Dynamics of Marine Fish Assemblages in Hecate Strait, British Columbia

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ABSTRACT

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Data was analysed from the Hecate Strait assemblage surveys conducted between 1984 and 2003. The results supported earlier analyses and indicated that three distinct fish assemblages were present over the depth range of 20-220 metres. The assemblages persisted over time with little bathymetric variation. The dominant species components of the assemblage included regular species, present year round, seasonal species, present seasonally and transient species, moving among assemblages. Diversity, species richness and evenness changed very little over the study period. Depth was a prominent feature of all of the Assemblages. The shallowest assemblage, Reef Island, had a median depth of 45 meters with the biomass dominated by spotted ratfish, rock sole, spiny dogfish, Pacific halibut and big skate. The intermediate assemblage, Bonilla, had a median depth of 74 meters and English sole, spotted ratfish, spiny dogfish, arrowtooth flounder and Pacific sanddab were dominant proportions of the biomass. The deepest assemblage, Butterworth, had a median depth of 101 meters and arrowtooth flounder, English sole, spotted ratfish, Dover sole and rex sole were the dominant components. Diversity, species richness and evenness metrics changed very little over the study period although species relative abundance changed over time. The assemblages defined here appear to be useful units for multispecies stock assessments for the region.

RÉSUMÉ

Fargo, J.J. 2012. Dynamics of marine fish assemblages in Hecate Strait, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 2996: iv + 65 p

Les données des relevés des assemblages dans le détroit d'Hécate effectués entre 1984 et 2003 ont été analysées. Les résultats ont corroboré les analyses précédentes et ont indiqué que trois assemblages de poissons distincts étaient présents à des profondeurs de 20 à 220 m. Les assemblages ont résisté au cours du temps, ne présentant qu'une faible variation dans les données bathymétriques. Les espèces dominantes de l'assemblage étaient les espèces habituelles, les espèces présentes à longueur d'année, les espèces saisonnières, les espèces présentes de manière saisonnière et les espèces de passage se déplaçant parmi les assemblages. La diversité ainsi que la richesse et l'uniformité des espèces ont très peu changé au cours de la période à l'étude. La profondeur était une caractéristique importante de tous les assemblages. L'assemblage le moins profond, celui de l'île Reef, était situé à une profondeur moyenne de 45 m, où la biomasse était dominée par la chimère d'Amérique, la fausse limande, l'aiguillat commun, le flétan du Pacifique et la raie biocellée. L'assemblage intermédiaire de la pointe Bonilla, lui, était situé à une profondeur moyenne de 74 m où la sole anglaise, la chimère d'Amérique, l'aiguillat commun, la plie à grande bouche et la limande sordide étaient les espèces dominantes dans la biomasse. L'assemblage le plus profond, celui de Butterworth, était quant à lui situé à une profondeur moyenne de 101 m et la plie à grande bouche, la sole anglaise, la chimère d'Amérique, la limande-sole et la plie royale étaient les espèces dominantes de la biomasse. Les paramètres relatifs à la diversité ainsi qu'à la richesse et à l'uniformité des espèces ont très peu changé au cours de l'étude même si l'abondance relative des espèces a changé au cours du temps. Les assemblages décrits ici semblent constituer des unités utiles pour l'évaluation des stocks de bon nombre d'espèces dans la région.

INTRODUCTION

In recent years scientists have increasingly focused on species interactions and environmental influence with primary consideration of the structure and function of a marine ecosystem in addition to sustainable fishing yields (Pikitch et al. 2004) (Table 1). Pauly and Christensen (2002) predict that if fisheries management does not progress towards incorporating ecosystem consideration the structure of the ecosystem can be altered irreversibly as in the case of the trophic cascades observed after top predators are eliminated by commercial fisheries.

A study of the Hecate Strait ecosystem began in April of 1984 with the primary objective of conducting research into the ecological basis for multispecies stock assessment for that region. The research was jointly carried out by the Pacific Biological Station in Nanaimo, B.C. and the Institute of Ocean Sciences in Sidney, B.C. on Vancouver Island. The fishery in Hecate Strait targets approximately 45 species taken by various gear types. The fishery is small on a world scale but this lends itself to modelling as many of the physical processes occur on a geographically tractable scale and the groundfish fleet size over time has included less than 50 vessels (Tyler 1989).

One of the sub projects was related to analysis and distribution of demersal fish assemblages using research survey data. Commensurate with this the multispecies groundfish Species Assemblage Research Survey was initiated in 1984 and continued through 2003. The catch rate data from those surveys are the focus of this report. Information on diet of fish species in the Strait was also collected on the surveys and those data were investigated using a mass balance approach (Pearsall and Fargo 2007).

A total of 12 systematic bottom trawl surveys of Hecate Strait were conducted by the Pacific Biological Station (Fargo et al. 1990, Tyler 1989) between 1984 and 2003. Survey haul locations are summarized in Figure 1. The fishing gear used for all surveys was a Yankee 36 trawl net. The survey design has been summarised by Fargo et al. (1990). Briefly, haul locations were arrayed over a grid of 19 km^2 (10 nm^2) blocks, with an attempt made to establish one trawl site within each 18 m depth interval within each block. The 1984 survey involved one chartered and one research vessel, while all other surveys were single-vessel surveys. A survey in winter was conducted in 1986. The summer surveys provide synoptic data that can be used to map fish assemblages available to bottom trawlers, and to provide an index of relative abundance indices for species inhabiting the region. To date only data from the first three surveys has been analysed (Fargo and Tyler 1991).

This report summarises the results of analysis for all summer Species Assemblage Surveys from 1984 -2003. It focuses on the distribution of fish assemblages, the physical and biological characteristics associated with them and their change in structure over time. It includes a summary of the ecosystem metrics associated with the region along with an evaluation of their utility.

METHODS

DATA

Species catch composition data were the basis for a cluster analysis to characterize demersal fish assemblages in the Strait. Data for each survey were analysed independently in the following way: 1. Species composition data for usable stations (trawl sites with no mishaps) were converted to species percentage composition by weight. For the two-vessel survey (1984), the data sets were combined. 2. The data was then analysed using an agglomerative clustering technique, where individual stations represented collections (entities) and species catch composition represented attributes. Cluster analysis was used to group sites into geographic areas with relatively homogeneous species composition. We rejected the reverse clustering of species that would group those species that occurred together in relatively equal proportions among sites since this technique ignores the fact that ubiquitous species should be classified as part of more than one assemblage. We preferred the alternative of examining and comparing the composition of the dominant species within clusters of sites, where sites are grouped by relatively similar percentage species composition. Previous studies have shown that fairly homogeneous habitat areas can be delineated by clustering the sites, and that a list of the species tending to cohabit will result (Gabriel & Tyler 1980, Gomes et al. 1989, Overholtz & Tyler 1985). We define the dominant species as collectively, making up at least 90% of the biomass of any assemblage.

CLUSTER ANALYSIS

A general question facing researchers in many areas of inquiry is how to organize observed data into meaningful structures. Cluster analysis (first used by Tyron 1939) is an exploratory data analysis tool which aims at sorting different objects into groups in a way that the degree of association between two objects is maximal if they belong to the same group and minimal otherwise. Cluster analysis simply discovers structures in data without explaining why they exist. Discussions of the results refer to clustering algorithms and do not mention statistical significance testing. In fact, cluster analysis is a collection of different algorithms that put objects into clusters according to well defined similarity rules. Unlike many other statistical procedures, cluster analysis methods are mainly used when we do not have any a priori hypotheses. In that sense, cluster analysis finds the most significant solution possible. Therefore, statistical significance testing is really not appropriate.

Cluster analysis in this study was carried out according to the following procedure. First, a Bray-Curtis dissimilarity coefficient was calculated for each pair of sites then clustering was based on a group average fusion strategy. A dendrogram was produced for each analysis showing the dissimilarity level among sites. The software used for the cluster analysis was an R language function calling the agglomerative nesting routine AGNES. The starting point for this analysis was a data matrix consisting of n rows of samples (stations) and p columns of variables (species) with individual values representing the proportion of the catch of each haul represented for each species caught, called an n x p (n by p) matrix for each survey. A matrix of dissimilarity was then calculated among sites.

The Bray-Curtis index is a modified Manhattan measurement where the summed differences between the variables are standardised by the summed variables of the objects. The general equation of the Bray-Curtis dissimilarity is:

$$d^{BCD}(i, j) = \frac{\sum_{k=0}^{n-1} \left| y_{i,k} - y_{j,k} \right|}{\sum_{k=0}^{n-1} (y_{i,k} + y_{j,k})}$$

In the equation above, d^{BCD} is the Bray-Curtis dissimilarity between the objects *i* and *j*, *k* is the index catch proportion and *n* is the total number of samples (stations) *y*. The Bray-Curtis dissimilarity index is bounded between 0 and 1, where 0 means the two sites have the same composition (that is they share all the species), and 1 means the two sites do not share any species.

Using this approach samples (stations) all start out as individuals, and the two samples most similar (or least dissimilar) are fused to form the first cluster. Subsequently, samples are continually fused one-by-one in order of highest similarity (or equivalently lowest dissimilarity) to the sample or cluster to which they are most similar. The hierarchy is determined by the cluster at a height characterized by the similarity at which the samples fused to form the cluster. Eventually, all samples are contained in the final cluster at similarity 0.0 or dissimilarity of 1.0.

After the dissimilarity matrices were computed for each survey, clustering was done via the group-average method (UPGMA (Unweighted Pair Group arithiMetric Average) (Kaufman, L. and Rousseeuw, P.J. (1990). For the group average version of hierarchical clustering, the proximity of two clusters is defined to be the average of the pairwise proximities between all pairs of points in the different clusters. This is expressed by the following equation:

$$proximity(cluster1, cluster2) = \frac{\sum_{\substack{p1 \in cluster1 \\ p2 \in cluster2}} proximity(p1p2)}{(size(cluster1))(size(cluster2))}$$

(Steinbach, M. 2000)

DENDROGRAMS

Fargo & Tyler (1991) used a previously defined rockfish assemblage adjacent to the survey area to assist in interpretation of the dendrograms. The deep-water rockfish complex in Moresby Gully, in southern Hecate Strait is considered to be a discrete group based on biological and geographic characteristics (Leaman & Nagtegaal 1987). The cluster for this group of species joined with other major clusters in the dendrograms at dissimilarity levels ranging from 0.65 to 0.77, and values within this range were subsequently used to interpret the dendrograms for the period 1984-2003.

Dendrograms were also compared to Non-metric multidimensional scaling (nMDS) ordination plots to determine if assemblages were geographically distinct and persistent through time (Tyler and Gabriel 1982, Overholtz and Tyler 1985, Gabriel 1992; Gomes et al. 2001, Jørgensen et al. 2005; Duffy-Anderson et al. 2006).

CPUE ANALYSIS

Bootstrapped mean catch rates were computed for the species components of each assemblage as indicated by the following formula (Fargo et al. 1991).

$$U_{ij} = (\sum_{k=1}^{n} C_{ik} / E_{ik})$$

where:

U_{ij} is the mean CPUE in kg·hr-1 for species *i* in assemblage *j* and C_{jk} is the weight of species *i* (kg) in haul *k* for assemblage *j*, E_{ik} is the effort expended to catch species *i* in haul *k* for assemblage *j, k* is a vector representing the individual stations in assemblage *j* and *n* is the total number of stations in assemblage *j*.

ECOLOGICAL METRICS

Diversity, species richness and evenness were estimated within and among assemblages. Shannon's diversity index (Pielou 1977) was calculated as follows:

$$diversity = 1 - \sum_{i=1}^{S} P_i \ln(P_i)$$

where:

S is the number of species and P_i is the proportion of the sample comprised of species *i*. The index takes on values from 0 (the entire sample consists of only one species) to a maximum of ln S for a given S. Diversity increases as species number increases and dominance decreases. The index is not directly sensitive to density, since it is based on proportionalized data. Diversity is considered here as a single statistic and the number of species and the evenness of the histogram of species' biomass proportions are confounded. Thus, an assemblage with few species and high evenness could have the same diversity as another assemblage with many species and low evenness. We therefore examined species richness and evenness for each assemblage in addition to diversity.

Species 'richness', S^*, for each assemblage was equal to the number of fish species present in the data. The 'evenness', of the distribution of individuals among the assemblages was estimated using the following equation (Pielou 1977):

$$V' = H'/\ln S^*$$

where:

V' is a measure of evenness, H' is Shannon's diversity index for an assemblage and S^* is the number of species present in an assemblage.

It is useful to assess the total species richness of the study area as a measure of the completeness of the species inventory and this was done as well. One method to estimate total species richness or maximum number of species present in an ecosystem, S_{max}, is derived from a species accumulation curve (Simberloff 1972). This is a cumulative curve of the number of new species encountered in relation to the sampling effort. S_{max} is equivalent to the asymptote of the curve assuming that the sampling effort was adequate. An alternative to these computations is a simple but reliable non-parametric method that has been shown to be effective on fish communities; the Chao 2 index (Chao 1984) which can be calculated from the following formula:

$$S_{max} = S_{obs} + (a^2/2b)$$

where:

S_{obs} is the number of species caught, *a* is the number of species only found in one sample and *b* is the number of species only found in two samples (Chao 1984).

RESULTS

CLUSTER ANALYSIS

Dendrograms for each survey are depicted in Figures (2-12). Species assemblages classified from the dendrograms were named after prominent landmarks in their geographic areas. The different colours for the legs of the dendrograms represent corresponding species percent composition for clustered sites. The labels at the bottom of each dendrogram leg indicate the specific geographical trawling site. The height of the dendrogram legs represents the level of dissimilarity between sites. Thus sites that cluster out at a height of 0.2 are less dissimilar than sites clustering out at a height of 0.6.

Dendrogram legs in black represent sites that could not be classified at the chosen dissimilarity level. Many of these represent species composition that is intermediate to two assemblages. This relates to the gradual transition from one assemblage to another near boundaries where species composition blurs and components of more than one assemblage occur. It is also characteristic of the bathymetry in Hecate Strait which does not follow even lines but can vary somewhat during a trawling operation. In some cases, 1984, 1989, 2000, for instance clusters for one assemblage are not adjacent to one another in the dendrogram. This was due to the fact that although the species composition was similar the relative percentage of species components differed. Fargo and Tyler (1991) noted this in their analysis as well.

Four clusters appear in the dendrogram for 1984, one each for Butterworth and Bonilla and two for Reef Island. The two for reef Island are not adjacent. This may partially reflect different catchability coefficients for the two vessels. Reef Island and Bonilla are more closely related than other combinations. Butterworth assemblage contains the fewest haul stations while the rest are evenly split between Reef Island and Bonilla.

In the dendrogram for 1987, there are three clusters, one for each assemblage. There are also several long legs in the dendrogram that lie between the Bonilla assemblage and the Reef Island assemblage. The species composition here reflected both assemblages. Reef Island and Bonilla appear to be more closely related than other combinations. Trawling sites are fairly evenly split among assemblages.

The dendrogram for 1989 shows three distinct clusters at the 0.75 dissimilarity level. Each of these represents a different assemblage. The long legs in black adjacent to the Reef Island assemblage contain catches with a low number of species that were difficult to classify. Butterworth and Bonilla are more closely related than other combinations. This was due to the presence of turbot in the catches of both assemblages. Bonilla and Butterworth contain the most stations while Reef Island contains the fewest.

The clusters in the dendrogram for 1991 represent all three assemblages at the 0.7 dissimilarity level. The Butterworth assemblage represents more stations than either of the other two assemblages and Butterworth and Bonilla are more closely related as in 1989. The Butterworth assemblage is represented by the highest number of stations while Bonilla contains the fewest.

For 1993 and 1995 three distinct groups are clustered at the 0.7 dissimilarity level. Reef Island and Bonilla are more closely related than other combinations in 1993. Butterworth contains the most stations in 1993 and Reef Island the most in 1995. Bonilla contains the fewest stations in both surveys and is smaller than in previous years.

In 1996, Butterworth and Bonilla are most closely related while Reef Island represents the most stations and Bonilla the least. In 1998 Butterworth is clustered at the lowest dissimilarity level while Reef Island and Bonilla do no fall out until a dissimilarity level of 0.78. Reef Island Bonilla are most closely related. Butterworth contains the most stations.

In 2000 the Bonilla assemblage is represented by split clusters. Bonilla and Reef Island are most closely related. Butterworth contains the highest number of stations. In 2002 Bonilla and Reef Island assemblages are most closely related and haul stations are more evenly split between assemblages than for any other year's survey. In 2003 Bonilla and Butterworth assemblages are most closely related. Bonilla assemblage is composed of the fewest stations while the rest of the stations are evenly split between Reef Island and Butterworth.

FISH ASSEMBLAGES

Fargo and Tyler (1991) defined three fish assemblage groups with characteristic depth ranges and geographical boundaries. The results of this analysis corroborated the results of their analysis (Figures 13 and 14). Geographic boundaries were stable among years and the list of dominant species remained stable as well.

In the Reef Island assemblage Pacific cod, Pacific halibut, rock sole, spiny dogfish and spotted ratfish were all rank 1 species over time (Figure 15). Rock sole was the Rank 1 species in 1989, 1993, 1995 and 2000, accounting for 29%, 24%, 18% and 30% of the biomass, respectively. Pacific halibut was the Rank 1 species in 1991 and 1998, accounting for 23% and 22% of the biomass, respectively. Spiny dogfish was the Rank 1 species in 1984 and 2002, accounting for 43% and 31% of the biomass, respectively. Spotted ratfish was the rank 1 species in 1996 and 2003, accounting for 26% and 42% of the biomass, respectively. Pacific cod was the rank 1 species in 1987, accounting for 52% of the biomass. Spotted ratfish and Pacific cod are transient species, occurring in all three assemblages and spiny dogfish is a seasonal (summer) species in this assemblage. Rock sole and spotted ratfish accounted for 38% of the total biomass of this assemblage for (Figure 16).

Arrowtooth flounder was the rank 1 species in the Butterworth assemblage in all years except 1993 when English sole was the rank 1 species, accounting for 32% of the biomass (figure 17). Arrowtooth flounder accounted for 43%, 58%, 54%, 45%, 37%, 46%, 28%, 40%, 36% and 49% of the biomass in 1984-1991 and 1995-2003. Arrowtooth flounder accounted for 39% of the total biomass in this assemblage while English sole, spotted ratfish, Dover sole accounted for 10% each and rex sole for 9% of the biomass. Spiny dogfish was a seasonal component, accounting for 5% of the biomass overall (figure 18).

Rank 1 species in the Bonilla assemblage were; English sole accounting for 35%, 46%, 45% and 32% of the biomass in 1984, 1989, 1991 and 2003(figure 19). Spiny dogfish accounted for 48%, 60% and 35% of the biomass in 1987, 1993 and 1998, arrowtooth flounder for 25% of the biomass in 1995, walleye pollock for 26% of the biomass in 1996 and spotted ratfish for 33% and 36% of the biomass in 2000 and 2002. English sole accounted for 24% of the total biomass, spotted ratfish for 13%, spiny dogfish for 11%, arrowtooth flounder for 8%, Pacific sanddab, rex sole and Pacific cod for 6% each, spiny dogfish for 5% and walleye pollock for 4% (Figure 20). Walleye pollock and spotted ratfish were transient components in this assemblage while spiny dogfish was a seasonal component. Biomass proportion of by assemblage for dominant species components is presented in figure 21. Arrowtooth flounder is dominant in both the Butterworth and Bonilla assemblages but its presence in the Bonilla assemblage consisted mainly of juveniles. English sole, spiny dogfish and spotted ratfish are dominants in all three assemblages.

CPUE

Reef Island

CPUE was highest for spiny dogfish, Rock sole and Pacific cod although the high rate for Pacific cod was the result of one large catch in 1987 (Figure 22, Table 2). There was an increasing trend in CPUE for spotted ratfish, rock sole and sand sole and a decreasing trend for spiny dogfish, big skate, lingcod and Pacific halibut. Without the large CPUE in 1987 Pacific cod CPUE showed little trend. Rock sole showed the largest increase in CPUE from 20 kg/h in 1984 to 108 kg/h in 2003. Spiny dogfish showed the largest decrease in CPUE from 79 kg/h in 1984 to 12 kg/h in 2003. The average coefficient of variation ranged from 0.24 for rock sole to 0.56 for Pacific cod.

Boxplots of CPUE for all species (for which there was enough data) in the Reef Island assemblage provide further detail (figure 23 and 24). The lowest rates observed were those for small non-schooling species like poachers and sculpins. Catch rates for foraging species such as shiner perch and Pacific sand lance were slightly higher. The highest rates observed were for flatfish species, specifically rock sole and Pacific halibut and elasmobranchs, big skate, spiny dogfish and spotted ratfish. Flatfish species also comprised much of the intervening distribution with the exception of Pacific herring, Pacific cod and yellowtail rockfish.

Butterworth

For the Butterworth assemblage, CPUE were highest for arrowtooth flounder and lowest for spiny dogfish (Figure 25, Table 3). There was an increasing trend for rex sole, a decreasing trend for arrowtooth flounder and spiny dogfish and no obvious trend for spotted ratfish, Dover sole and English sole. Spotted ratfish is a transient component of this assemblage while spiny dogfish is a seasonal (summer) component. The CPUE in 1993 for English sole was nearly three times that of any other in that series. The largest increase in CPUE was that for rex sole which went from 31 kg/h in 1984 to 200 kg/h in 2002. Spiny dogfish CPUE showed the largest decrease from 109 kg/h in 1984 to 13 kg/h in 2003. Average CV ranged from 0.25 for spiny dogfish to 0.34 for Dover sole. Boxplots of CPUE by species for the Butterworth assemblage are presented in Figure 26 and 27. The lowest rates observed were those for poachers, eelpouts and small foraging species. The highest rates observed were those for arrowtooth flounder, rex sole and English sole, with arrowtooth flounder dominating. The slope of the medians for species in the Butterworth assemblage is steeper than in the Reef Island assemblage indicating fewer species contribute to the total biomass of this assemblage.

Bonilla

CPUE for rex sole, Pacific sanddab and spotted ratfish increased over the period 1984-2003 (Figure 28, Table 4) but showed little trend for English sole, arrowtooth flounder and spiny dogfish. Rates were highest for English sole and lowest for Pacific sanddab and rex sole. The largest increase in CPUE occurred for spotted ratfish which went from 11 kg/h in 1984 to 181 kg/h in 2002 while the largest decrease occurred for spiny dogfish which went from 64 kg/h in 1984 to 17 kg/h in 2003. CPUE for spotted ratfish in 2000 and 2002 was more than twice as high as that for any other year in that time series. CPUE for rex sole in 2003 was more than twice as high as that for any other in that time series. Average CV for this assemblage ranged from 0.31 for spiny dogfish to 0.50 for arrowtooth flounder.

Boxplots of CPUE by species for the Bonilla assemblage are presented in Figures 29 and 30. The lowest rates observed were for small species such as sculpins, poachers, eelpouts and small foraging species. However, two flatfish species, speckled sanddab and butter sole were in this group as well. The highest rates observed were those for English sole, Pacific halibut, big skate, spiny dogfish and Pacific sanddab. Pacific sanddab is a relatively small species that appears to be quite abundant in this assemblage. The slope of the medians indicates that species contribute more evenly to the biomass of this assemblage than was observed for the other assemblages.

Depth distribution

The sequence of Boxplots in Figure 31 provides bathymetric information for 80 species including many non commercial species although it is incomplete for species at the outer limits. There is a continuous trend in median depths between 30 and 140 m. After that the trend becomes noticeably steeper indicating fewer species per unit depth and slope rockfish species begin to dominate. Flatfish species are found throughout the overall range. Shelf and inshore rockfish species are present throughout the range as well. Boxplots of depths for each assemblage are presented in Figures 32 and 33. Median depth was 45 meters for the Reef Island assemblage 74 meters for the Bonilla assemblage and 101 meters for the Butterworth assemblage.

Figure 34 contains boxplots of depth by dominant species for the combined surveys. Pacific sanddab occupied the depth range of the Bonilla assemblage almost exclusively. The shallowest depth preference was exhibited by sand sole encountered almost entirely in the Reef Island assemblage while the deepest preference was exhibited by flathead sole, split between the Butterworth and Bonilla assemblages. Sand sole, big skate, butter sole, rock sole, Pacific halibut and lingcod occupied the depth range of the Reef Island assemblage almost exclusively. English sole, spiny dogfish, Pacific cod and spotted ratfish inhabited the depths of all assemblages to some degree while Dover sole, rex sole, walleye pollock and flathead sole mainly occupied the depths of Bonilla and Butterworth assemblages. Overall, median depth overlapped for lingcod and Pacific sanddab only. The medians for all others in the Bonilla assemblage were greater than for dominant species in the Reef Island assemblage and less than for species in the Butterworth assemblage.

The relationship between mean depth and median depth vs the number of species encountered was dome-shaped (figure 35). A peak was apparent at ~60-69 meters for both. The mean depth for most species fell within a 30-140 m range. However because of the fishing gear used the depths of deepwater rockfish species were not sampled completely. Similarly, the depth range of 1 to 20 meters was not completely sampled.

ECOLOGICAL METRICS

The diversity index ranged from 2.4 to 3.5 between 1984 and 2003 (Figure 36, Table 5). There is no significant trend apparent over this time period for any of the assemblages. However annual differences in the index were as high as 63%. Species richness ranged from 28 to 56 over the time period analysed (Figure 37). The index fluctuates least in the Bonilla assemblage and most in the Butterworth assemblage. Transient species that move among assemblages as well as the distribution of species that are in the margins of their depth range is also a factor. Species richness is highest for the Butterworth assemblage and lowest for the Reef Island assemblage. The estimated maximum number of fish species present in the Hecate Strait ecosystem over a depth range of 20-220 m the Chao 2 method was 153. Hart (1972) lists ~ 150 marine fish species present over that depth range.

Evenness showed the least fluctuation of all the ecological indices indicating that the proportions of biomass are relatively constant e.g. abundance has not changed dramatically over the time period for any of the assemblages (Figure 38). The relationship between richness and evenness was inverse for Reef Island and Bonilla and proportionate for Butterworth. However none of the relationships were significant.

DISCUSSION

As mentioned previously scientists use cluster analysis mainly without a priori hypotheses. Results require close inspection to explain the grouping. Several phenomena affected the results of the cluster analysis in this case. Trawling stations near the assemblage boundaries resulted were unclassifiable or were classified as separate clusters. Stations where very few species were caught remained unclassifiable and appeared as long legs in the dendrograms. The timing of migration of important species such as spiny dogfish can produce misleading information regarding its role in assemblages. Careful examination of the results can help to avoid these problems.

Species composition and bathymetric boundaries of assemblages were relatively stable over the survey period. Historically, the abundance of English sole, rock sole and Pacific cod has exhibited dramatic fluctuations which will likely have an important effect on assemblage production. Similarly, transient species such as spiny dogfish and spotted ratfish exert an effect on all three assemblages. Given the significant proportion of the total biomass that arrowtooth flounder comprises and its position as a top predator will likely affect production in more than one assemblage.

The effect of the bottom trawl fishery in Hecate Strait is the selective removal of commercially valuable species such as Pacific cod, English sole, rock sole and Dover sole while avoiding or minimising the removal of non commercial species. This may create an advantage for the non target species and have a detrimental effect in the long term. Quotas for commercial species may need to be lowered to prevent this. To date multispecies surplus production models developed in many studies predict group quotas that are lower than the sum of individual species quotas. This type of model should be developed for Hecate Strait and the results compared with results from single species assessments. In addition, long term effects such as climate change exacerbate the need for this comparison and for a holistic approach to stock assessment.

Multispecies management takes species interactions into account and may be an improvement over single species management. It does not require the enormous amount of data that ecosystem management requires. Managers of fisheries off the coasts of Alaska and California have used a multispecies approach (Witherell *et al*. 2000; Field and Francis 2006). Managers of fisheries in Florida and the southeastern United States have recently adopted a multi-species approach as well (Pierce and Mahmoudi 2001).

Ecosystem metrics such as species diversity, richness and evenness do not appear to provide enough information about ecosystem structure for use as a management tool. However the value for species richness this area is higher than many temperate inshore ecosystems and is even impressive when compared with much large offshore ecosystems in the temperate zone (Table 6.). There will, undoubtedly, be improvements in the utility of these metrics with more research. A recent global study by Fisher et al. (2010) indicated that fish body size may act as a factor of considerable importance in mediating the relationship between global marine fish species richness and ecosystem functioning.
Over the time period of this study the relative abundance of assemblage components underwent some change while diversity was not affected. The value of this metric is limited and may occur only in the very long term. It is doubtful that management measures based on diversity alone would be appropriate. Marine ecosystems today have already been considerably perturbed by modern fisheries and long term changes in the physical environment; the latter entirely beyond our control. However, knowledge of species interactions and their effect on production is of value. In this case more information on diet is needed to examine how interactions between species change over time. This will allow us to illuminate some of the processes that operate and affect ecosystem structure and function. That insight will certainly improve our understanding of the ecosystem and by extension our management and sustainable use of this natural resource.

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Table 1. Number of fish species in recent studies of marine ecosystems

Area	Number of fish species in study	Time frame	Source data
This study	121	1984-2003	Trawl survey
Scotian shelf[1]	79	1970-2000	Trawl survey
Virgin Islands[2]	35	2000-2001	Visual survey (reefs)
North Sea[3]	90	1985-2005	Trawl survey
Georges Bank[4]	35[a]	1993-2002	Trawl survey
Florida[5]	184	1998-2002	Dive survey (reefs)
N.E. Mediterranean[6]	79	1991	Trawl survey
Australia[7]	47	2005-2006	Remote video camera
N.W. Mediterranean[8]	60	1996-1998	Trawl survey
Netherlands Antilles[9]	286	1993-1999	Dive survey
Northumberland Strait[10]	23	2001-2006	Trawl survey

[1] Shackell and Frank (2003)
[2] Gratwicke and Speight (2005)
[3] Hiddink and Hofstede (2004)
[4] Gifford, Collie and Steele (2009)
[5]Walker, Jordan, Spieler, R.E. (2009)
[6]Demestre, Sanchez and Abello (2000)
[7] Wraith (2007)
[8] Gaertner, Bertrand, Gil de Sola, Durbec, Ferrandis and Souplet (2005)
[9] Pattengill-Semmens (2002)
[10] Bosman (2005)
[a] including squid

Table 2. Mean catch rates and 90% confidence limits for dominant species in the Reef Island species assemblage in Hecate Strait based on surveys conducted from 1984-2003.

Year	**Species**	**Mean**	**10% c.i.**	**90%. c.i**	**Standard deviation**	**Standard error**	**Variance**	**Coefficient of variation**
1984	Spiny dogfish	78.556	57.487	101.936	17.612	0.557	310.183	0.224
1987	Spiny dogfish	51.71	38.517	65.952	10.813	0.342	116.921	0.209
1989	Spiny dogfish	55.815	36.4	76.46	16.306	0.516	265.886	0.292
1991	Spiny dogfish	20.104	13.358	27.647	5.733	0.181	32.867	0.285
1993	Spiny dogfish	35.923	26.454	46.65	7.952	0.251	63.234	0.221
1995	Spiny dogfish	10.47	7.774	13.332	2.25	0.071	5.062	0.215
1996	Spiny dogfish	22.86	15.246	31.305	6.526	0.206	42.589	0.285
1998	Spiny dogfish	22.966	15.682	31.667	6.356	0.201	40.399	0.277
2000	Spiny dogfish	24.635	16.074	34.939	7.976	0.252	63.617	0.324
2002	Spiny dogfish	57.195	31.789	86.743	24.491	0.774	599.809	0.428
2003	Spiny dogfish	11.604	8.324	15.114	2.798	0.088	7.829	0.241
1984	Big skate	57.285	45.406	69.719	9.758	0.309	95.219	0.17
1987	Big skate	96.754	66.221	130.5	24.751	0.783	612.612	0.256
1989	Big skate	85.623	62.494	113.019	20.495	0.648	420.045	0.239
1991	Big skate	49.289	33.582	68.214	13.596	0.43	184.851	0.276
1993	Big skate	65.632	48.702	84.644	14.337	0.453	205.55	0.218
1995	Big skate	33.482	25.722	42.102	6.493	0.205	42.159	0.194
1996	Big skate	44.865	34.39	56.314	8.672	0.274	75.204	0.193
1998	Big skate	33.244	24.262	43.56	7.584	0.24	57.517	0.228
2000	Big skate	56.565	33.481	83.189	20.002	0.633	400.08	0.354
2002	Big skate	32.554	22.865	43.011	8.182	0.259	66.945	0.251
2003	Big skate	53.57	29.636	81.925	20.901	0.661	436.852	0.39
1984	Spotted ratfish	18.265	12.086	25.591	5.342	0.169	28.537	0.292
1987	Spotted ratfish	9.383	5.634	13.822	3.307	0.105	10.936	0.352
1989	Spotted ratfish	50.193	29.277	74.499	19.617	0.62	384.827	0.391
1991	Spotted ratfish	10.256	2.917	21.196	9.789	0.31	95.825	0.954

Year	Species	Mean	10% c.i.	90%. c.i	Standard deviation	Standard error	Variance	Coefficient of variation
1993	Spotted ratfish	92.605	48.507	145.312	41.286	1.306	1704.534	0.446
1995	Spotted ratfish	13.089	7.364	19.716	5.058	0.16	25.583	0.386
1996	Spotted ratfish	63.192	33.397	96.951	26.878	0.85	722.427	0.425
1998	Spotted ratfish	34.539	15.745	59.412	18.515	0.585	342.805	0.536
2000	Spotted ratfish	10.571	6.442	15.477	3.579	0.113	12.809	0.339
2002	Spotted ratfish	29.677	18.629	42.679	9.586	0.303	91.891	0.323
2003	Spotted ratfish	150.755	97.462	212.394	46.967	1.485	2205.899	0.312
1984	Pacific cod	9.438	6.28	13.091	2.847	0.09	8.105	0.302
1987	Pacific cod	201.39	64.026	370.035	140.836	4.454	19834.78	0.699
1989	Pacific cod	11.191	4.376	20.508	8.078	0.255	65.254	0.722
1991	Pacific cod	5.677	2.272	10.52	4.307	0.136	18.55	0.759
1993	Pacific cod	19.17	7.178	35.271	13.686	0.433	187.307	0.714
1995	Pacific cod	6.892	3.267	11.844	3.911	0.124	15.296	0.567
1996	Pacific cod	8.022	3.868	13.183	4.122	0.13	16.991	0.514
1998	Pacific cod	11.456	5.346	19.342	6.367	0.201	40.539	0.556
2000	Pacific cod	3.956	2.599	5.51	1.195	0.038	1.428	0.302
2002	Pacific cod	10.523	4.463	18.868	6.393	0.202	40.87	0.608
2003	Pacific cod	8.874	4.573	14.54	4.061	0.128	16.492	0.458
1984	Lingcod	19.055	10.051	30.078	8.313	0.263	69.106	0.436
1987	Lingcod	18.419	9.424	28.3	7.715	0.244	59.521	0.419
1989	Lingcod	51.161	23.854	86.14	27.218	0.861	740.82	0.532
1991	Lingcod	68.564	39.462	101.176	27.367	0.865	748.953	0.399
1993	Lingcod	33.05	7.348	73.851	33.692	1.065	1135.151	1.019
1995	Lingcod	11.971	7.807	16.582	3.317	0.105	11.002	0.277
1996	Lingcod	5.985	3.594	8.579	2.039	0.064	4.158	0.341
1998	Lingcod	17.078	7.724	29.019	8.078	0.255	65.254	0.473
2000	Lingcod	2.581	1.778	3.473	0.728	0.023	0.53	0.282
2002	Lingcod	19.859	11.416	29.937	7.484	0.237	56.01	0.377
2003	Lingcod	11.457	5.219	19.338	6.108	0.193	37.308	0.533
1984	Pacific halibut	50.075	39.784	61.287	8.316	0.263	69.156	0.166
1987	Pacific halibut	42.956	28.298	58.458	12.096	0.383	146.313	0.282

Year	Species	Mean	10% c.i.	90%. c.i	Standard deviation	Standard error	Variance	Coefficient of variation
1989	Pacific halibut	34.399	26.785	42.251	6.436	0.204	41.422	0.187
1991	Pacific halibut	54.143	35.303	74.631	15.617	0.494	243.891	0.288
1993	Pacific halibut	72.669	56.093	91.325	14.18	0.448	201.072	0.195
1995	Pacific halibut	32.947	27.006	39.54	4.976	0.157	24.761	0.151
1996	Pacific halibut	38.939	28.578	49.649	8.365	0.265	69.973	0.215
1998	Pacific halibut	35.376	20.004	53.191	13.583	0.43	184.498	0.384
2000	Pacific halibut	32.379	22.876	42.906	7.638	0.242	58.339	0.236
2002	Pacific halibut	17.347	11.684	23.751	4.871	0.154	23.727	0.281
2003	Pacific halibut	26.261	18.859	34.206	6.14	0.194	37.7	0.234
1984	Rock sole	19.457	14.607	24.808	4.163	0.132	17.331	0.214
1987	Rock sole	35.692	23.296	49.629	10.255	0.324	105.165	0.287
1989	Rock sole	93.621	64.265	126.263	24.954	0.789	622.702	0.267
1991	Rock sole	51.181	39.299	64.021	9.549	0.302	91.183	0.187
1993	Rock sole	90.338	62.386	121.321	23.164	0.733	536.571	0.256
1995	Rock sole	35.841	26.91	45.387	7.297	0.231	53.246	0.204
1996	Rock sole	89.711	67.842	112.605	17.412	0.551	303.178	0.194
1998	Rock sole	44.582	27.764	63.908	14.424	0.456	208.052	0.324
2000	Rock sole	81.414	54.535	110.081	22.578	0.714	509.766	0.277
2002	Rock sole	66.331	50.767	82.689	12.614	0.399	159.113	0.19
2003	Rock sole	106.924	72.821	146.066	29.813	0.943	888.815	0.279
1984	Sand sole	5.325	3.288	7.536	1.787	0.057	3.193	0.336
1987	Sand sole	6.402	3.018	10.582	3.202	0.101	10.253	0.5
1989	Sand sole	9.667	5.982	13.991	3.413	0.108	11.649	0.353
1991	Sand sole	5.983	3.8	8.47	1.859	0.059	3.456	0.311
1993	Sand sole	10.695	6.356	16.239	4.148	0.131	17.206	0.388
1995	Sand sole	6.759	5.239	8.481	1.319	0.042	1.74	0.195
1996	Sand sole	3.609	2.803	4.48	0.657	0.021	0.432	0.182
1998	Sand sole	3.487	2.408	4.733	0.929	0.029	0.863	0.266
2000	Sand sole	5.068	3.417	7.131	1.441	0.046	2.076	0.284
2002	Sand sole	9.623	6.266	13.456	2.841	0.09	8.071	0.295
2003	Sand sole	20.232	14.024	26.934	5.056	0.16	25.563	0.25

Table 3. Mean catch rates and 90% confidence limits for dominant species in the Butterworth species assemblage in Hecate Strait based on surveys conducted from 1984-2003.

Year	Species	Mean	10% c.i.	90% c.i.	Standard deviation	Standard error	Variance	Coefficient of variation
1984	Spiny dogfish	108.583	83.748	134.72	19.277	0.61	371.603	0.178
1987	Spiny dogfish	79.534	50.252	110.635	24.518	0.775	601.132	0.308
1989	Spiny dogfish	38.19	23.965	54.613	12.41	0.392	154.008	0.325
1991	Spiny dogfish	31.75	23.776	41.215	6.974	0.221	48.637	0.22
1993	Spiny dogfish	26.286	19.32	33.933	5.86	0.185	34.34	0.223
1995	Spiny dogfish	41.219	28.644	56.376	11.037	0.349	121.815	0.268
1996	Spiny dogfish	20.463	15.041	26.663	4.695	0.148	22.043	0.229
1998	Spiny dogfish	31.958	21.886	43.974	9.217	0.291	84.953	0.288
2000	Spiny dogfish	50.495	36.247	67.421	12.431	0.393	154.53	0.246
2002	Spiny dogfish	29.212	19.656	40.598	8.325	0.263	69.306	0.285
2003	Spiny dogfish	8.32	5.264	12.054	2.879	0.091	8.289	0.346
1984	Spotted ratfish	104.44	54.362	164.563	46.8	1.48	2190.24	0.448
1987	Spotted ratfish	72.556	36.038	119.974	33.905	1.072	1149.549	0.467
1989	Spotted ratfish	61.89	39.93	85.633	17.445	0.552	304.328	0.282
1991	Spotted ratfish	54.074	34.652	76.366	16.154	0.511	260.952	0.299
1993	Spotted ratfish	58.443	37.003	84.12	18.762	0.593	352.013	0.321
1995	Spotted ratfish	9.008	6.343	12.078	2.332	0.074	5.438	0.259
1996	Spotted ratfish	27.937	20.619	36.39	6.205	0.196	38.502	0.222
1998	Spotted ratfish	80.383	50.05	116.384	26.951	0.852	726.356	0.335
2000	Spotted ratfish	61.177	40.378	83.956	17.123	0.541	293.197	0.28
2002	Spotted ratfish	59.436	38.366	83.005	18.276	0.578	334.012	0.307
2003	Spotted ratfish	118.01	68.952	175.107	44.149	1.396	1949.134	0.374
1984	Arrowtooth flounder	483.743	354.372	637.019	107.665	3.405	11591.75	0.223
1987	Arrowtooth flounder	838.718	641.651	1054.165	162.261	5.131	26328.63	0.193
1989	Arrowtooth flounder	992.853	785.595	1217.335	170.4	5.389	29036.16	0.172
1991	Arrowtooth flounder	414.506	322.203	515.091	74.805	2.366	5595.788	0.18
1993	Arrowtooth flounder	72.257	43.745	104.733	24.689	0.781	609.547	0.342
1995	Arrowtooth flounder	91.777	55.342	135.16	31.4	0.993	985.96	0.342
1996	Arrowtooth flounder	127.775	76.958	191.911	46.476	1.47	2160.019	0.364

Year	Species	Mean	10% c.i.	90% c.i.	Standard deviation	Standard error	Variance	Coefficient of variation
1998	Arrowtooth flounder	236.274	175.097	306.325	52.765	1.669	2784.145	0.223
2000	Arrowtooth flounder	246.896	152.499	356.616	81.57	2.579	6653.665	0.33
2002	Arrowtooth flounder	498.37	375.894	635.898	102.914	3.254	10591.29	0.207
2003	Arrowtooth flounder	644.824	506.636	794.967	115.235	3.644	13279.1	0.179
1984	Rex sole	33.939	22.685	46.114	9.327	0.295	86.993	0.275
1987	Rex sole	57.921	36.456	82.27	18.66	0.59	348.196	0.322
1989	Rex sole	60.429	36.258	88.275	21.693	0.686	470.586	0.359
1991	Rex sole	75.423	55.399	97.055	16.615	0.525	276.058	0.22
1993	Rex sole	35.103	23.032	48.87	10.884	0.344	118.461	0.31
1995	Rex sole	64.867	41.611	89.987	19.174	0.606	367.642	0.296
1996	Rex sole	83.623	63.186	105.503	16.42	0.519	269.616	0.196
1998	Rex sole	73.757	52.811	100.037	18.577	0.587	345.105	0.252
2000	Rex sole	125.118	94.941	158.97	25.424	0.804	646.38	0.203
2002	Rex sole	199.569	153.07	248.79	40.211	1.272	1616.925	0.201
2003	Rex sole	57.189	41.42	74.297	13.767	0.435	189.53	0.241
1984	Dover sole	66.727	36.984	104.041	26.647	0.843	710.063	0.399
1987	Dover sole	74.423	31.567	126.083	40.352	1.276	1628.284	0.542
1989	Dover sole	124.268	69.223	187.066	47.435	1.5	2250.079	0.382
1991	Dover sole	49.742	34.064	67.701	13.501	0.427	182.277	0.271
1993	Dover sole	29.173	18.276	41.526	9.216	0.291	84.935	0.316
1995	Dover sole	22.464	15.064	30.808	6.502	0.206	42.276	0.289
1996	Dover sole	32.403	21.967	44.335	9.006	0.285	81.108	0.278
1998	Dover sole	32.726	19.735	48.594	11.952	0.378	142.85	0.365
2000	Dover sole	91.807	61.478	127.057	26.508	0.838	702.674	0.289
2002	Dover sole	118.378	74.767	164.425	36.625	1.158	1341.391	0.309
2003	Dover sole	84.097	51.085	123.992	29.323	0.927	859.838	0.349
1984	English sole	46.473	31.442	62.948	12.384	0.392	153.363	0.266
1987	English sole	40.598	18.934	65.645	19.908	0.63	396.328	0.49
1989	English sole	56.992	33.651	82.194	19.451	0.615	378.341	0.341
1991	English sole	87.328	67.279	109.164	16.882	0.534	285.002	0.193
1993	English sole	168.672	115.968	227.082	45.707	1.445	2089.13	0.271

Year	Species	Mean	10% c.i.	90% c.i.	Standard deviation	Standard error	Variance	Coefficient of variation
1995	English sole	40.024	26.184	56.132	11.986	0.379	143.664	0.299
1996	English sole	41.036	27.311	55.948	11.244	0.356	126.428	0.274
1998	English sole	52.044	31.418	75.04	17.613	0.557	310.218	0.338
2000	English sole	66.102	43.446	91.275	19.44	0.615	377.914	0.294
2002	English sole	63.514	38.593	91.008	21.835	0.69	476.767	0.344
2003	English sole	66.924	34.521	106.343	30.845	0.975	951.414	0.461

Table 4. Mean catch rates and 90% confidence limits for dominant species in the Bonilla species assemblage in Hecate Strait based on surveys conducted from 1984-2003.

Year	Species	Mean	10% c.i.	90% c.i.	Standard deviation	Standard error	Variance	Coefficient of variation
1984	Spiny dogfish	64.35	51.516	78.749	10.511	0.332	110.481	0.163
1987	Spiny dogfish	94.235	66.924	128.347	24.093	0.762	580.473	0.256
1989	Spiny dogfish	38.268	26.294	51.994	10.707	0.339	114.64	0.28
1991	Spiny dogfish	8.356	5.412	11.722	2.475	0.078	6.126	0.296
1993	Spiny dogfish	207.619	128.361	302.685	70.967	2.244	5036.315	0.342
1995	Spiny dogfish	48.536	25.273	77.658	22.302	0.705	497.379	0.459
1996	Spiny dogfish	22.85	14.341	32.357	7.549	0.239	56.987	0.33
1998	Spiny dogfish	87.019	41.852	140.478	43.554	1.377	1896.951	0.501
2000	Spiny dogfish	25.299	19.396	31.579	4.735	0.15	22.42	0.187
2002	Spiny dogfish	12.081	9.099	15.421	2.46	0.078	6.052	0.204
2003	Spiny dogfish	17.707	10.571	26.147	6.011	0.19	36.132	0.339
1984	Spotted ratfish	11.268	8.293	14.648	2.605	0.082	6.786	0.231
1987	Spotted ratfish	5.489	3.675	7.446	1.497	0.047	2.241	0.273
1989	Spotted ratfish	34.63	23.526	46.692	9.369	0.296	87.778	0.271
1991	Spotted ratfish	16.204	10.032	23.246	5.197	0.164	27.009	0.321
1993	Spotted ratfish	7.588	4.167	11.561	3.145	0.099	9.891	0.414
1995	Spotted ratfish	28.453	12.448	48.666	15.644	0.495	244.735	0.55
1996	Spotted ratfish	15.946	9.754	22.915	5.186	0.164	26.895	0.325
1998	Spotted ratfish	13.125	5.557	22.293	8.736	0.276	76.318	0.666
2000	Spotted ratfish	87.358	48.41	132.421	36.114	1.142	1304.221	0.413
2002	Spotted ratfish	181.814	114.752	257.908	58.079	1.837	3373.17	0.319
2003	Spotted ratfish	37.751	25.544	52.55	11.126	0.352	123.788	0.295
1984	Pacific sanddab	25.985	17.675	36.156	7.353	0.233	54.067	0.283
1987	Pacific sanddab	11	6.036	17.632	4.635	0.147	21.483	0.421
1989	Pacific sanddab	15.693	7.617	25.591	7.47	0.236	55.801	0.476
1991	Pacific sanddab	16.45	8.442	26.064	7.308	0.231	53.407	0.444
1993	Pacific sanddab	2.077	1.509	2.667	0.536	0.017	0.287	0.258
1995	Pacific sanddab	30.793	11.857	56.066	18.631	0.589	347.114	0.605
1996	Pacific sanddab	54.079	27.711	87.775	24.915	0.788	620.757	0.461

Year	Species	Mean	10% c.i.	90% c.i.	Standard deviation	Standard error	Variance	Coefficient of variation
1998	Pacific sanddab	31.113	14.589	53.859	16.935	0.536	286.794	0.544
2000	Pacific sanddab	51.834	29.449	78.358	20.876	0.66	435.807	0.403
2002	Pacific sanddab	30.051	13.147	52.165	16.703	0.528	278.99	0.556
2003	Pacific sanddab	64.711	30.182	107.988	32.532	1.029	1058.331	0.503
1984	Arrowtooth flounder	6.789	4.682	9.444	1.891	0.06	3.576	0.279
1987	Arrowtooth flounder	4.233	2.629	6.211	1.55	0.049	2.403	0.366
1989	Arrowtooth flounder	31.885	13.221	57.637	19.888	0.629	395.533	0.624
1991	Arrowtooth flounder	13.853	6.386	22.815	7.067	0.223	49.942	0.51
1993	Arrowtooth flounder	19.593	6.378	38.198	16.146	0.511	260.693	0.824
1995	Arrowtooth flounder	69.049	36.594	110.652	31.051	0.982	964.165	0.45
1996	Arrowtooth flounder	23.717	11.357	39.336	11.777	0.372	138.698	0.497
1998	Arrowtooth flounder	12.881	4.549	24.625	9.516	0.301	90.554	0.739
2000	Arrowtooth flounder	9.158	4.967	14.651	3.93	0.124	15.445	0.429
2002	Arrowtooth flounder	34.602	16.909	56.067	15.923	0.504	253.542	0.46
2003	Arrowtooth flounder	37.597	23.058	54.593	12.75	0.403	162.562	0.339
1984	Rex sole	23.35	15.891	31.608	6.416	0.203	41.165	0.275
1987	Rex sole	5.054	3.029	7.539	1.999	0.063	3.996	0.396
1989	Rex sole	36.998	21.76	55.211	13.271	0.42	176.119	0.359
1991	Rex sole	12.124	5.136	21.251	7.184	0.227	51.61	0.593
1993	Rex sole	7.729	3.651	12.504	4.131	0.131	17.065	0.534
1995	Rex sole	22.279	14.513	30.762	6.584	0.208	43.349	0.296
1996	Rex sole	22.758	13.644	33.148	7.82	0.247	61.152	0.344
1998	Rex sole	8.502	3.816	14.745	5.125	0.162	26.266	0.603
2000	Rex sole	8.606	5.236	12.637	3.066	0.097	9.4	0.356
2002	Rex sole	29.056	16.468	42.912	11.198	0.354	125.395	0.385
2003	Rex sole	74.166	42.63	114.013	29.331	0.928	860.308	0.395
1984	English sole	83.469	61.772	106.853	18.461	0.584	340.809	0.221
1987	English sole	36.934	22.5	54.915	13.198	0.417	174.187	0.357
1989	English sole	327.488	210.316	465.1	99.65	3.151	9930.123	0.304
1991	English sole	203.158	153.544	258.348	42.005	1.328	1764.42	0.207
1993	English sole	16.478	10.344	24.115	5.612	0.177	31.495	0.341

Year	Species	Mean	10% c.i.	90% c.i.	Standard deviation	Standard error	Variance	Coefficient of variation
1995	English sole	79.494	44.777	119.753	30.139	0.953	908.359	0.379
1996	English sole	187.276	130.309	248.178	46.449	1.469	2157.51	0.248
1998	English sole	15.163	6.747	26.62	8.371	0.265	70.074	0.552
2000	English sole	65.779	38.354	99.754	24.652	0.78	607.721	0.375
2002	English sole	113.531	70.684	158.588	36.452	1.153	1328.748	0.321
2003	English sole	252.592	164.25	353.269	75.266	2.38	5664.971	0.298

Table 5. Species diversity, richness and evenness for assemblages in Hecate Strait.

		Reef Island			Butterworth			Bonilla		
Year	n	H'	S*	V'	H'	S*	V'	H'	S*	V'
1984	146	2.871	33	0.821	2.939	32	0.848	3.297	39	0.900
1987	90	2.944	37	0.815	2.604	28	0.781	2.810	34	0.797
1989	95	3.201	48	0.827	2.779	43	0.739	2.919	38	0.802
1991	99	3.329	41	0.896	2.991	50	0.764	3.095	41	0.833
1993	94	3.248	39	0.887	3.380	49	0.869	2.718	36	0.758
1995	102	3.438	44	0.908	3.362	56	0.835	3.161	33	0.904
1996	101	3.236	44	0.855	3.081	44	0.814	3.261	30	0.959
1998	86	3.366	36	0.939	3.229	47	0.839	3.256	48	0.841
2000	106	3.239	46	0.846	3.121	53	0.786	3.264	52	0.826
2002	94	3.337	44	0.882	3.072	44	0.812	3.223	48	0.832
2003	96	3.000	54	0.752	2.734	39	0.746	3.381	49	0.869

Table 6. Species richness in Hecate Strait and the B.C. coast compared to large scale marine ecosystems in the temperate zone[1].

Marine ecosystem	Richness	Area (km^2)	Latitude	Longitude	Region
Oyashio Current	37	532831	45.2	151.6	North Pacific
Barents sea	59	1865429	76.0	37.3	North Atlantic
Hecate Strait	150	25000	53.0	131.0	North Pacific
Iceland shelf/sea	152	51820	66.6	-17.6	North Atlantic
West Greenland shelf	157	365548	70.2	-57.1	North Atlantic
Baltic sea	157	394265	58.9	19.7	North Atlantic
Greenland sea	162	1171612	75.5	-11.8	North Atlantic
Newfoundland Labrador shelf	171	681296	49.5	-53.0	North Atlantic
Faroe Plateau	174	150558	60.6	-11.2	North Atlantic
North sea	190	695626	57.4	2.8	North Atlantic
Black sea	193	461958	43.5	34.4	North Atlantic
Scotian shelf	197	414534	47.0	-61.7	North Atlantic
Norwegian sea	232	1102919	68.0	3.7	North Atlantic
East Bering sea	249	1186827	58.9	-168.8	North Pacific
West Bering sea	311	2170639	57.5	-175.5	North Pacific
Gulf of Alaska	317	1474706	54.1	-139.3	North Pacific
B.C. shelf/slope	325	110000	49.0	125.0	North Pacific
Okhotsk sea	391	1557816	53.8	148.9	North Pacific

[1]Information for large scale ecosystems from Fisher et al. 2010.

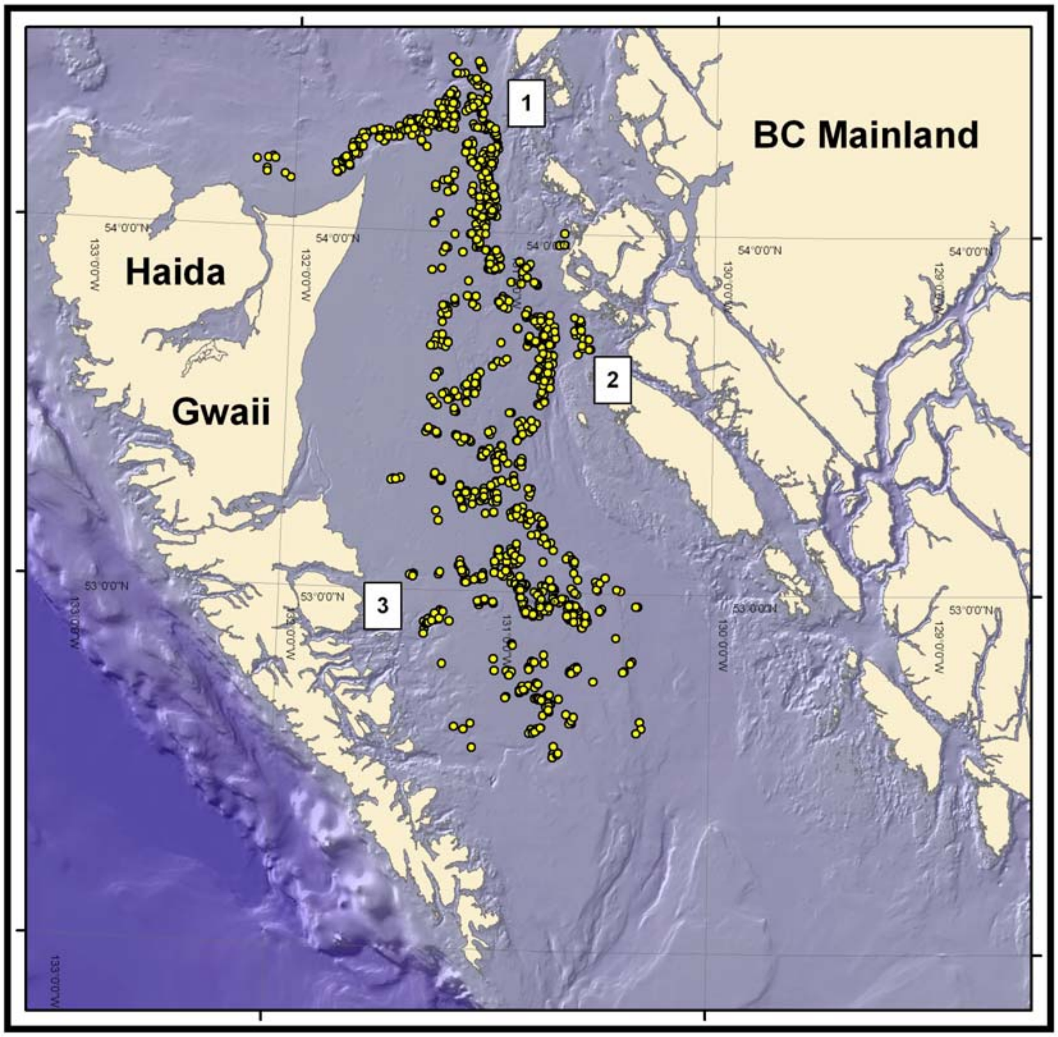

Figure 1. The study area. Trawling sites are depicted in yellow and represent 1020 hauls made between 1984 and 2003. The numbered white boxes correspond to landmarks: 1) Butterworth rocks, 2) Bonilla Island and 3) Reef Island.

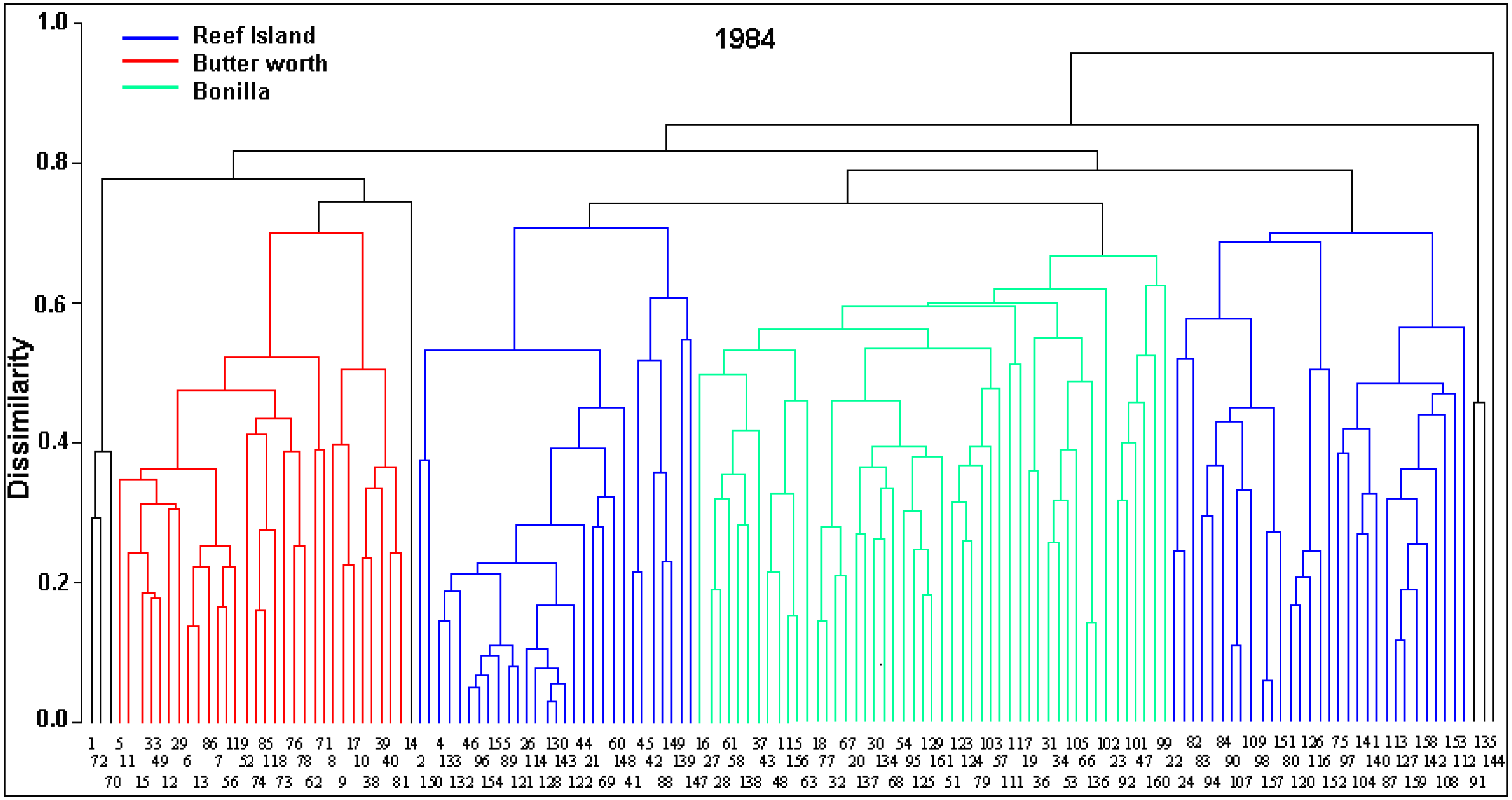

Figure 2. Dendrogram of species assemblages from the cluster analysis of the 1984 Hecate Strait survey catch rate data.

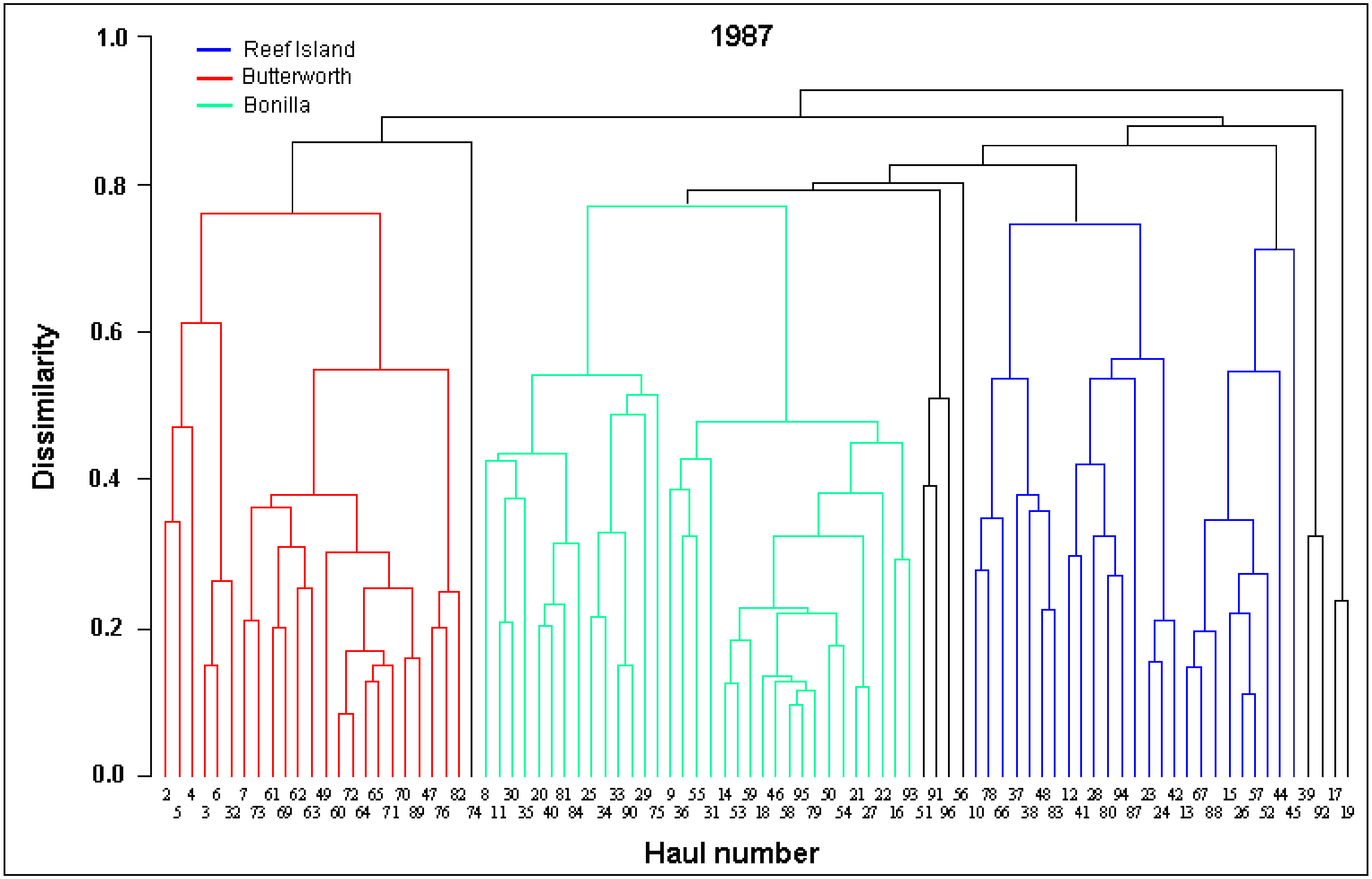

Figure 3. Dendrogram of species assemblages from the cluster analysis of the 1987 Hecate Strait survey catch rate data.

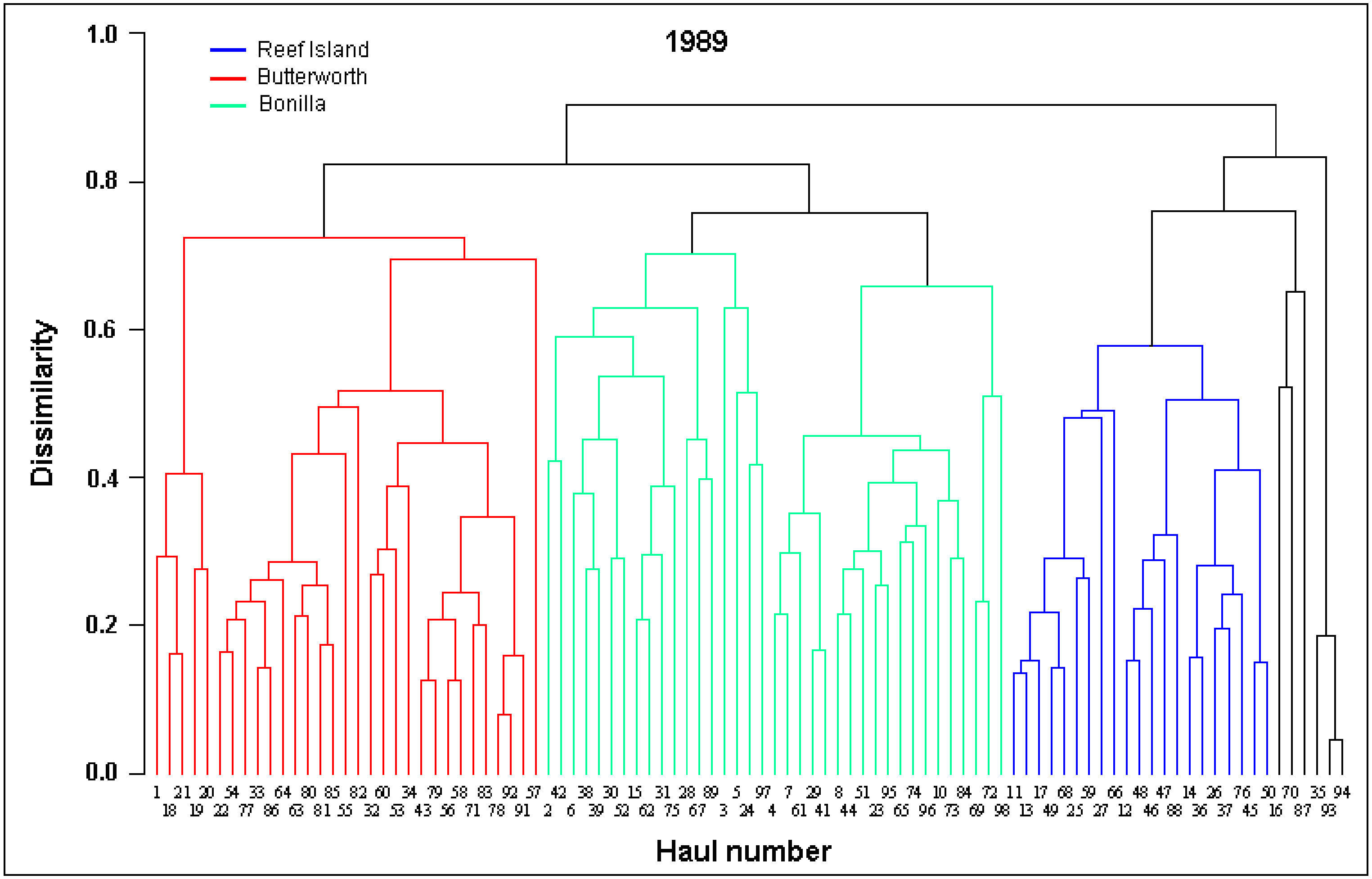

Figure 4. Dendrogram of species assemblages from the cluster analysis of the 1989 Hecate Strait survey catch rate data.

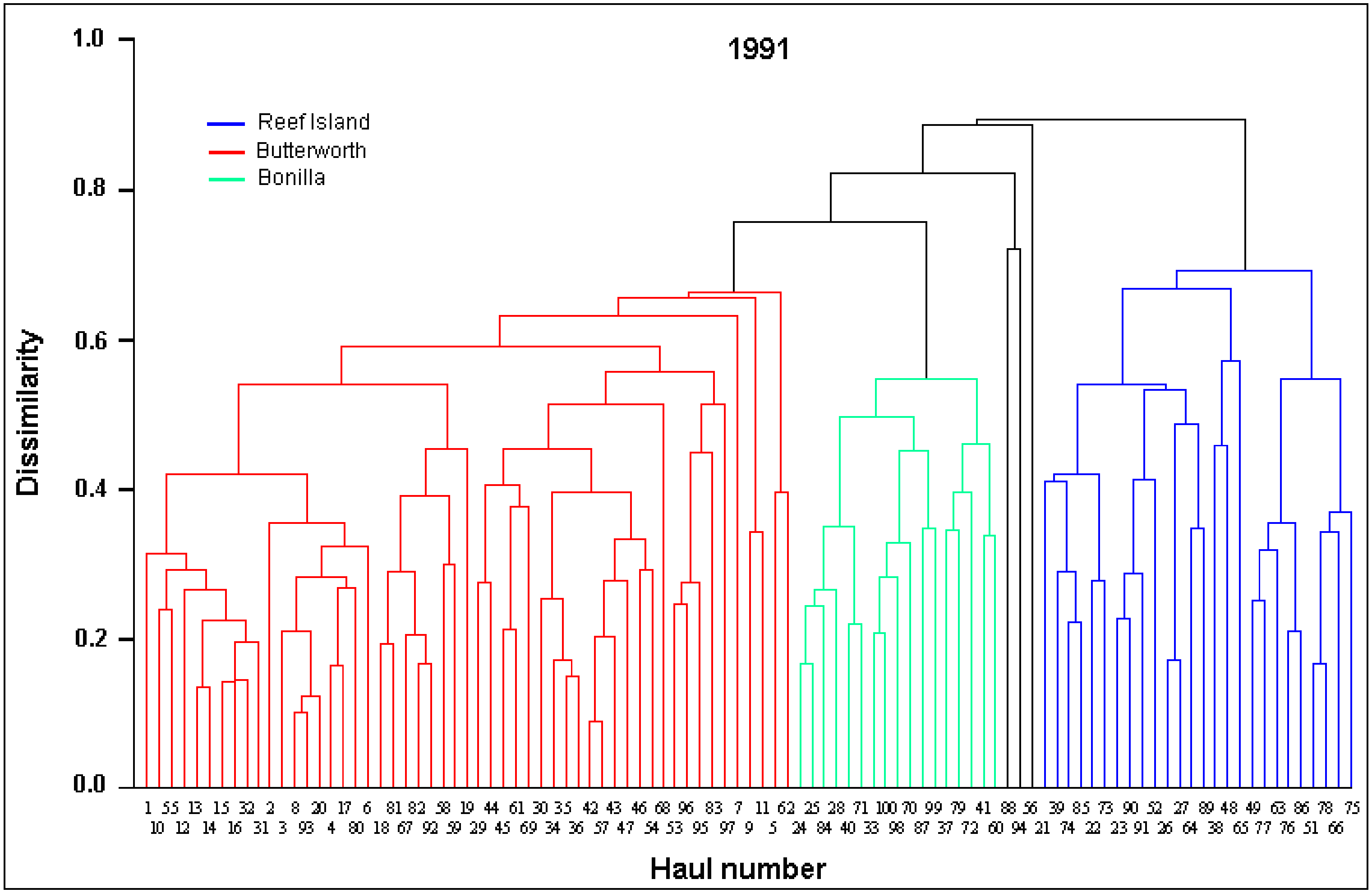

Figure 5. Dendrogram of species assemblages from the cluster analysis of the 1991 Hecate Strait survey catch rate data.

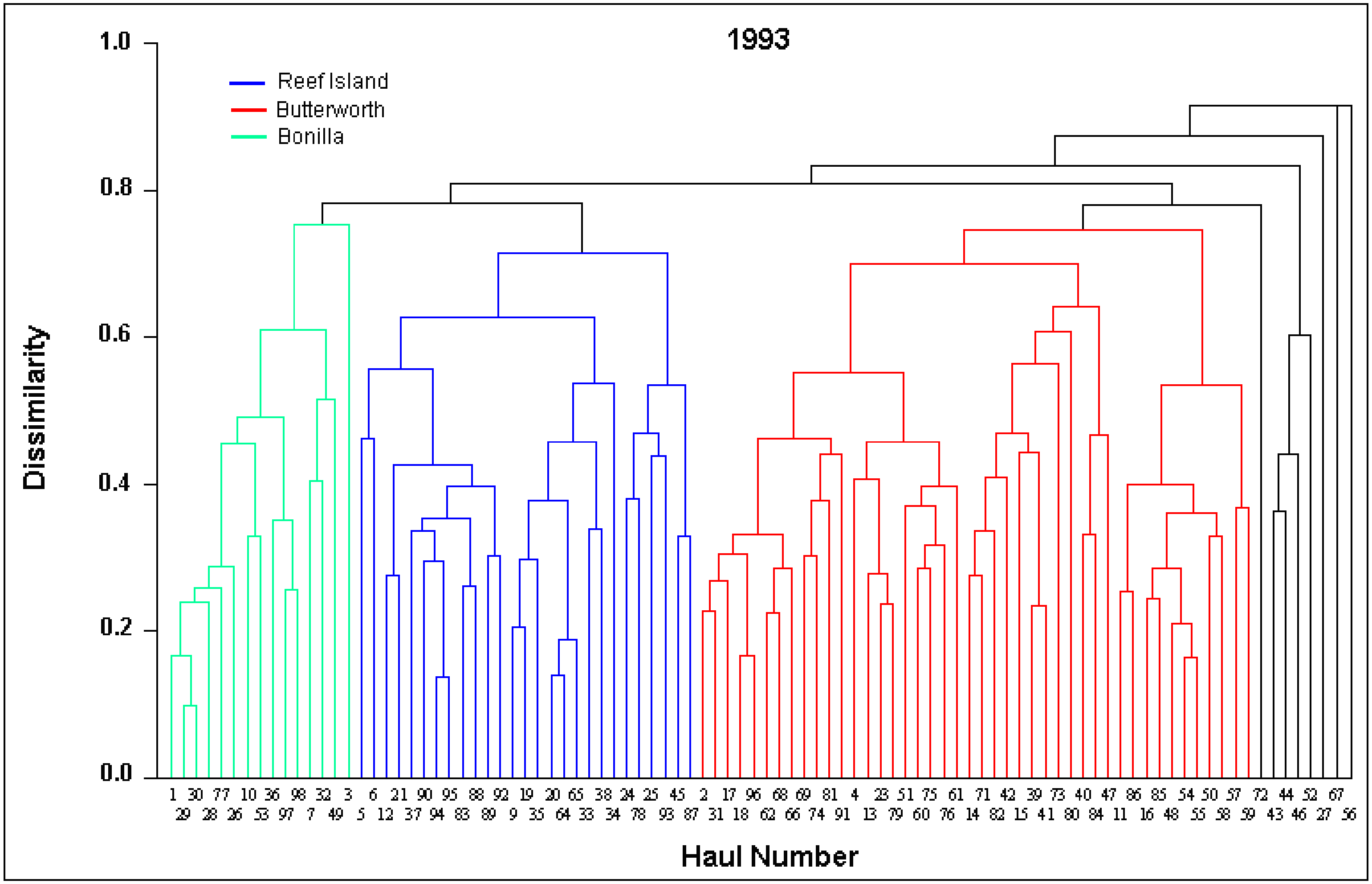

Figure 6. Dendrogram of species assemblages from the cluster analysis of the 1993 Hecate Strait survey catch rate data.

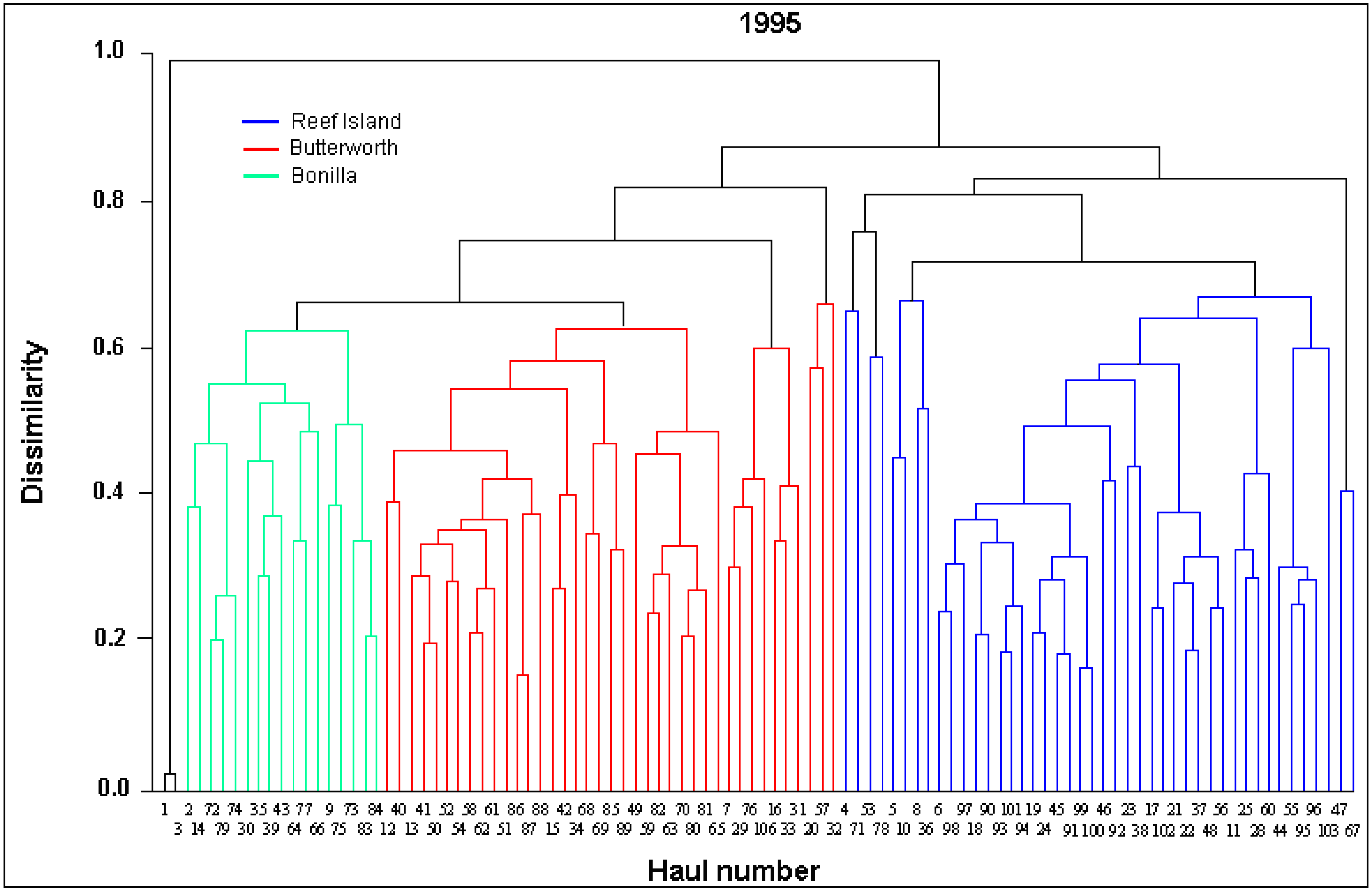

Figure 7. Dendrogram of species assemblages from the cluster analysis of the 1995 Hecate Strait survey catch rate data.

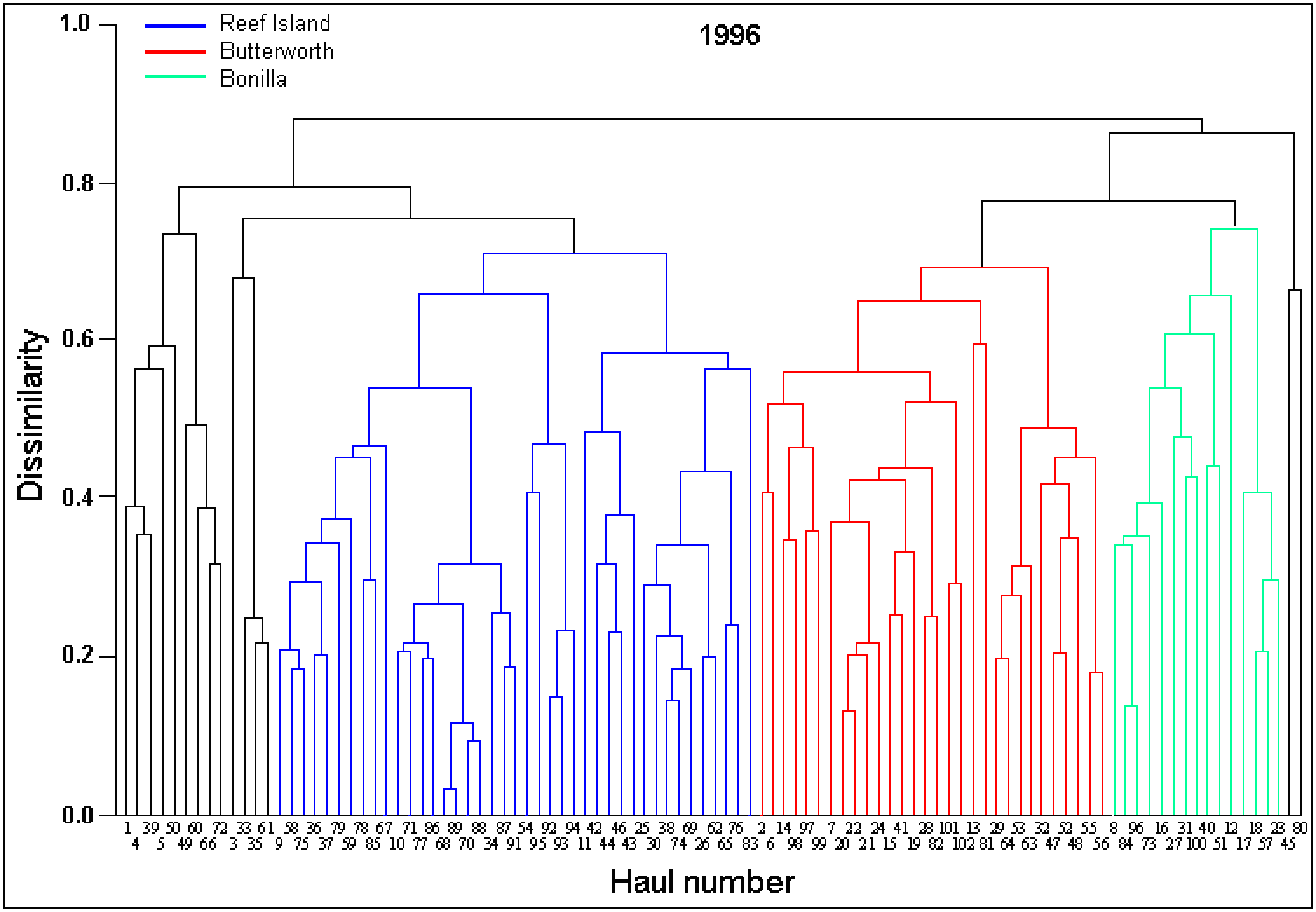

Figure 8. Dendrogram of species assemblages from the cluster analysis of the 1996 Hecate Strait survey catch rate data

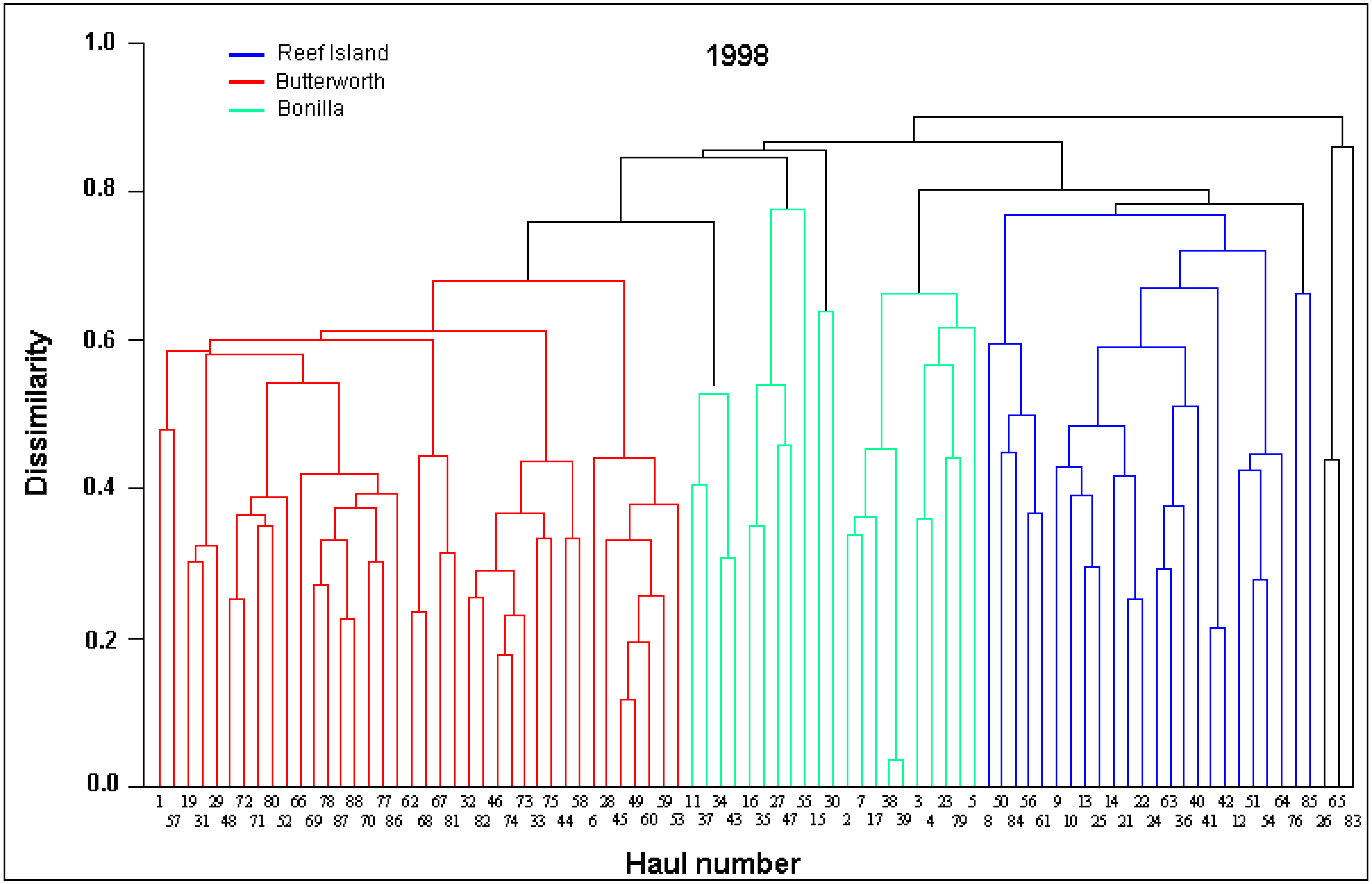

Figure 9. Dendrogram of species assemblages from the cluster analysis of the 1998 Hecate Strait survey catch rate data.

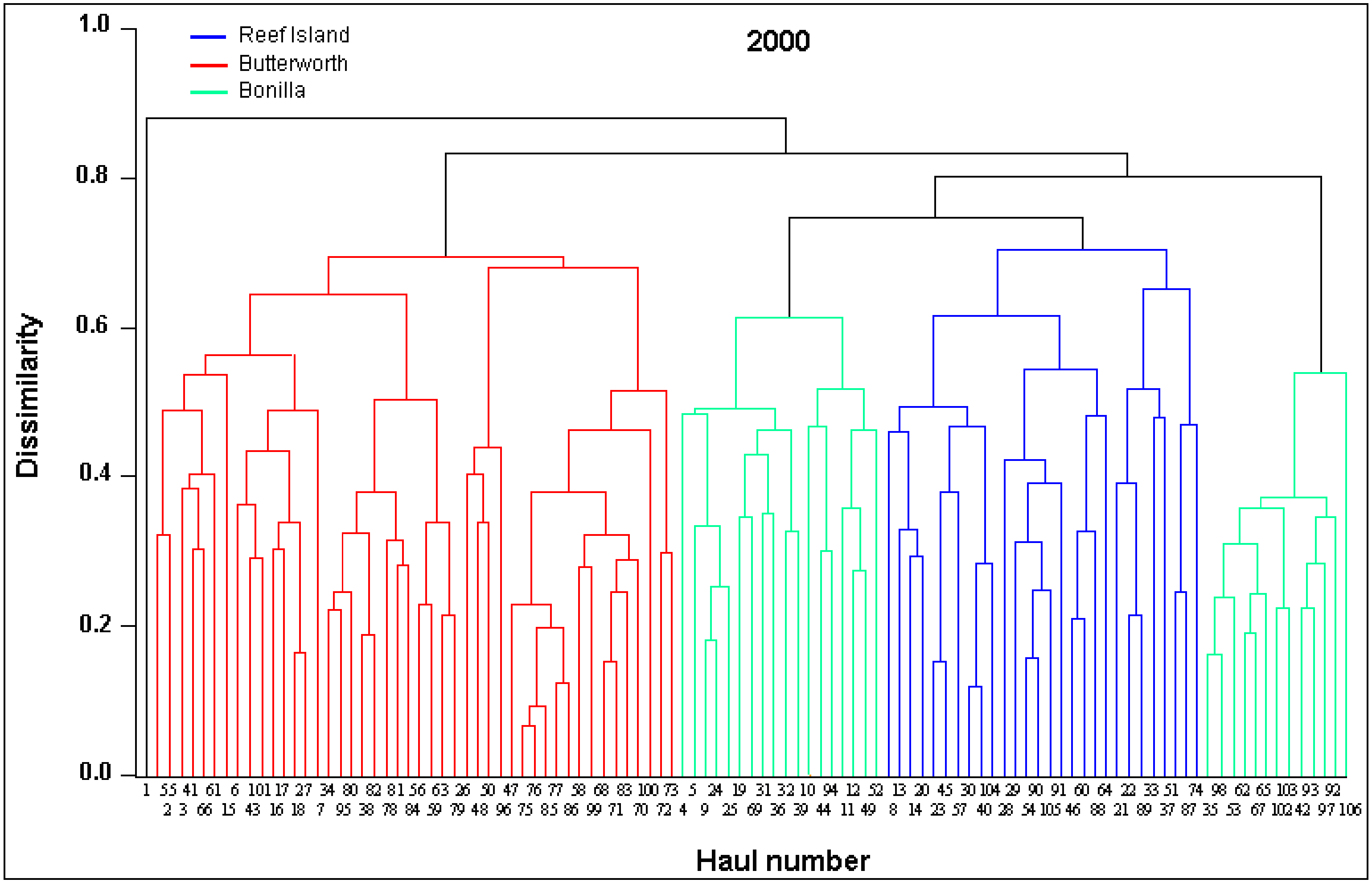

Figure 10. Dendrogram of species assemblages from the cluster analysis of the 2000 Hecate Strait survey catch rate data.

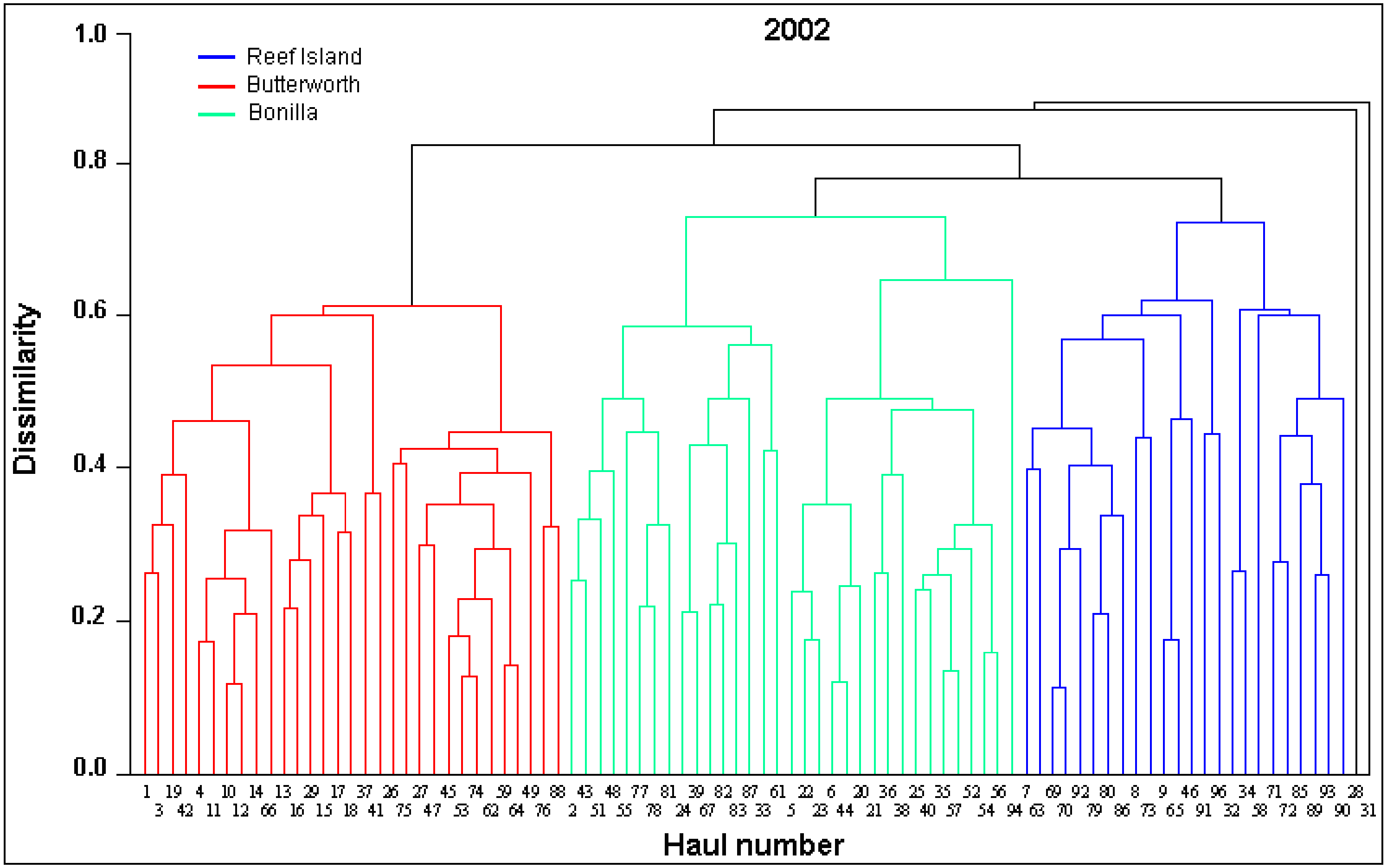

Figure 11. Dendrogram of species assemblages from the cluster analysis of the 2002 Hecate Strait survey catch rate data.

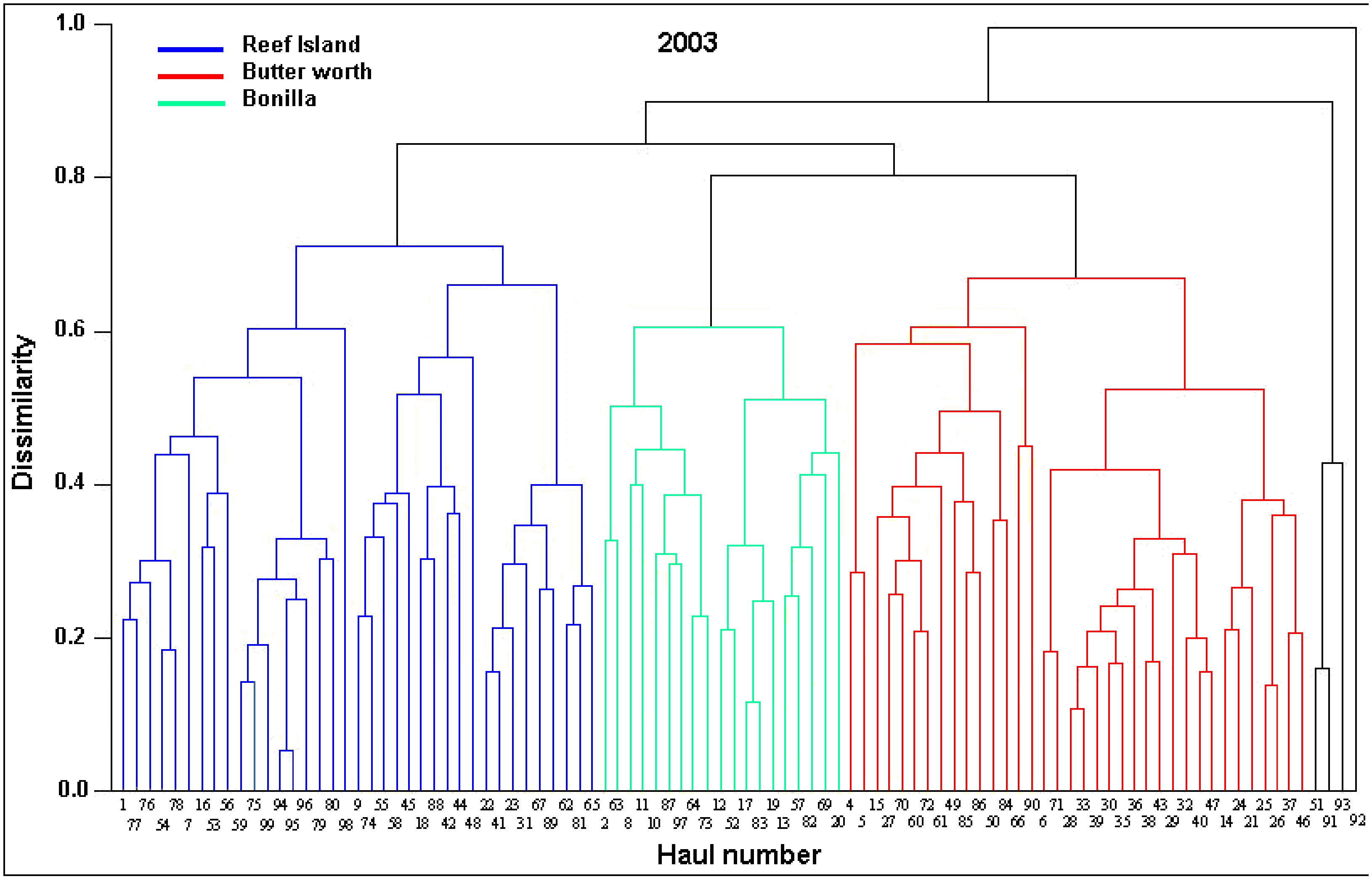

Figure 12. Dendrogram of species assemblages from the cluster analysis of the 2003 Hecate Strait survey catch rate data.

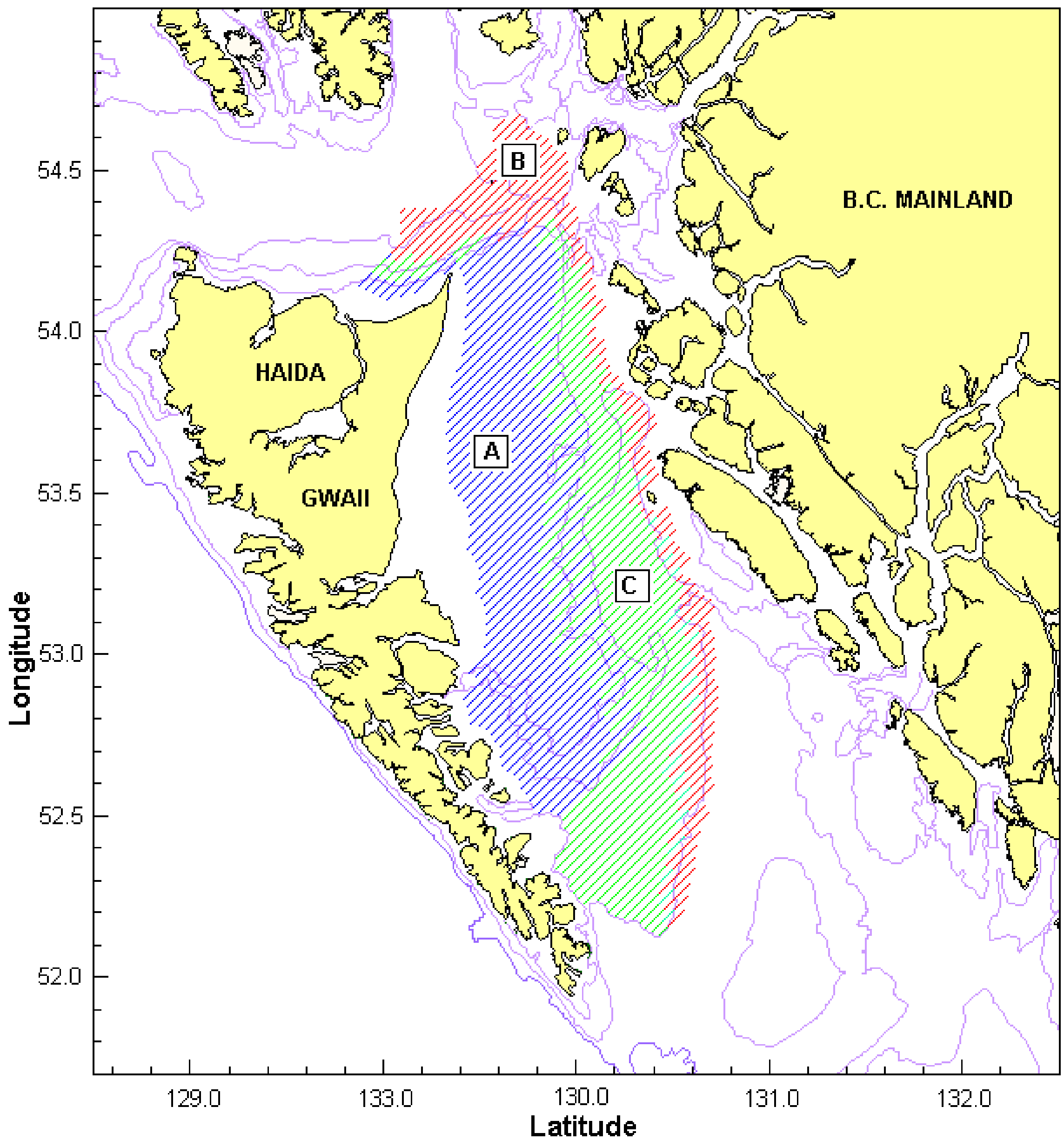

Figure 13. Boundaries for fish assemblages in Hecate Strait fish: A=Reef Island , B=Butterworth and C=Bonilla. The overlap of colours indicates a gradual transition rather than a sharp transition.

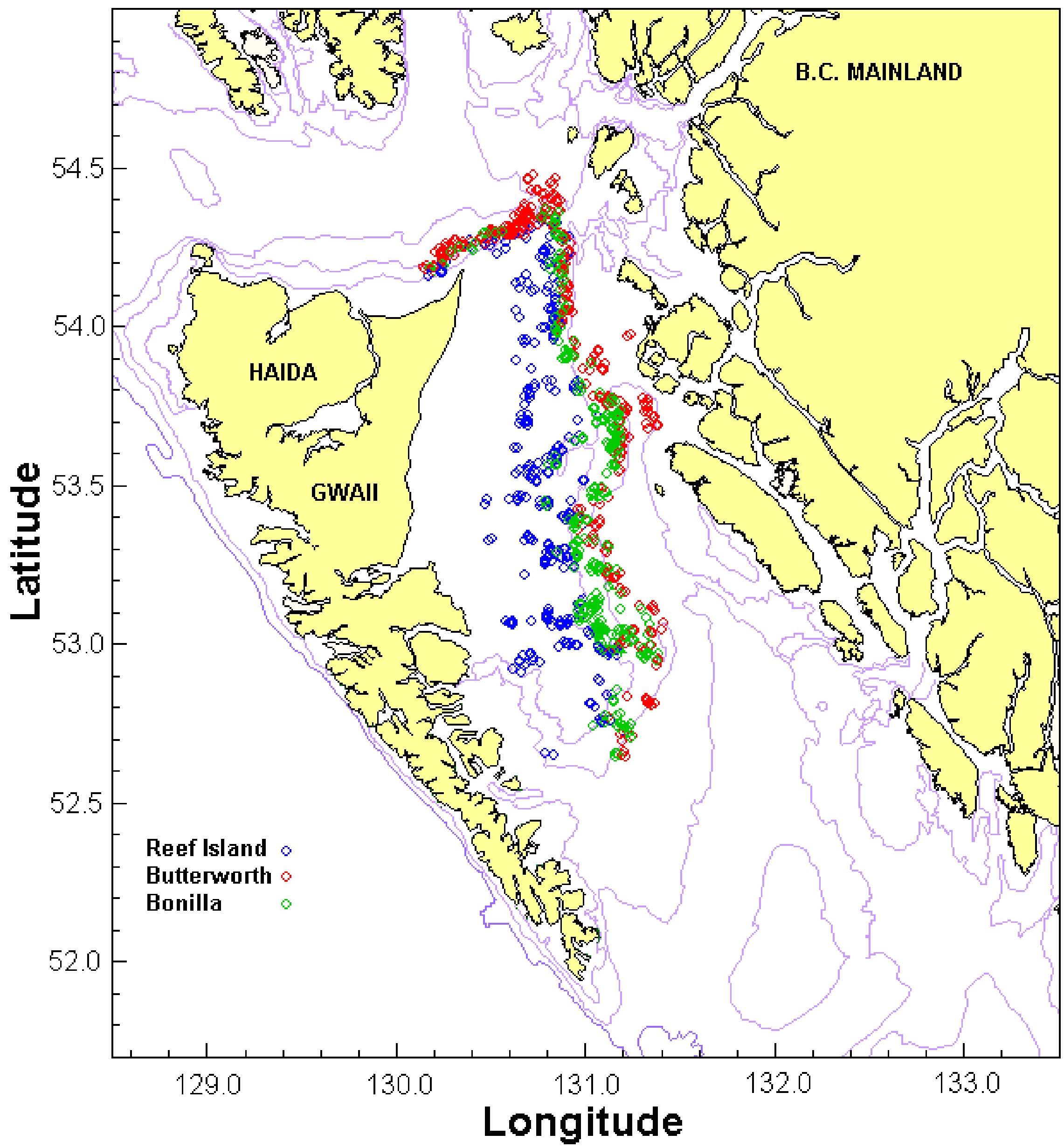

Figure 14. Haul locations (1984-2003) as classified components of assemblages in the cluster analysis.

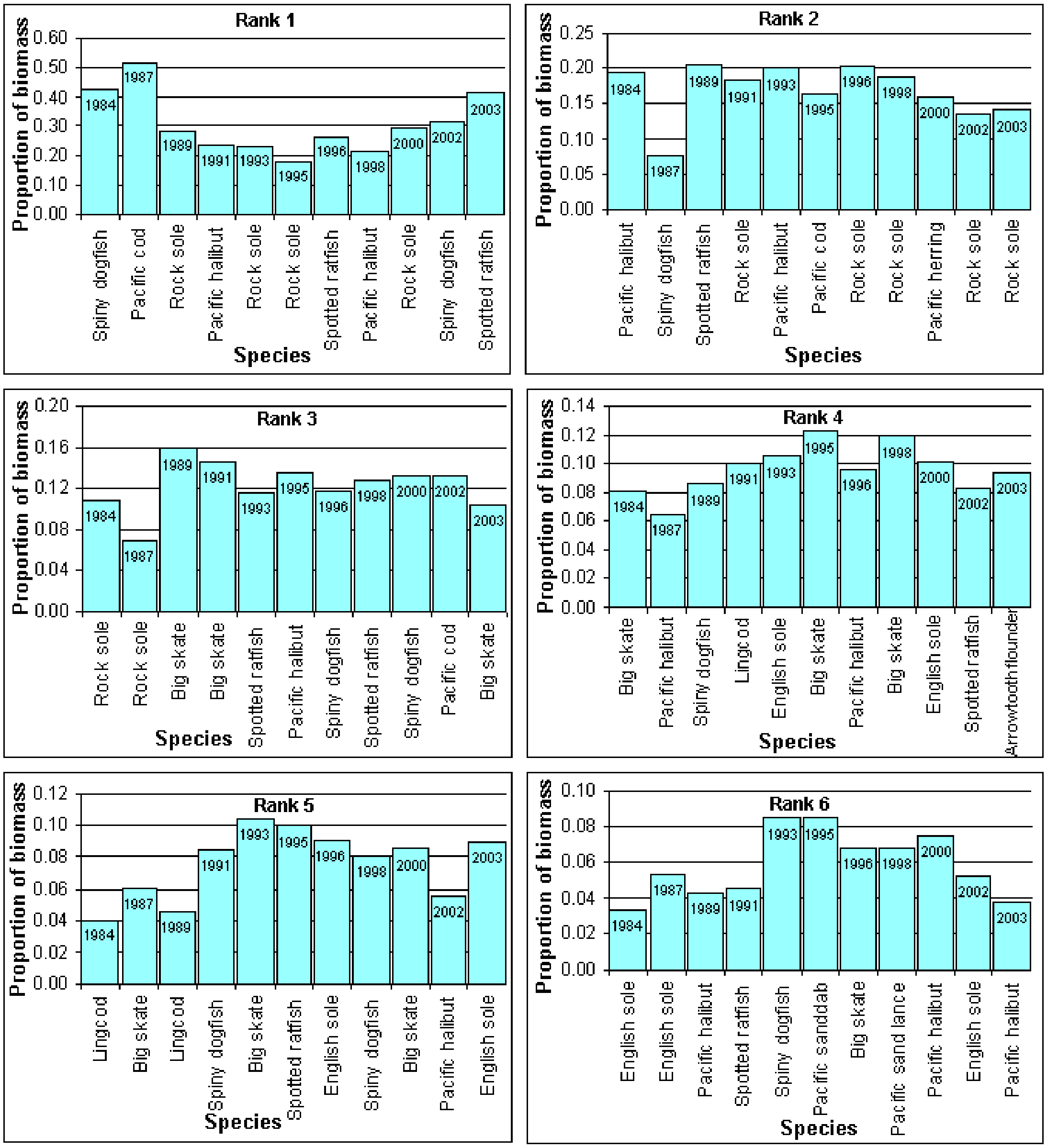

Figure 15. Species proportion by weight and year for the Reef Island assemblage. The rank 1 group is the highest weight proportion, rank 2 group is the second highest weight proportion …..

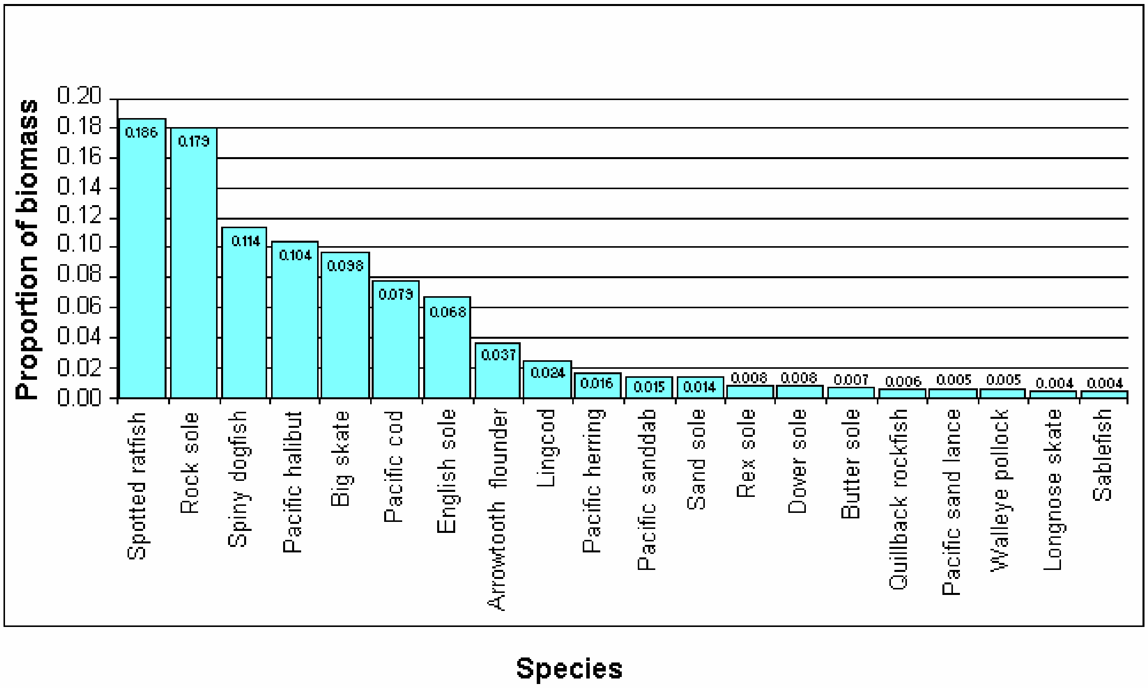

Figure 16. Species weight proportions for the Reef Island assemblage combined years (1984-2003)

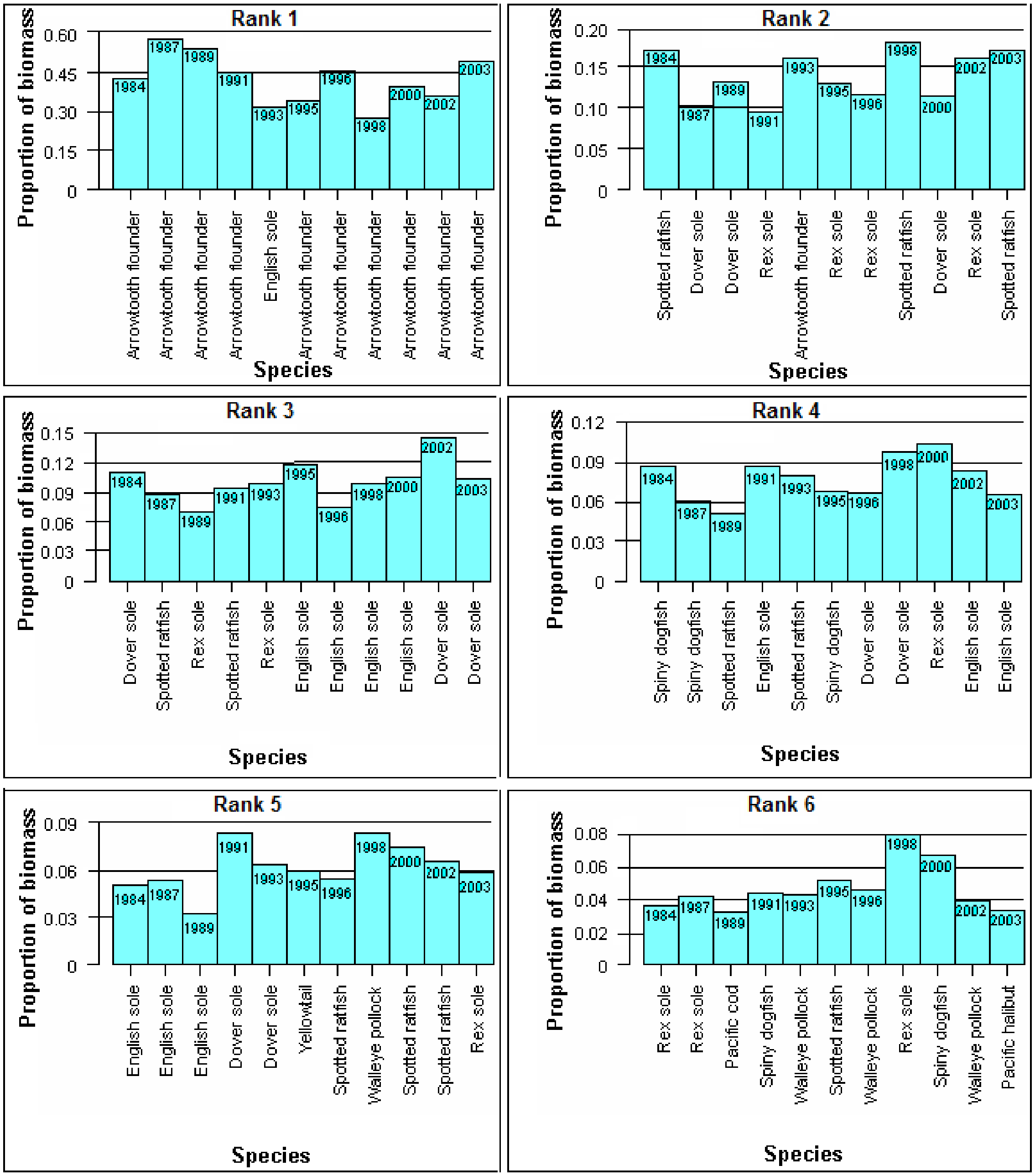

Figure 17. Species proportion by weight and year for the Butterworth assemblage. The rank 1 group is the highest weight proportion, rank 2 group is the second highest weight proportion ….

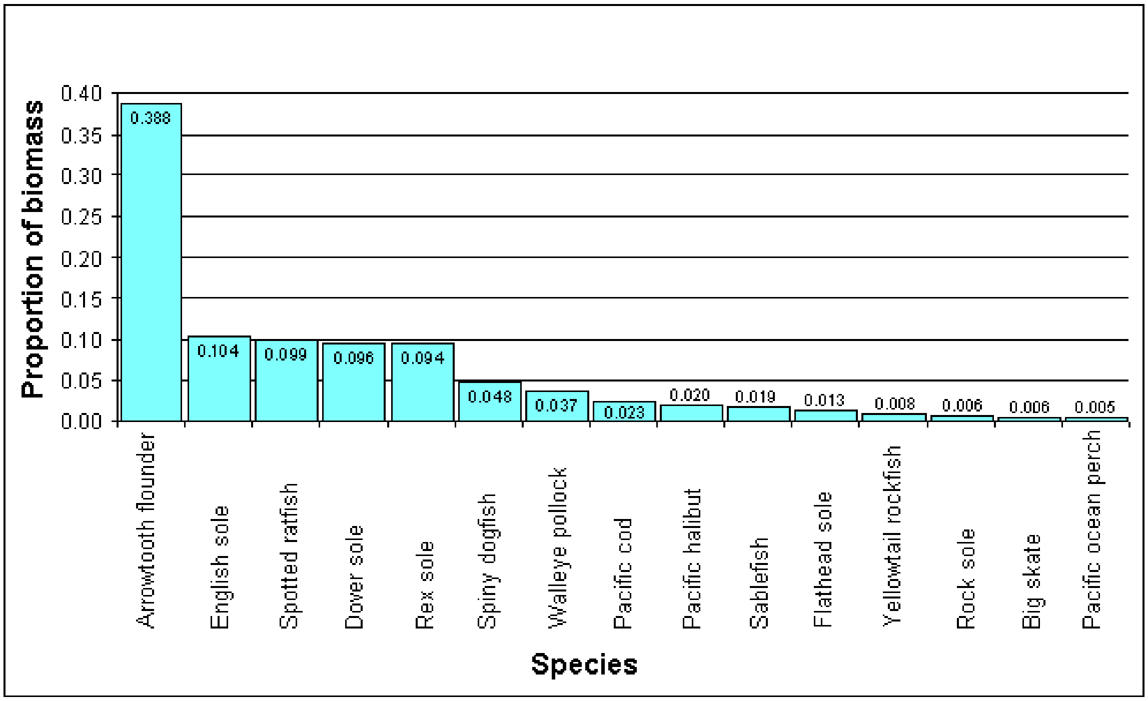

Figure 18. Species weight proportions for the Butterworth assemblage combined years (1984-2003)

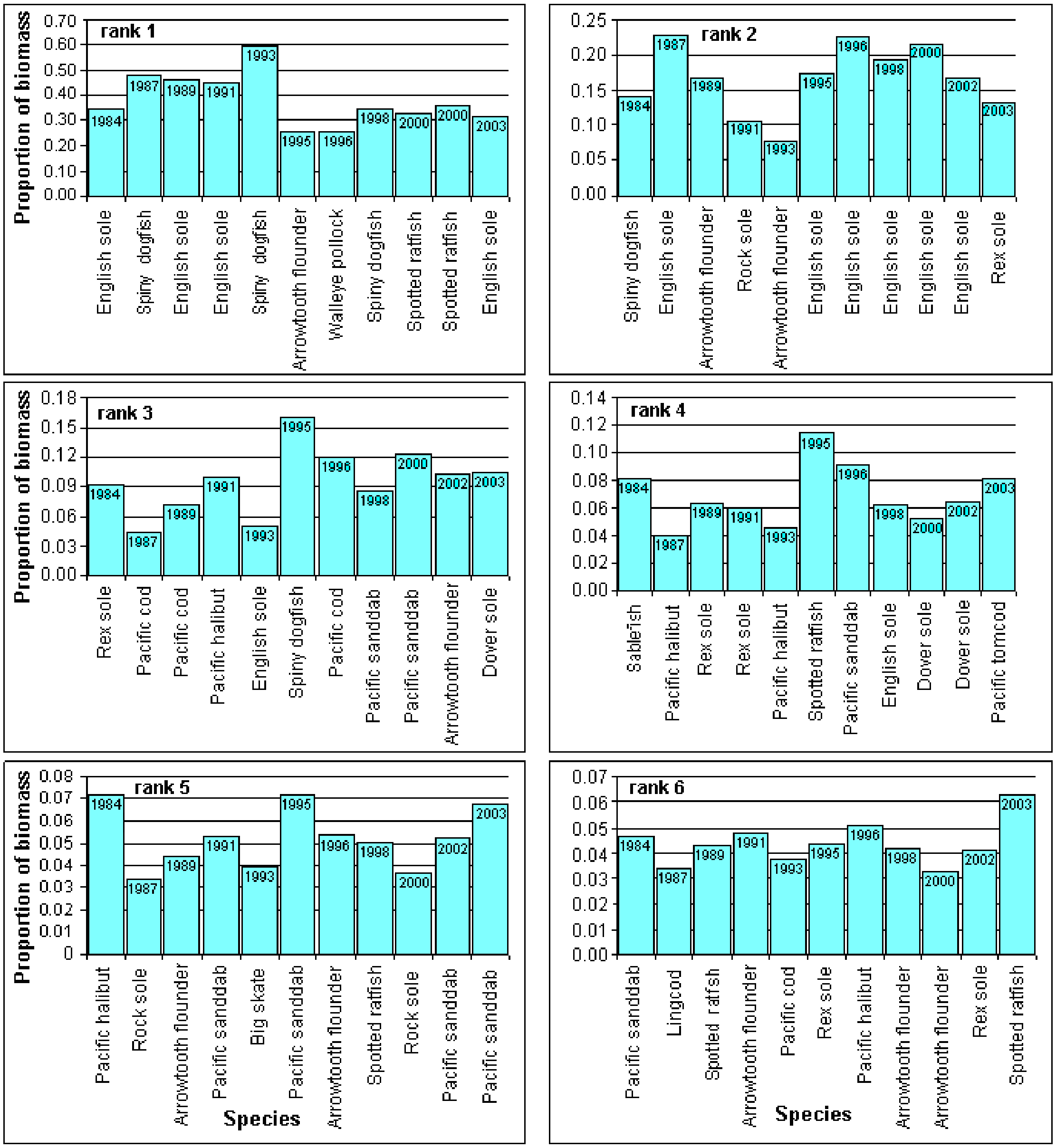

Figure 19. Species proportion by weight and year for the Bonilla assemblage. The rank 1 group is the highest weight proportion, rank 2 group is the second highest weight proportion …..

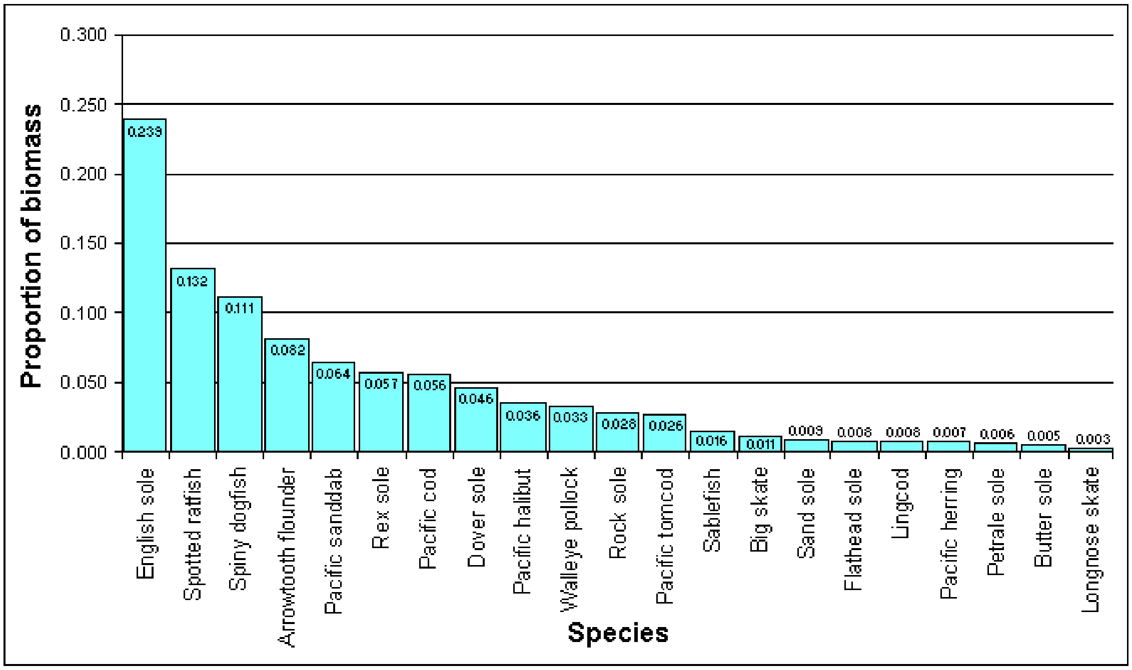

Figure 20. Species weight proportions for the Bonilla assemblage combined years (1984-2003)

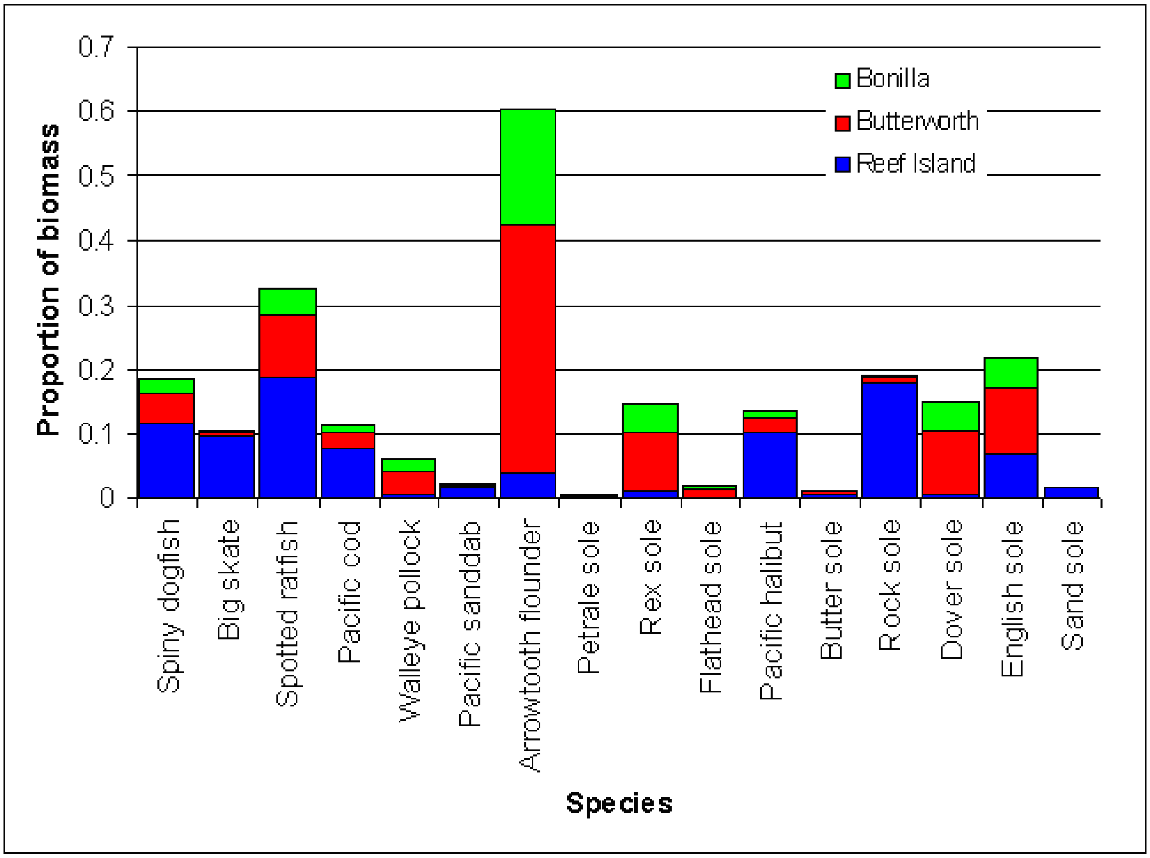

Figure 21. Proportion of biomass by assemblage for dominant species components.

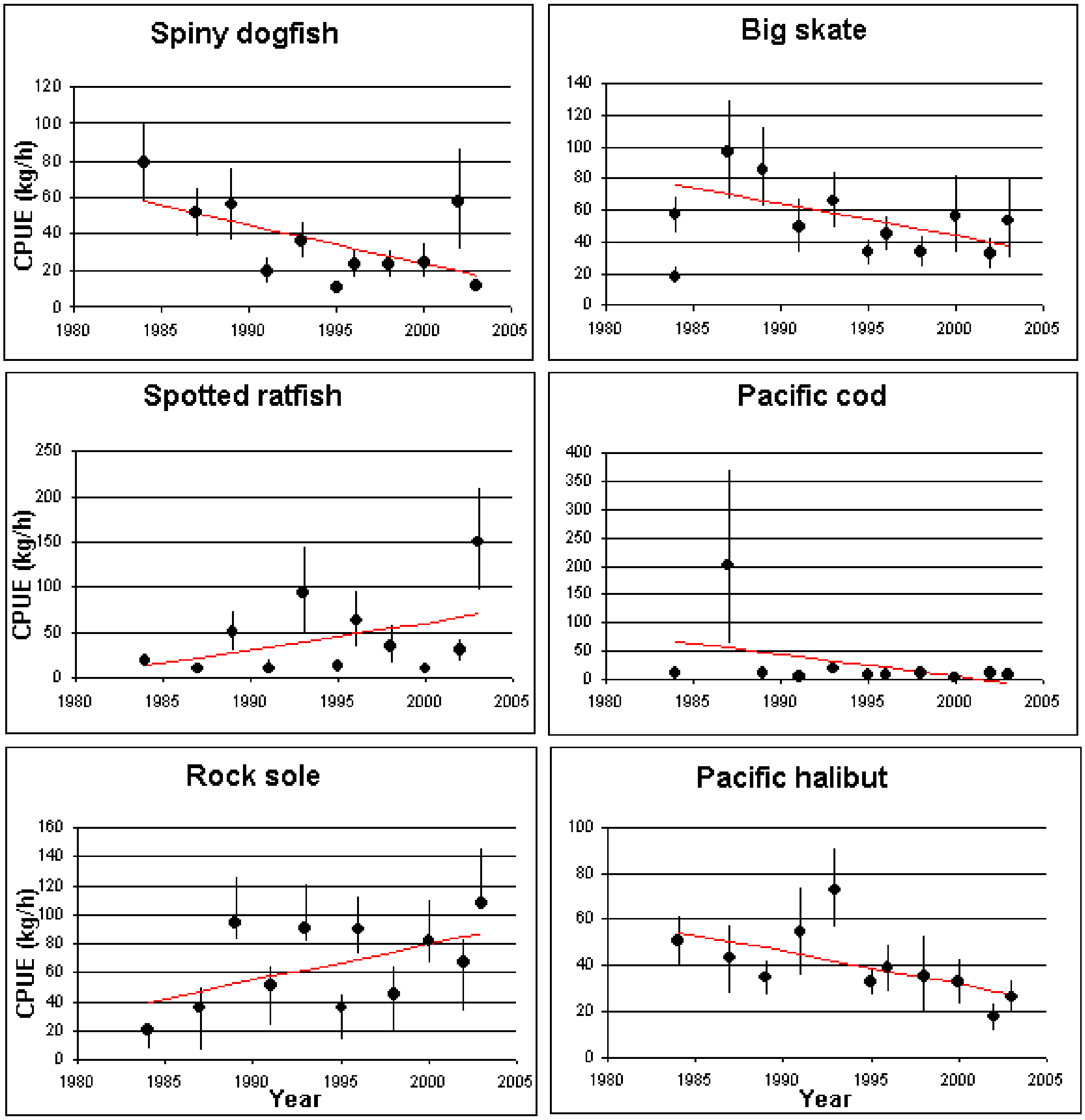

Figure 22. Mean CPUE (backtransformed) and 90% confidence interval for dominant species in the Reef Island Assemblage, 1984-2003.

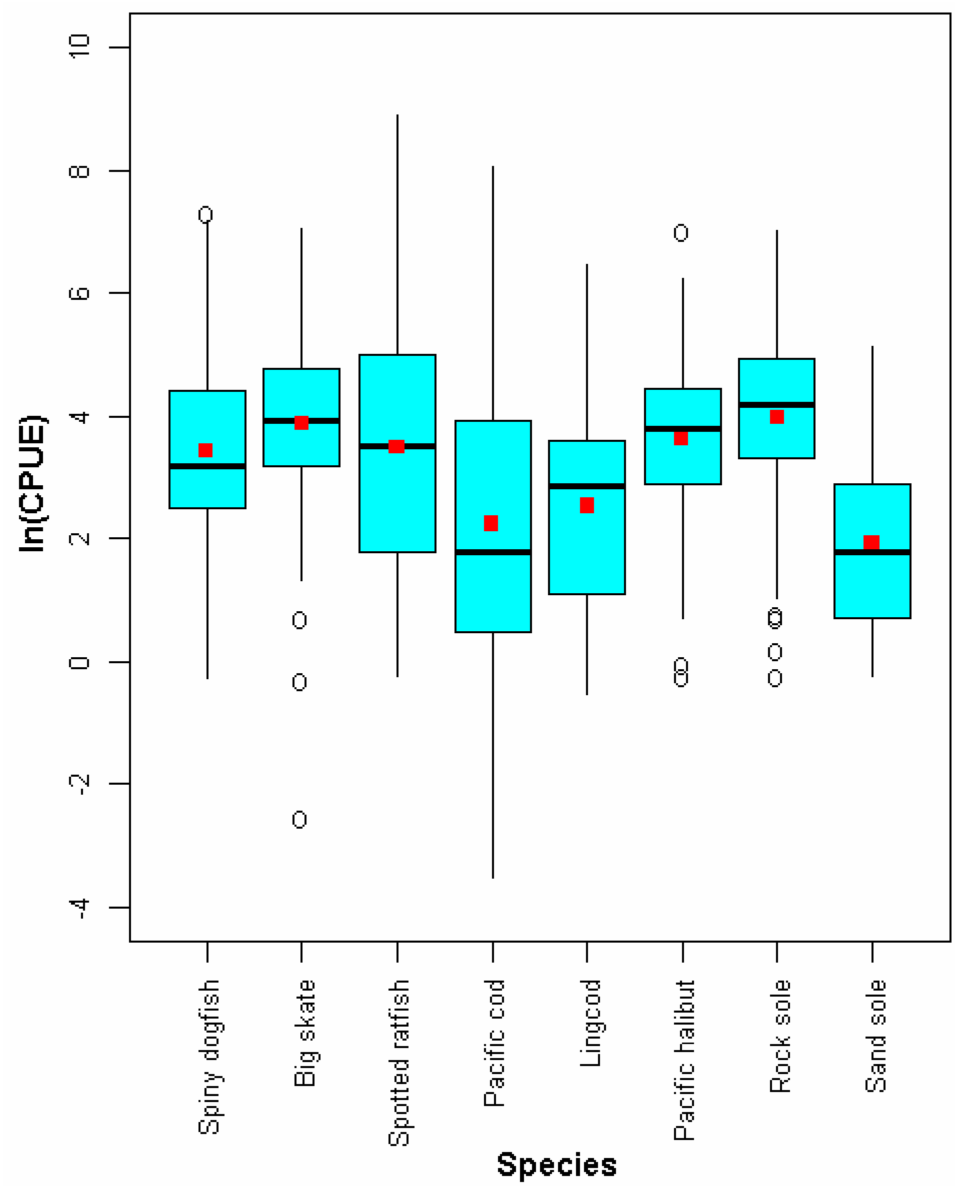

Figure 23. Boxplots of ln(CPUE) for dominant species in the Reef Island assemblage, 1984-2003. Points in red represent the mean value.

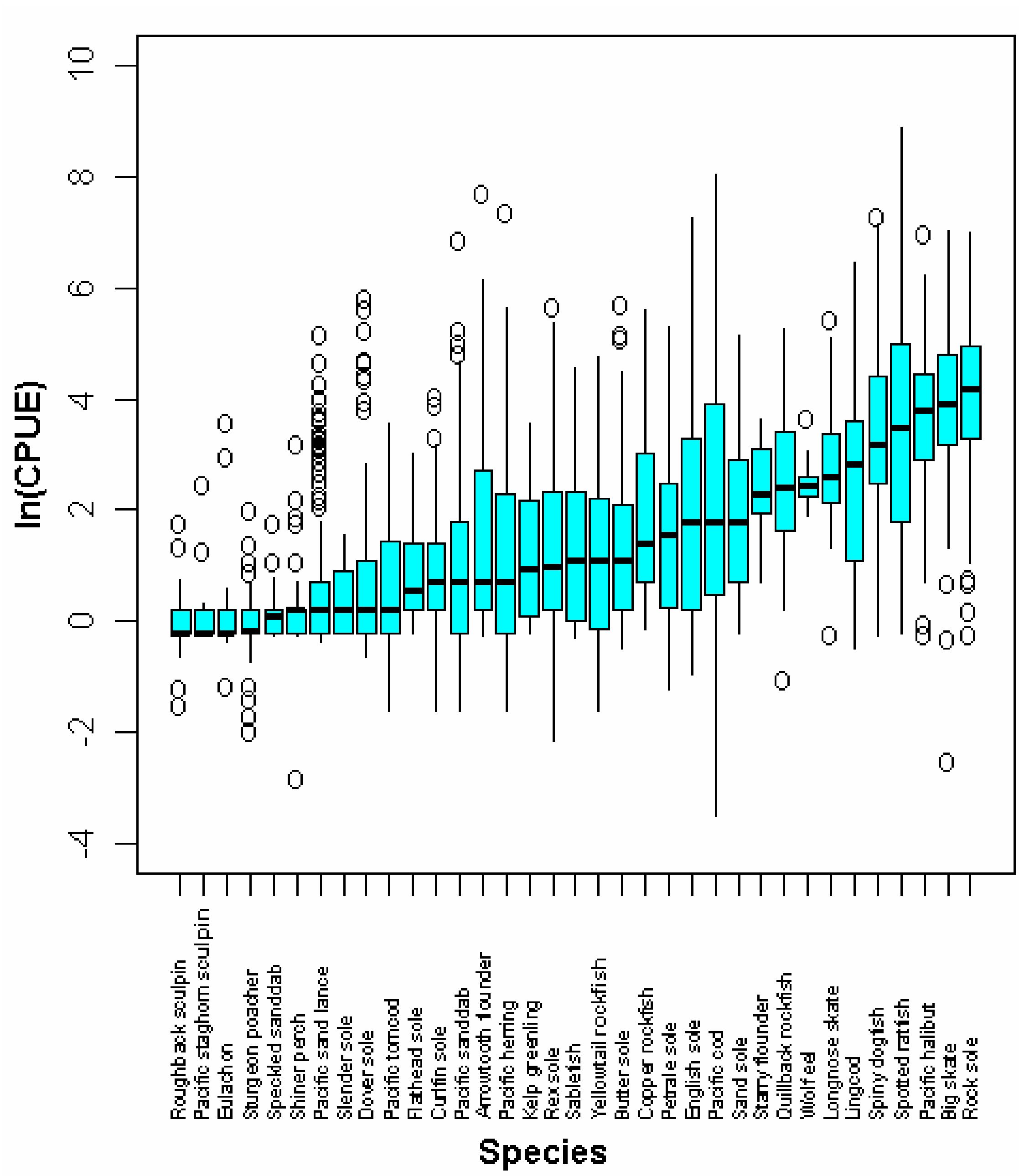

Figure 24. Boxplots of ln(CPUE) for species in the Reef Island assemblage, 1984-2003.

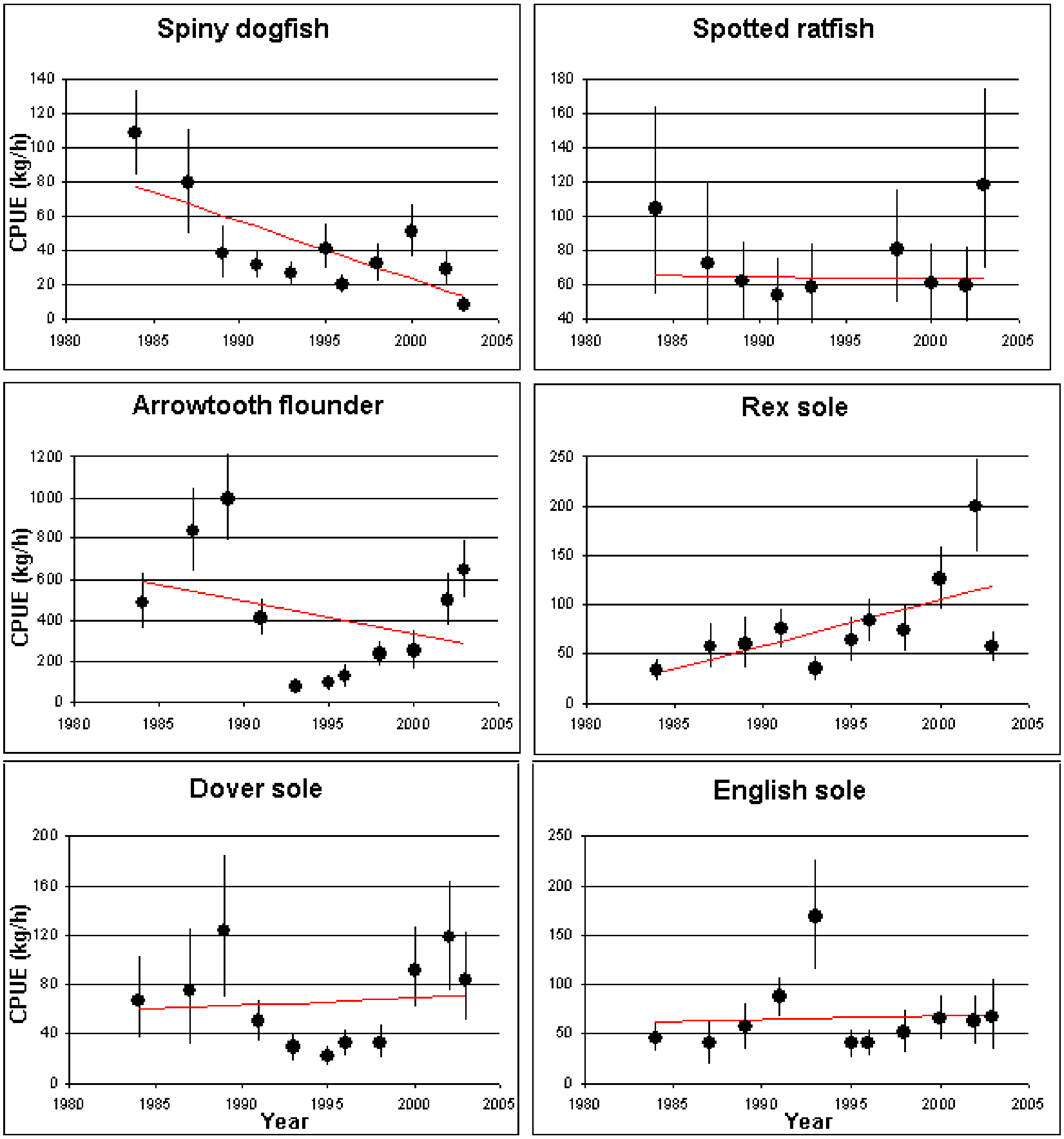

Figure 25. Mean CPUE (backtransformed) and 90% confidence interval for dominant species in the Butterworth Assemblage, 1984-2003.

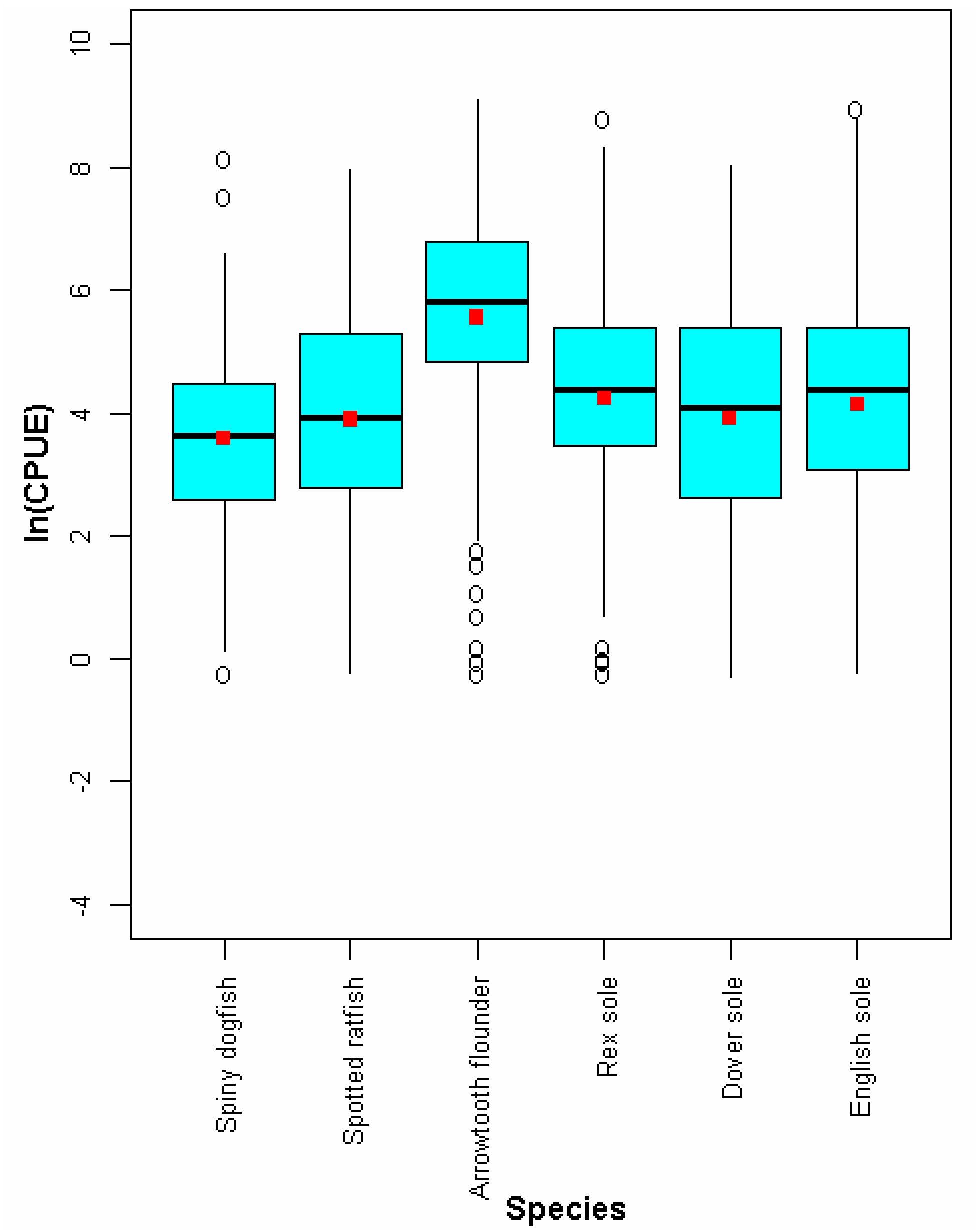

Figure 26. Boxplots of ln(CPUE) for dominant species in the Butterworth assemblage, 1984-2003. Points in red represent the mean value.

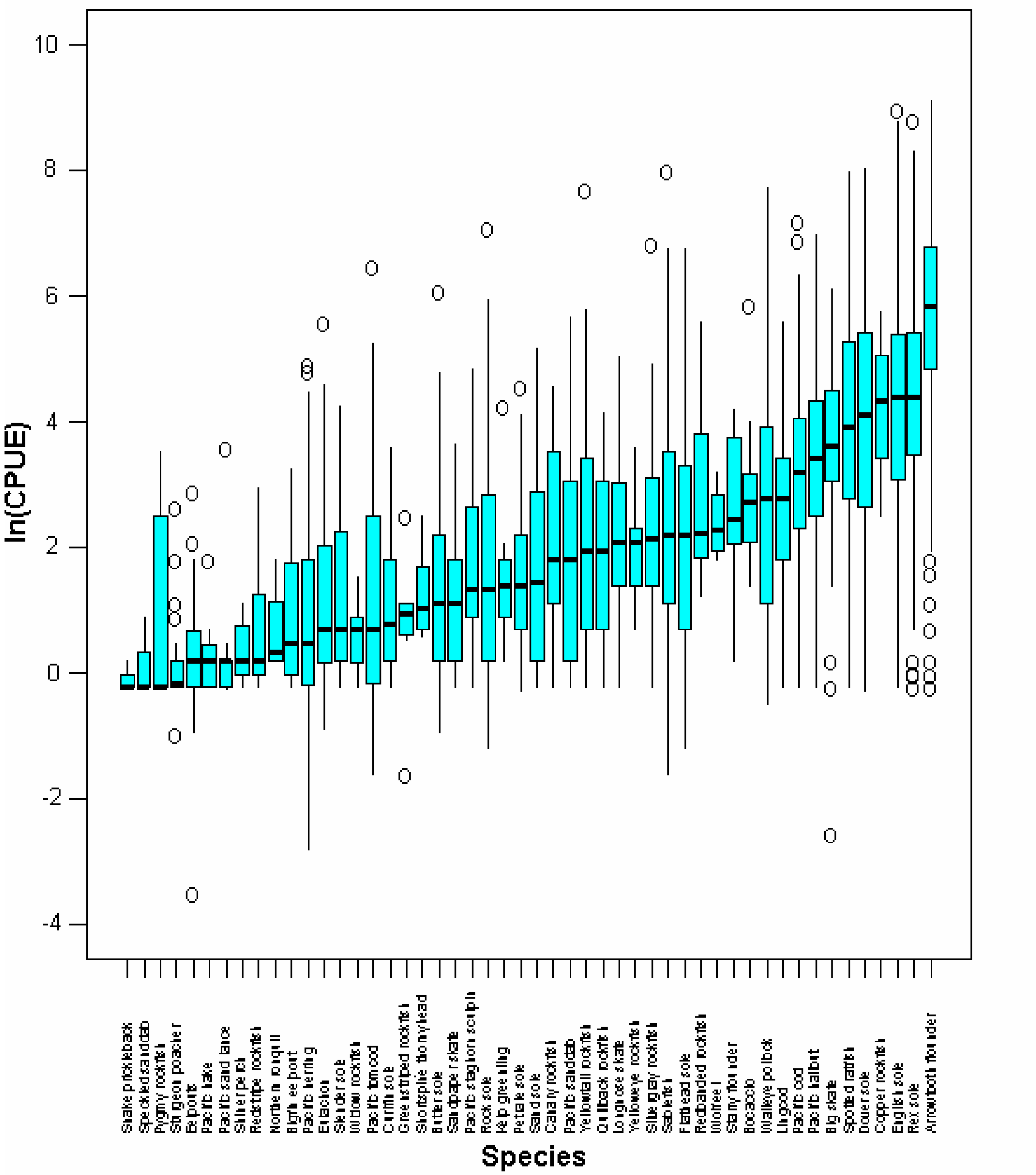

Figure 27. Boxplots of ln(CPUE) for all species in the Butterworth assemblage, 1984-2003.

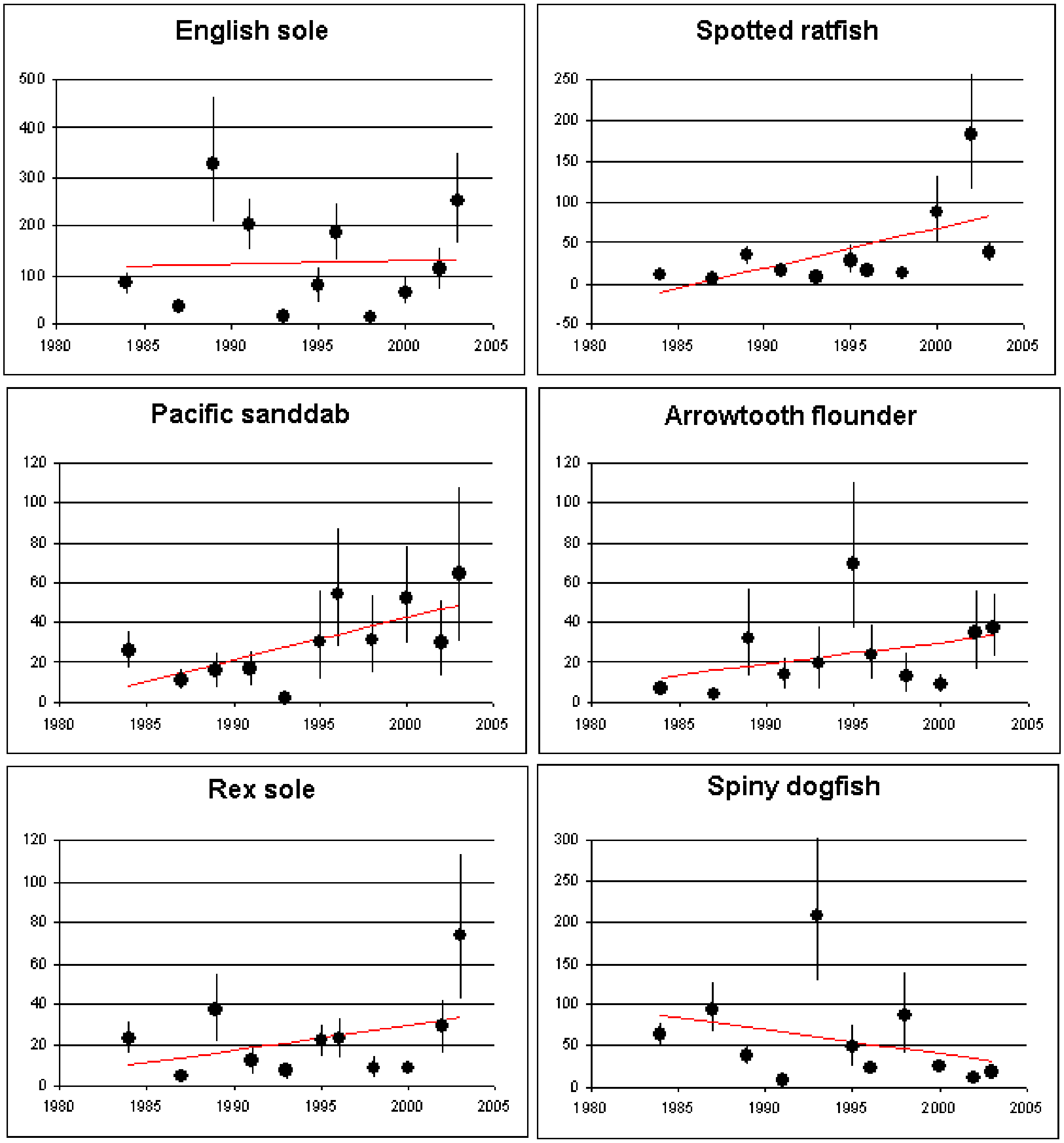

Figure 28. Mean CPUE (backtransformed) and 90% confidence interval for dominant species in the Bonilla Assemblage, 1984-2003.

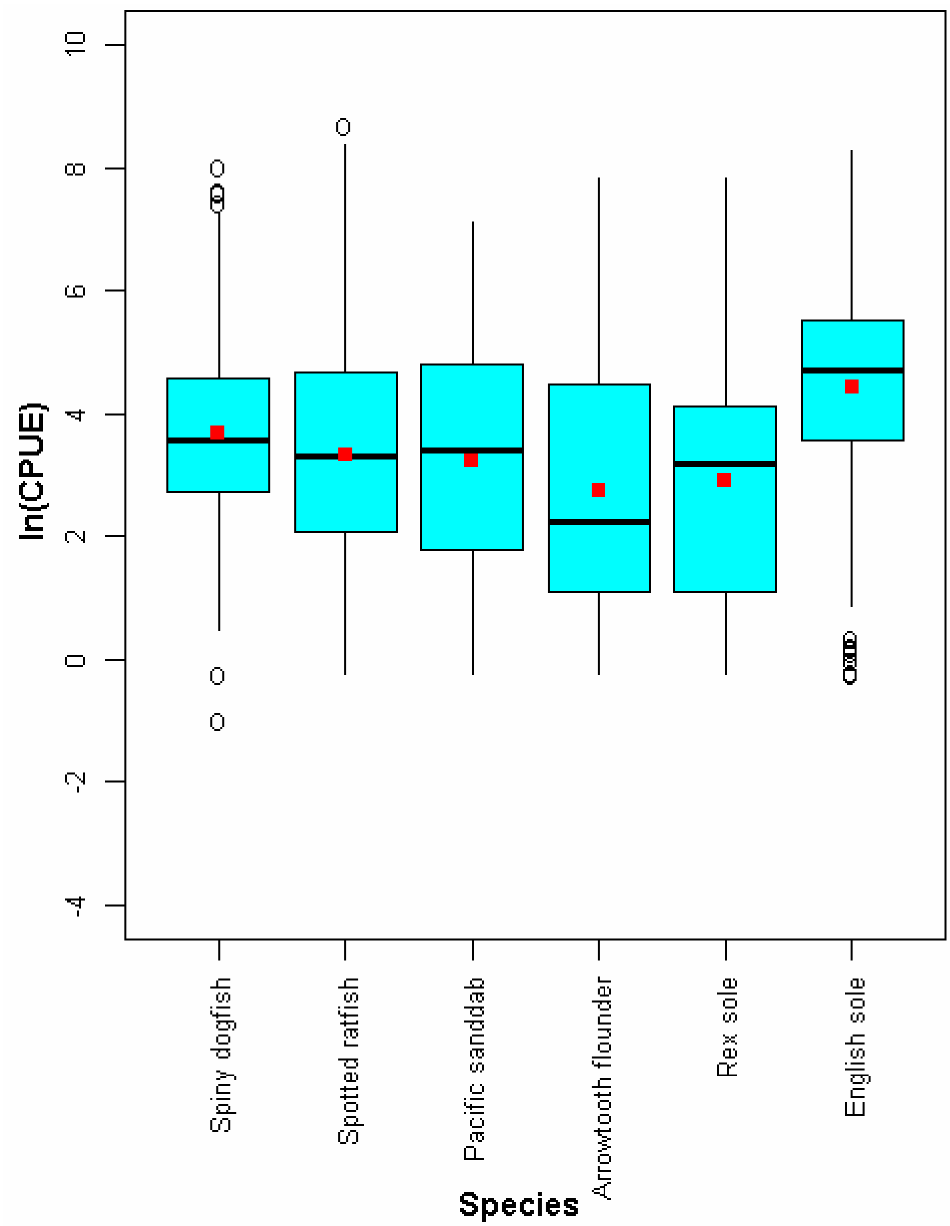

Figure 29. Boxplots of ln(CPUE) for dominant species in the Bonilla assemblage, 1984-2003. Points in red represent the mean value.

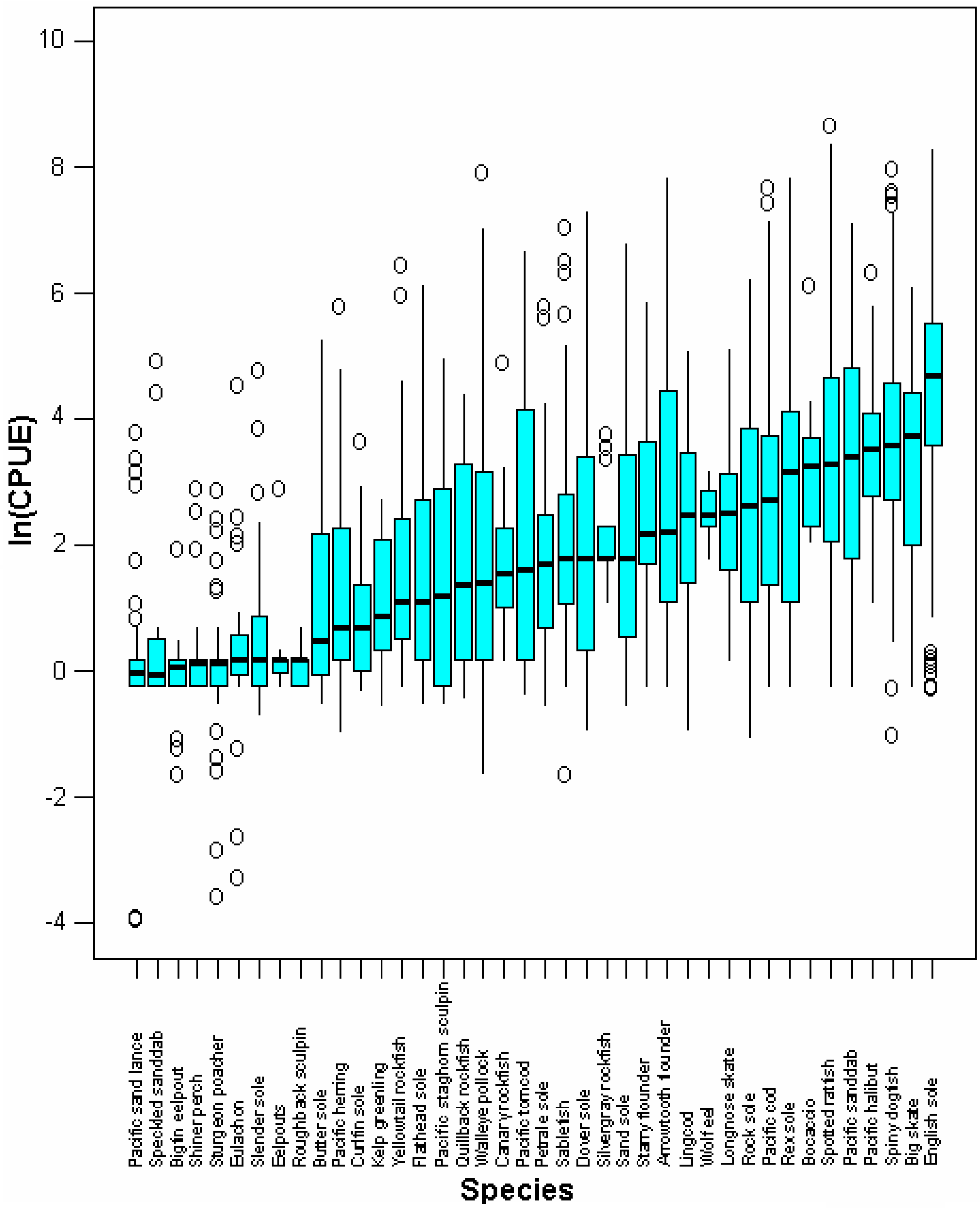

Figure 30. Boxplots of ln(CPUE) for all species in the Bonilla assemblage, 1984-2003.

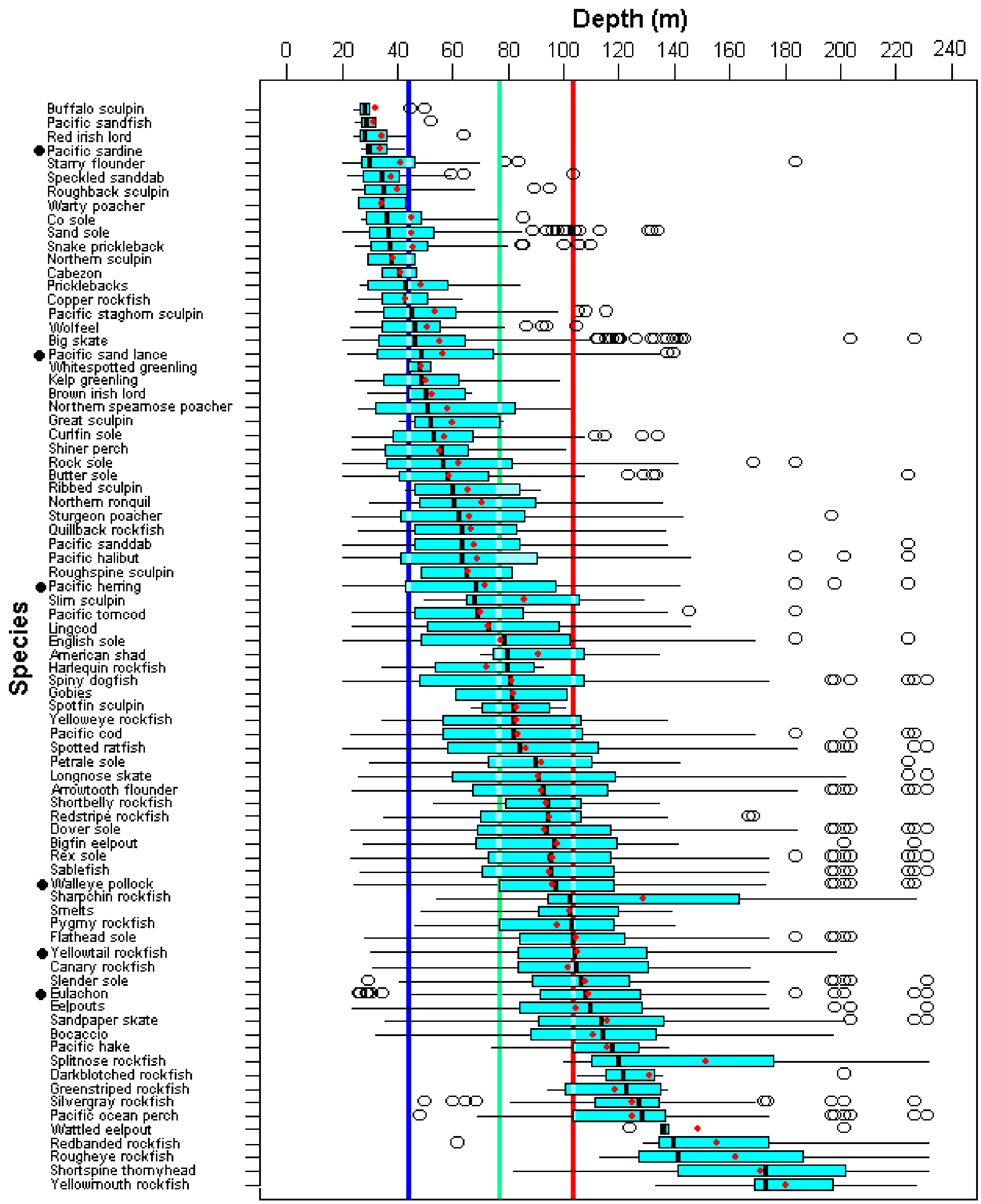

Figure 31. Boxplots of depth for species in all assemblages, 1984-2003. Red dots indicate the mean value. Black dots indicate pelagic or semi-pelagic species.

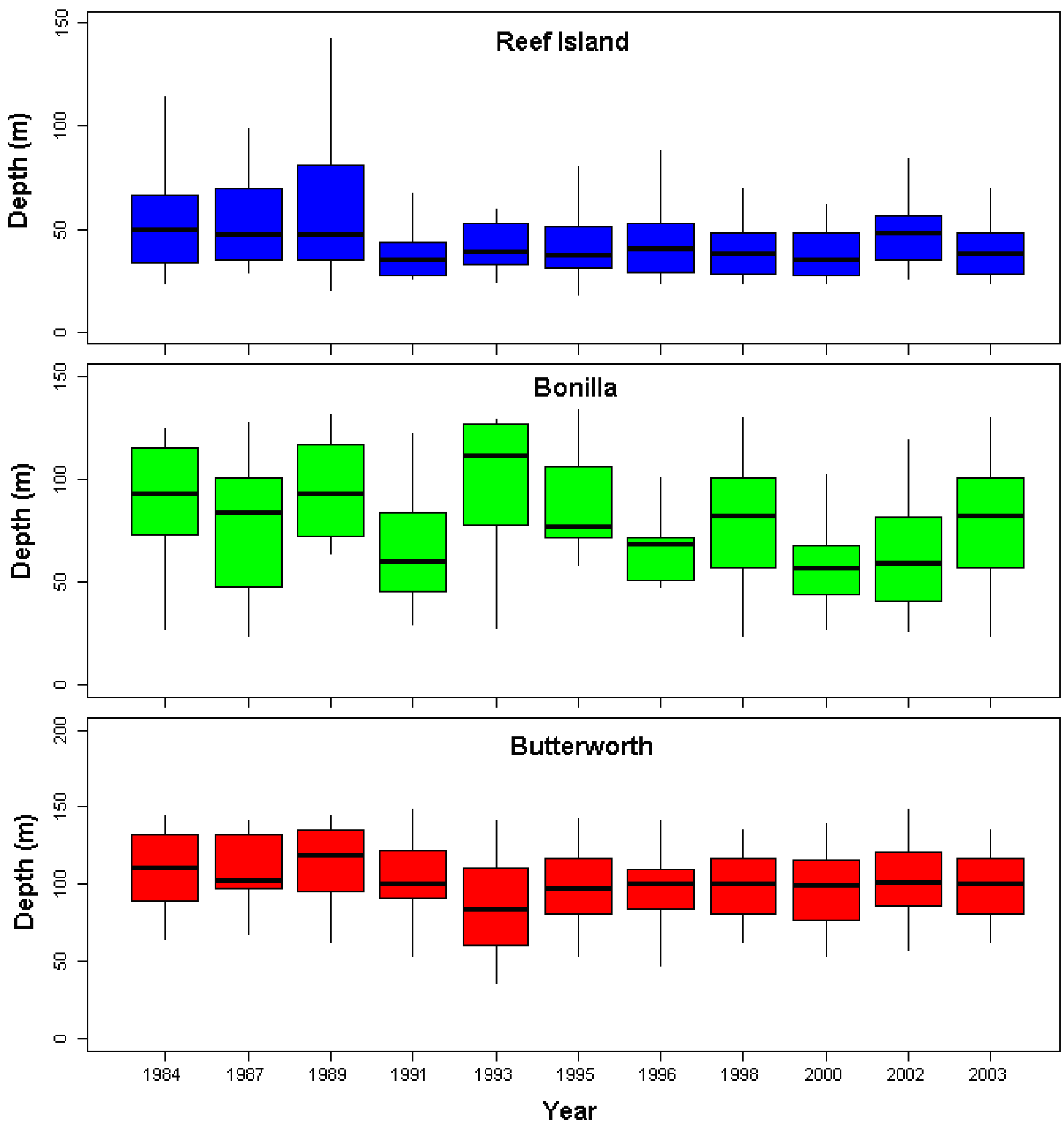

Figure 32. Boxplots of depth by year for the three assemblages.

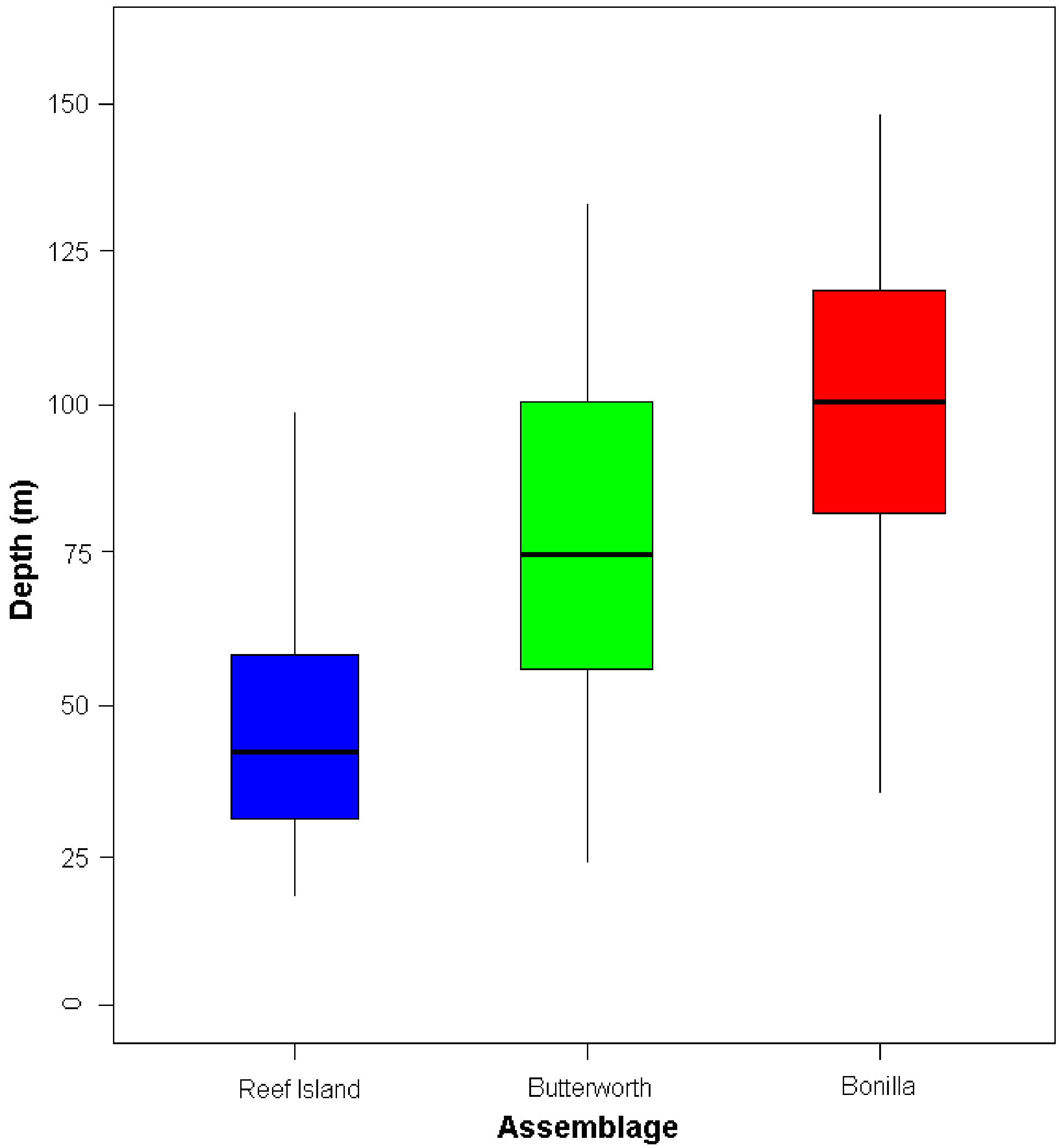

Figure 33. Boxplots of depth by assemblage.

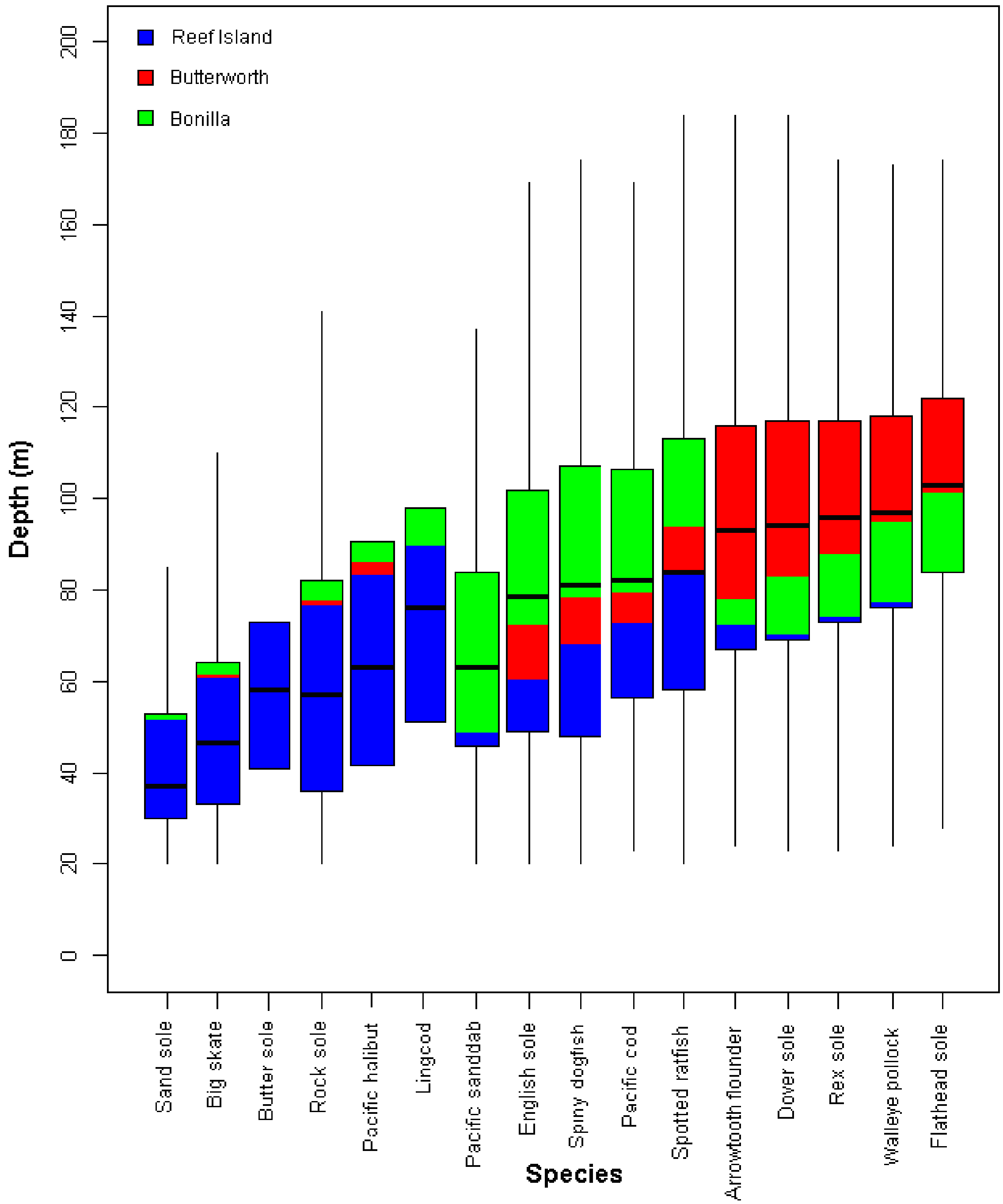

Figure 34. Boxplots of depth by dominant species for the combined Hecate Strait assemblage surveys. The colours in the box are proportional to the relative abundance of each species in each assemblage.

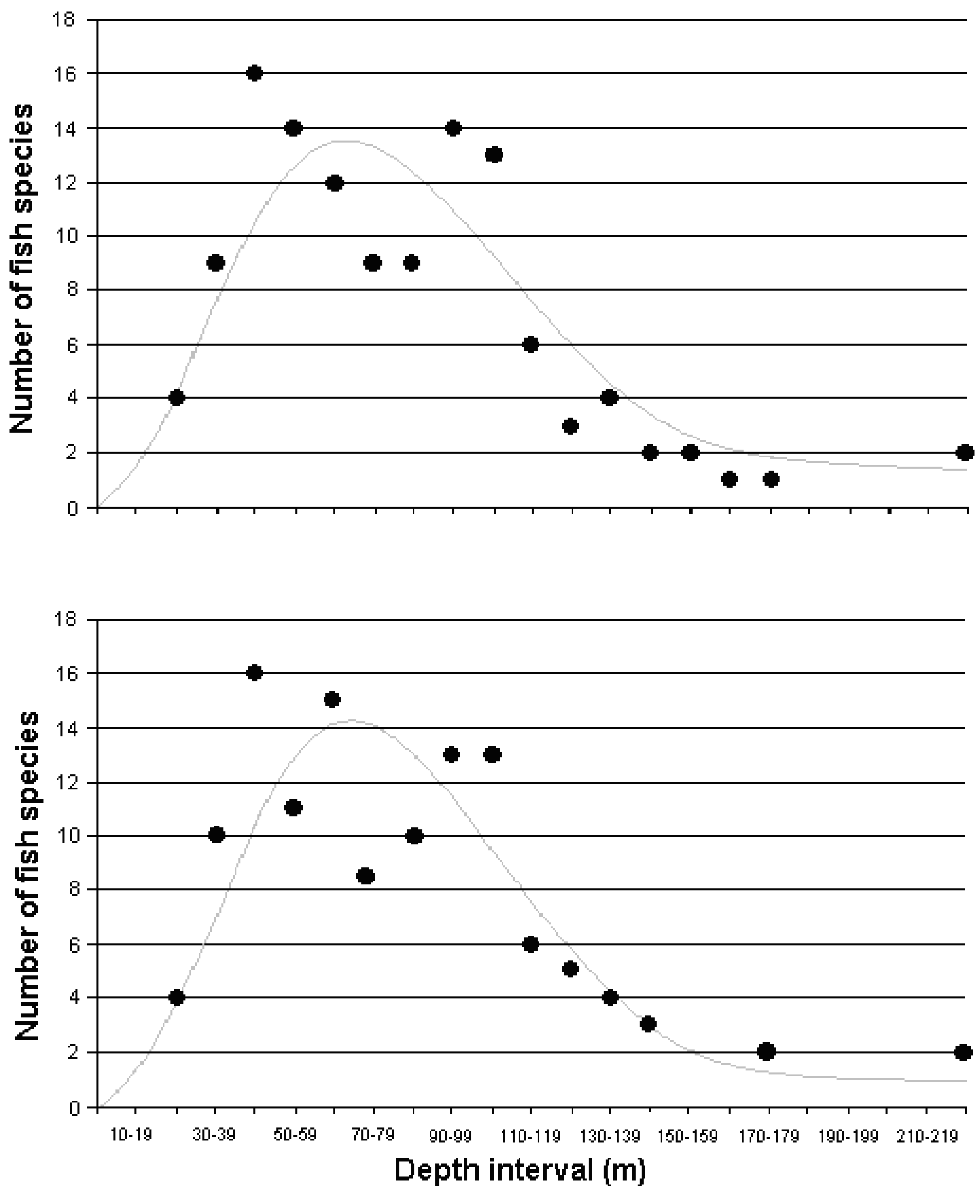

Figure 35. The relationship between mean depth (top panel) and median depth (bottom panel) and the number of species encountered for surveys combined.

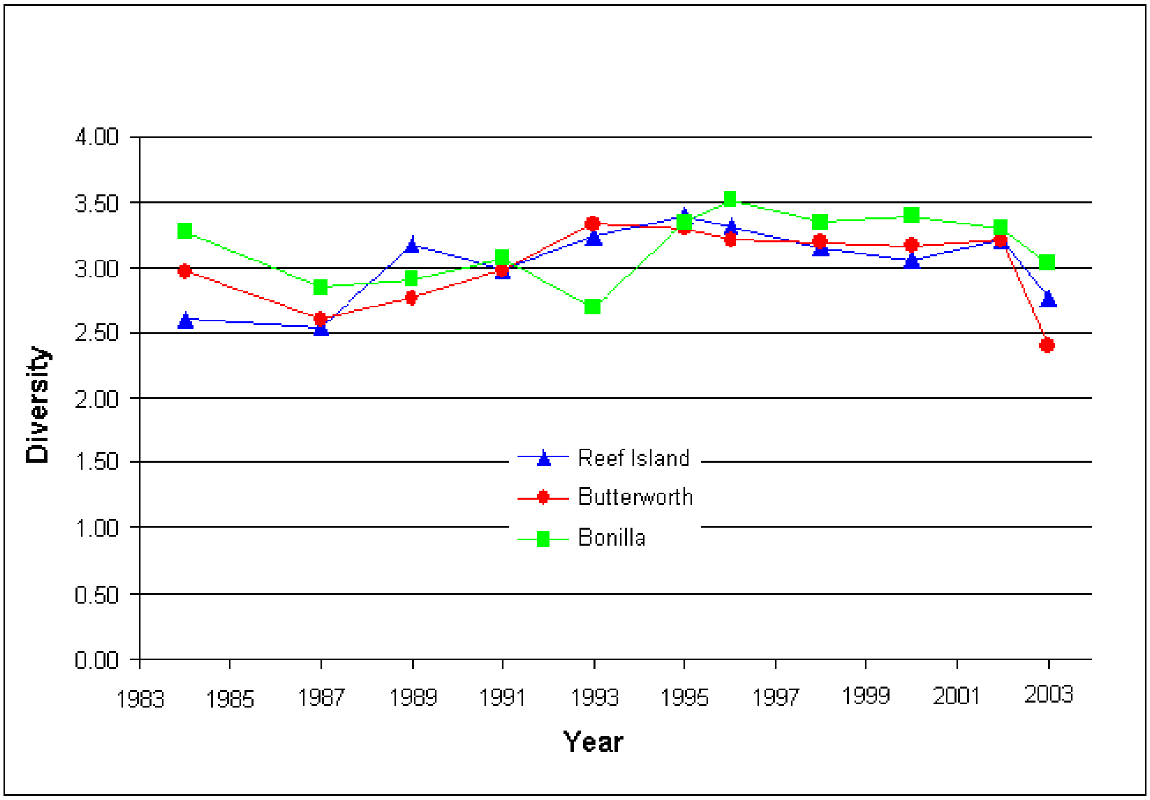

Figure 36. Diversity index (1984-2003) by assemblage for Hecate Strait determined from Assemblage Survey catch rate data.

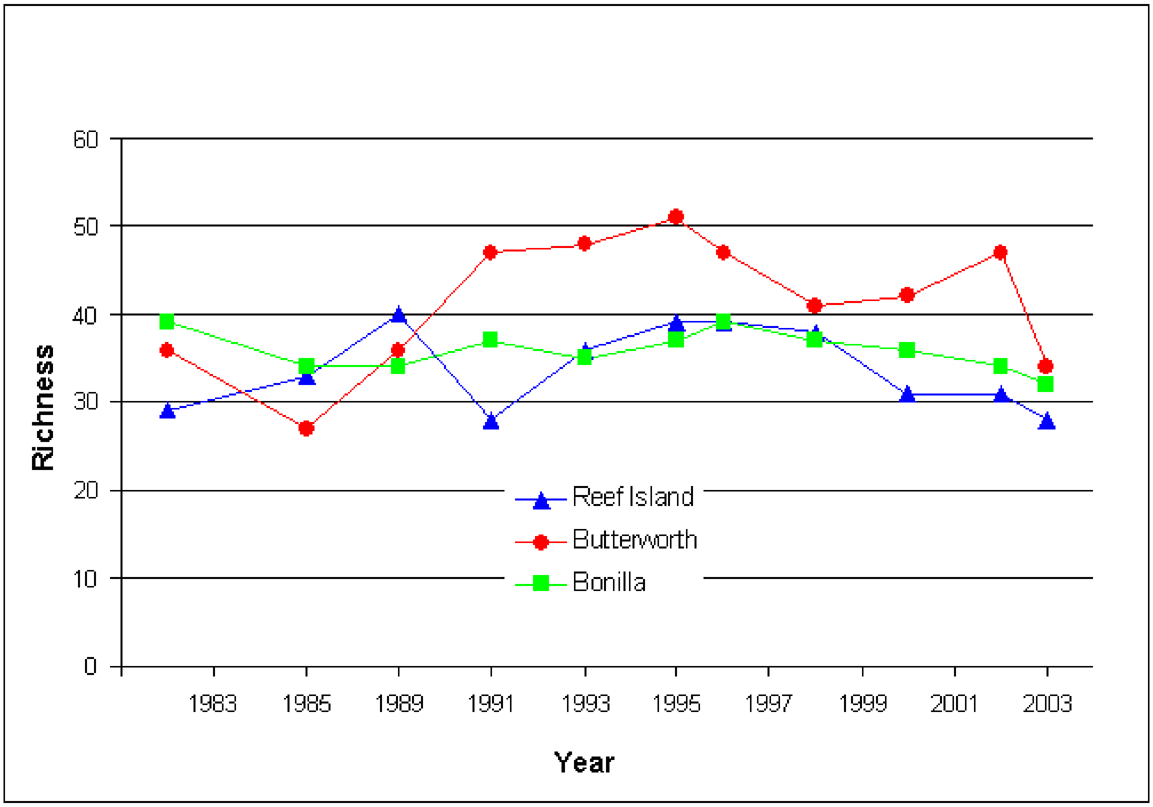

Figure 37. Richness index (1984-2003) by assemblage for Hecate Strait determined from Assemblage Survey data.

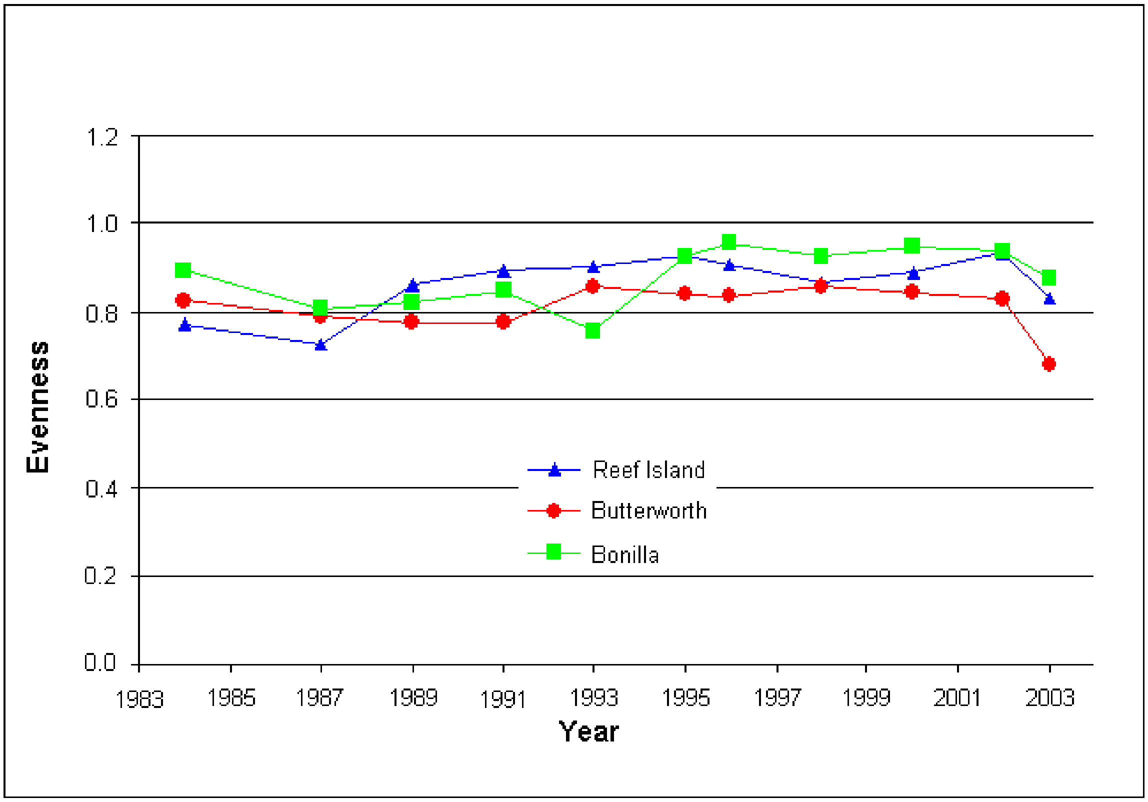

Figure 38. Evenness index (1984-2003) by assemblage for Hecate Strait determined from Assemblage Survey data.