.983	165.005	14	940	2000	1060	oceanic	non-volcanic		medium
Snares	Bobs Gun	750	-48.087	165.170	22	460	2000	1540	oceanic	non-volcanic	54	medium
Southwest Chatham Rise	Mt Sally	10	-44.638	176.102	1.5	813	1050	237	continental	volcanic		low
Southwest Chatham Rise	Neils pinnacle	50	-44.967	174.635	5.7	676	1000	324	continental	volcanic		low
Southwest Chatham Rise	West-Willies	0	-44.744	175.805	3	891	1050	159	continental	volcanic		low
Southwest Chatham Rise	Willies	50	-44.751	175.913	3	869	1100	231	continental	volcanic		low
West Northland	Tauroa Knoll	1400	-34.800	171.667	75	885	1350	465	continental	volcanic	67	medium

Appendix 2: List of research surveys by region and seamount from which orange roughy spawning level was estimated (June-July period only).

Seamount name by region	Voyage code	Voyage dates
Aucklands		
DSW	swa9301	1 Jul to 11 Aug 1993
Bay of Plenty		
Mercury Knoll	smt0001, smt9801, smt9501	15 to 26 Jun 2000, 15 to 28 Jun 1998, 15 to 26 Jun 1995
Colville Knolls	smt0001, smt9801, smt9501	15 to 26 Jun 2000, 15 to 28 Jun 1998, 15 to 26 Jun 1995
Ohena Knoll	smt0001, smt9801, smt9501	15 to 26 Jun 2000, 15 to 28 Jun 1998, 15 to 26 Jun 1995
Challenger		
Twin Peaks	wil9001, aex8901, aex8801	7 to 29 Jul 1990, 8 to 31 Jul 1989
MegaBrick	wil9001	7 to 29 Jul 1990
East Cape		
Main Hill	tan9708, tan9507	14 Jun to 4 Jul 1997, 9 Jun to 7 Jul 1995
Hill 3	tan9507	9 Jun to 7 Jul 1995
Hill7	tan9507	9 Jun to 7 Jul 1995
East Chatham Rise		
Possum	swa0001, tan9406, tan9206	5 to 23 Jul 2000, 2 May to 31 Jul 1994, 1 Jun to 27 Jul 1992
Not Till Sunday	swa0001, tan9406, tan9206	5 to 23 Jul 2000, 2 May to 31 Jul 1994, 1 Jun to 27 Jul 1992
Cotopaxi	swa0001, tan9406	5 to 23 Jul 2000, 2 May to 31 Jul 1994
Sir Michael / Chile	swa0001, tan9406	5 to 23 Jul 2000, 2 May to 31 Jul 1994
Cathy	swa0001	5 to 23 Jul 2000
East Coast North Island		
Ritchie Hill	gal8603, arr8701, tan9306	14 Jun to 11 Jul 1986, 15 Jun to 12 Jul 1987, 6 Jun to 8 Jul 1993
North Hill	arr8701, tan9306	15 Jun to 12 Jul 1987, 6 Jun to 8 Jul 1993
North Chatham Rise		
Mt Muck	swa0001, tan9807	5 to 23 Jul 2000, 29 Jun to 1 Aug 1998
Northeast Chatham Rise		
Camerons	swa0001, tan9807, tan9406	5 to 23 Jul 2000, 29 Jun to 1 Aug 1998, 2 May to 31 Jul 1994
Smiths City	swa0001, tan9807, tan9406	5 to 23 Jul 2000, 29 Jun to 1 Aug 1998, 2 May to 31 Jul 1994
Erebus	swa0001, tan9807, tan9406	5 to 23 Jul 2000, 29 Jun to 1 Aug 1998, 2 May to 31 Jul 1994
Northwest Chatham Rise		
Graveyard	tan9908, tan9608, aex9901, tan9708	12 Jun to 11 Jul 1999, 10 Jun to 14 Jul 1996, 22 Jun to 4 Jul 1999, 14 Jun to 4 Jul 1997
Morgue	tan9908, tan9608, aex9901, tan9708	12 Jun to 11 Jul 1999, 10 Jun to 14 Jul 1996, 22 Jun to 4 Jul 1999, 14 Jun to 4 Jul 1997
Dead Ringer	tan9908, aex9901, tan9708	12 Jun to 11 Jul 1999, 22 Jun to 4 Jul 1999, 14 Jun to 4 Jul 1997

Appendix 2: *(cont'd)*

Puysegur		
Godiva	wil9101, gil9201	14 Jun to 29 Jul 1991, 18 Jun to 1 Aug 1992
Malcolms Mont	wil9101, gil9201	14 Jun to 29 Jul 1991, 18 Jun to 1 Aug 1992
Goomzy	gil9201	18 Jun to 1 Aug 1992
South Chatham Rise		
Mt Kiso	tan9206	1 Jun to 27 Jul 1992
Southeast Chatham Rise		
Teepee	tan9406	2 May to 31 Jul 1994
Condoms	tan9406	2 May to 31 Jul 1994
Charlie Horsecock	tan9406	2 May to 31 Jul 1994
Big Chief	tan9406, tan9206	2 May to 31 Jul 1994, 1 Jun to 27 Jul 1992
Tomahawk	tan9406	2 May to 31 Jul 1994
Snares		
Bobs Gun	swa9301	1 Jul to 11 Aug 1993
West Northland		
Tauroa Knoll	sex9901	17 to 28 Jun 1999

Appendix 3: Latitude and longitude boundaries applied to define the start position of a trawl on a particular seamount

	Bay of Plenty	
Mercury Knoll	36°20' – 36°40' S	176°25' – 176°35' E
Colville Knolls	36°00' – 36°15' S	176°40' – 176°55' E
Ohena Knoll	36°22' – 36°28' S	176°54' – 177°00' E
	West Northland	
Tauroa Knoll	34°38' – 34°52' S	171°30' – 171°50' E
	East Cape	
Main hill	37°38' – 37°45' S	179°20' – 179°28' E
Daves hill (#2)	37°30' – 37°34' S	179°19' – 179°23' E
Hill #3	37°37' – 37°41' S	179°13' – 179°18' E
Hill #4	37°41' – 37°44' S	179°08' – 179°12' E
Hill #7	37°48' – 37°52' S	179°08' – 179°13' E
Snake (#8)	37°55' – 37°59' S	179°02' – 179°06' E
	East coast North Island	
Ritchie Hill	39°24' – 39°31' S	178°23' – 178°27' E
North Hill	39°18' – 39°24' S	178°25' – 178°30' E
	Northwest Chatham Rise	
Graveyard	42°44' – 42°47' S	179°58' W – 179°58' E
Morgue	42°42' – 42°44' S	179°56' – 179°59' W
Dead Ringer	42°43' – 42°45' S	179°40' – 179°43' W
	North Chatham Rise	
Mt Muck	42°49' – 42°52' S	176°53' – 176°56' W
	Northeast Chatham Rise	
Smiths City	42°56' – 43°01' S	174°21' – 174°29' W
Camerons	43°05' – 43°10' S	174°13' – 174°20' W
Erebus	43°05' – 43°15' S	173°45' – 173°55' W
Hill 820 m	43°03' – 43°07' S	174°29' – 174°34' W
Easter	43°07' – 43°11' S	174°24' – 174°29' W
	East Chatham Rise	
Not Till Sunday	43°48' – 43°54' S	174°14' – 174°22' W
Dickies	44°06' – 44°09' S	174°31' – 174°37' W
Cotopaxi	44°08' – 44°11' S	174°25' – 174°29' W
Sir Michael	44°10' – 44°13' S	174°22' – 174°25' W
Possum	44°12' – 44°15' S	174°26' – 174°31' W
Cathy	44°10' – 44°12' S	174°29' – 174°32' W
	Southeast Chatham Rise	
Hill 94	44°30' – 44°35' S	175°26' – 175°34' W
Condoms	44°34' – 44°38' S	175°42' – 175°48' W
Mangrove	44°40' – 44°44' S	175°25' – 175°31' W
Teepee	44°36' – 44°38' S	175°08' – 175°12' W
Big Chief (incl. LC)	44°39' – 44°42' S	175°11' – 175°15' W
Tomahawk	44°38' – 44°39' S	175°09' – 175°11' W
Charlie Horse	44°39' – 44°42' S	175°19' – 175°22' W
Cooks	44°42' – 44°45' S	175°19' – 175°23' W
Flintstone	44°35' - 44°38' S	175°15' – 175°19' W
Hiawatha	44°42' – 44°45' S	175°13' – 175°18' W

Appendix 3: *(cont’d)*

Southern Chatham Rise

Fletchers	44°10’ – 44°18’ S	179°08’ – 179°16’ E
Nelson	44°12’ – 44°22’ S	179°48’ – 179°59’ E
Trevs Pinnie	44°22’ – 44°30’ S	179°09’ – 179°26’ W
Mt Kiso	44°20’ – 44°30’ S	178°34’ – 178°54’ W
Amaltal Pinnie	44°30’ – 44°40’ S	177°40’ – 178°00’ W
Hegerville	44°40’ – 44°45’ S	177°00’ – 177°07’ W
Nielsen	44°41’ – 44°46’ S	176°44’ – 176°49’ W
Paranoias	44°42’ – 44°45’ S	176°29’ – 176°36’ W
Dolly Parton	44°45’ – 44°48’ S	176°32’ – 176°37’ W
Featherlite	44°38’ – 44°41’ S	176°01’ – 176°05’ W
Chuckys	44°50’ – 44°55’ S	176°58’ – 177°05’ W

Southwest Chatham Rise

Willies	44°43’ – 44°47’ S	175°53’ – 175°57’ E
West-Willies	44°43’ – 44°46’ S	175°47’ – 175°50’ E
Neils Pinnie	44°55’ – 45°00’ S	174°33’ – 174°43’ E
Mt Sally	44°36’ – 44°40’ S	176°01’ – 176°04’ E

Puysegur Bank

Godiva	46°54’ – 46°56 S	165°26’ – 165°29’ E
Goomzy	46°56’ – 46°59’ S	165°23’ – 165°27’ E
Malcolms Monument	47°03’ – 47°10’ S	165°33’ – 165°40’ E
Duncan	47°15’ – 47°20’ S	165°45’ – 165°53’ E
Porirua	47°20’ – 47°24’ S	165°44’ – 165°52’ E

Snares

Bobs Gun	47°57’ – 48°12’ S	165°05’ – 165°15’ E
True confessions	47°57’ – 48°01’ S	164°58’ – 165°03’ E

Auckland Is

D.S.W.	50°01’ – 50°04’ S	165°56’ – 166°01’ E
Barbara Thomas	50°04’ – 50°07’ S	165°52’ – 165°58’ E
Jenny Shipley	50°05’ – 50°08’ S	165°58’ – 166°01’ E
AK47	50°12’ – 50°20’ S	165°45’ – 165°55’ E

Macquarie Ridge

Searle City	49°02’ – 49°20’ S	164°10’ – 164°30’ E
Jackos	49°50’ – 50°05’ S	163°35’ – 163°55’ E

Challenger Plateau

Megabrick/Twin T	40°00’ – 40°07’ S	167°55’ – 168°03’ E
Volcano	39°47’ – 39°50’ S	167°13’ – 167°17’ E

Northwest Challenger Plateau

Mt Oscar	37°16’ – 37°21’ S	167°13’ – 167°19’ E
Mt Boyes	37°27’ – 37°31’ S	167°38’ – 167°44’ E
Mt Longva	37°18’ – 37°23’ S	168°00’ – 168°06’ E

Louisville Ridge

Mt Ghost	40°37’ – 40°48’ S	165°12’ – 165°32’ W
Mt Whales	40°48’ – 41°01’ S	164°58’ – 165°10’ W
North 1	37°50’ – 38°05’ S	168°10’ – 168°25’ W
North 2	38°15’ – 38°40’ S	167°35’ – 168°15’ W
North 3	39°00’ – 39°20’ S	167°10’ – 167°40’ W