

**Inter-annual variability in the diets of hoki, hake, and ling
on the Chatham Rise from 1990 to 2009**

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**Published by Ministry of Fisheries
Wellington
2010**

ISSN 1176-9440

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**Ministry of Fisheries
2010**

Horn, P.L.; Dunn, M.R. (2010).
Inter-annual variability in the diets of hoki, hake, and ling on the Chatham Rise
from 1990 to 2009.
New Zealand Aquatic Environment and Biodiversity Report No. 54.

This series continues the
Marine Biodiversity Biosecurity Report series
which ceased with No. 7 in February 2005.

EXECUTIVE SUMMARY

Horn, P.L.; Dunn, M.R. (2010). Inter-annual variability in the diets of hoki, hake and ling on the Chatham Rise from 1990 to 2009.

New Zealand Aquatic Environment and Biodiversity Report 2010/54.

This report describes analyses of the semi-quantitative gut content data that have been collected routinely for hoki (*Macruronus novaezelandiae*), hake (*Merluccius australis*), and ling (*Genypterus blacodes*) during research trawl surveys on the Chatham Rise between 1989 and 2009, with the aim of identifying any major shifts in predator-prey relations during that time. All data used were collected during summer (December–January) to reduce biases related to potential seasonal fluctuations in diet. The available data fell into two categories. Data from 2005, 2006, and 2007 had been derived from laboratory examinations of stomachs, and the contents were identified to a relatively high taxonomic level. Data from all other years (1990, 1992–2004, 2008–09) were derived from at-sea examinations of stomachs. Gut contents were often identified much less comprehensively at sea than was possible in the laboratory (generally only to the broad groups fish, prawn, or squid). Consequently, for each of the three predator species, two analyses were completed. The first used all the available data ‘collapsed’ into broad groups, and the second using only data that had been identified to a relatively high taxonomic level.

Analyses using all the data in broad prey groups exhibited no strong changes or trends over time for any of the three predator species. Analyses using data where prey that had been identified to a higher taxonomic level were generally data-poor (particularly for ling and hake). Differences between years were found for hoki and hake, but some of these were likely to be a consequence of the more precise identifications that were completed in the laboratory, relative to at-sea identifications.

For hake, there were no obvious between-year differences or trends in diet between 1990 and 2009, other than those probably related to the more comprehensive laboratory analyses of 2005–07 samples, and the systematic change in the mean size of hake over the period analysed.

For ling, there were some marked between-year differences in diet, but the differences were erratic; it was not possible to link estimated changes in abundance of common fish prey species to the ling diet. The potential importance of commercial fishing discards in the ling diet probably blurred relationships between some prey species abundance and their occurrence as ling prey. There was a potential inverse relationship between fish and galatheids in ling diet.

For hoki, the proportion of fish prey (primarily myctophids) in the diet appeared to have increased between 1990 and 2009, relative to prawn and euphausiid prey.

1. INTRODUCTION

Trophic relationships play a key role in how changes to the environment affect fish stocks, and to what extent stocks of different fish species are interconnected. The objective of the work presented here was to determine whether the semi-quantitative gut-content data that have been collected routinely for hoki (*Macruronus novaezelandiae*), hake (*Merluccius australis*), and ling (*Genypterus blacodes*) during Chatham Rise trawl surveys from 1989 to 2009 indicated any major shifts in predator-prey relations. During this 20 year period, both the hoki population (which dominates the demersal fish community on the Chatham Rise) and the hake population have declined markedly (Francis 2009, Horn & Francis 2010) and, as a consequence, density dependent changes in diet might have occurred.

This report fulfils the reporting requirements for Objective 2 of Project ENV2007-06 “Trophic relationships of commercial middle depth species on the Chatham Rise”, funded by the Ministry of Fisheries. The overall objective of this project is to quantify the feeding relationships between commercial fish stocks on the Chatham Rise and the ecosystems that support them. Objective 2 is “To quantify the inter-annual variability in the diets of hoki, hake and ling on the Chatham Rise 1992–2007”. Objective 1 of this project (To quantify seasonal dietary cycles for hoki, hake, and ling) was reported elsewhere (Dunn et al. 2010).

The current project (ENV2007-06) is closely linked to the Chatham Rise trophic study (ZBD2004-02). Project ZBD2004-02 collected and analysed stomach samples from 25 species caught during three middle-depth trawl surveys on the Chatham Rise during December-January 2005, 2006, and 2007. The diet of each predator species has been described, and a trophic guild structure for the 25 demersal fish species on the Chatham Rise proposed (Dunn et al. 2009).

2. METHODS

All biological data, and associated tow position data, were extracted from the Ministry of Fisheries *trawl* database, where latitude ranged from 42.5–45.0° S off east coast South Island (i.e., the Chatham Rise), where the species was hoki, hake, or ling, and where the stomach had been examined (i.e., a stomach fullness category had been recorded).

The main time series was the *Tangaroa* summer trawl survey series, conducted annually and predominantly in January from 1992 to 2009 (dates of tows have ranged from 27 December to 6 February) (Livingston et al. 2002, Stevens et al. 2009). It was considered useful to also include a survey by FV *Amaltal Explorer* conducted from late November to late December 1989 (Hurst & Schofield 1990). The data set therefore included only tows conducted between 26 November and 6 February. A few surveys conducted outside these dates were excluded to remove any possibility of introducing seasonal biases in diet.

Stomach content data recorded in past trawl surveys were not collected in any systematic or rigorously randomised manner. Fish selected for biological analyses at sea were generally chosen roughly randomly, but not all were examined for stomach contents. Sometimes, larger hoki were included in the biological sample to ensure a full representation of otoliths across size classes. Distribution plots of examined stomachs were therefore produced to determine whether, for each survey, the available data were collected from throughout the survey area. To ensure that stomachs for which a fullness category had been recorded had been selected randomly (rather than, for example, the preferential selection of only full stomachs for stomach contents analysis), the proportion by species of recorded stomachs classified as empty was calculated and examined for consistency over the time series.

The procedure applied to recording the stomach contents of fish was as follows. When a stomach was examined, the available data were stomach fullness category (0, empty; 1, trace; 2, part full; 3, full), prey digestion state category (1, fresh; 2, part digested; 3, digested; 4, mixed digestion states), prey species code (which may be broad, e.g., PRA: “prawn”), and percentage of the food bolus that each prey species comprised. If only one prey was recorded in a stomach, its percentage volume was 100. If two or more prey species were identified, then the percentage volume made up by each prey species was qualitatively

estimated by eye, with the sum of all the percentages being 100. If a prey item could not be identified it was still allocated a code (UNF: “unidentifiable”) and percentage volume.

The samples collected under Project ZBD2004-02 were analysed in detail in the laboratory, but prey number and weight were recorded instead of prey volume. To include data from the 2005, 2006, and 2007 surveys in the current analysis, it was necessary to convert them to percent volume. This was done by assuming that, for all prey categories, weight was proportional to volume. For example, if a stomach had been found to contain 12 g of isopods and 24 g of lanternfish, then it was allocated the percentages 33% isopod and 67% lanternfish. This assumption allowed a dataset to be created across all sample years. The use of prey volume also effectively standardised the observations, thereby ensuring that each stomach had the same influence on the estimated diet, regardless of whether it was full or contained only a trace of prey. Data from prey of all digestion states were used in the analysis.

To complete detailed analyses of diet by predator species, it was necessary to aggregate the prey items into taxonomic groups. Data from stomachs examined at sea (i.e., all surveys except those by *Tangaroa* in 2005, 2006, and 2007) were the least taxonomically detailed so were used to determine the prey groups for each predator. The more detailed data from the 2005–07 surveys were then added after they had been ‘collapsed’ to these taxonomic groups. The resulting prey groups differed between species, and are described in the results.

The contribution of different prey items to the diet was determined by the frequency of occurrence (%F). Other frequently used metrics, such as prey weight, prey abundance, and the index of relative importance (a composite statistic), were not possible for the data set examined here. Bootstrap methods, using 1000 replicates of random samples, with replacement, of stomachs from the data set were used to estimate confidence intervals (2.5th and 97.5th percentiles) around %F.

A three-dimensional Principal Component Analysis (PCA) implemented using PRIMER version 6.1.11 (Clarke & Gorley 2006) was used to identify which of potential predictors explained most of the variability in diet (Anderson et al. 2008). The percent volumes were square root transformed. The square root transformation has been considered the most appropriate for proportion data (K.R. Clarke, pers. comm., reported in Platell & Potter (2001)); this transformation reduces the contribution of highly abundant species in relation to less abundant ones. The potential predictors included fish length, weight, and sex, and the latitude, longitude, depth, bottom temperature, time of day, and year of the tow in which the fish was captured. Latitude, longitude, and time of day were recorded at the start position of the tow. Depth was calculated as the mean of the maximum and minimum fishing depths, and bottom temperature as the mean of recordings taken at 10 minute intervals throughout the tow.

The three most significant predictors from the PCA were selected as the explanatory model to identify the main causes of dietary variability. However, only the most significant of strongly correlated pairs of predictors was selected (i.e., where $R^2 > 0.9$). For example, both the fish length and weight predictors were often significant, but because they are strongly correlated (typically $R^2 > 0.98$), only one of these (the most significant) was included in the final model.

To further investigate the effects of the predictors identified from the PCA, the continuous predictors were first binned into 6 (for hake) or 10 (for hoki and ling) groups. The bin limits were chosen so that the number of observations in each bin was roughly equal. The binning of data in this way was considered objective, given that there were no *a priori* known biologically meaningful boundaries for these predator species. The binned data were averaged (mean of normalised proportions of prey species), square-root transformed, and then analysed using non-parametric multidimensional scaling (MDS), followed by ANOSIM and SIMPER tests implemented using PRIMER (Clarke & Warwick 2006). The non-parametric MDS represents the binned samples as points in a two- or three-dimensional space such that the relative distances between the points are in the same rank order as the relative (Bray-Curtis) dissimilarities. The ANOSIM (Analysis of Similarities) method is analogous to a multivariate analysis of variance, and was used to confirm the significant effect of the predictors identified by PCA after the data were grouped into bins. It is a non-parametric permutation procedure, applied to the rank dissimilarity matrix, where the null hypothesis is no significant difference between groups. The test statistic is R , takes a value of between -1 and 1. Typically, if R is within 0.3 of zero,

then the differences between groups are considered to be negligible (Clarke & Gorley 2006). The SIMPER (Similarity Percentages) method interprets the differences given that they have been shown to exist (using PCA or ANOSIM). It identifies the discriminating prey groups which have the largest average contribution to the overall Bray-Curtis dissimilarity, i.e., it shows which prey species are characteristic of the diet in each group. The actual mean percentage contributions of the prey groups identified by SIMPER were then plotted to show the main differences in dietary composition between bins.

3. RESULTS

3.1 Available data

Table 1 lists the numbers of hoki, hake, and ling for which stomach content information was available, for any Chatham Rise trawl survey conducted between late November and early February in any year. Most data were collected on the *Tangaroa* trawl surveys, conducted annually, predominantly in January. The *Amaltal Explorer* survey (aex8903) in December 1989 also provided a useful quantity of data. The 26 hake stomachs collected during a *James Cook* survey (jco8913) can be aggregated with the aex8903 sample, as these two surveys were concurrent. Insufficient data were available from survey jco8101. Only hake stomach data were collected during the *Oyang 7* survey in December 1984, but the sample size is relatively high.

Table 1: Numbers of hoki, hake, and ling samples available, by survey code, where stomach contents have been recorded during summer trawl surveys on the Chatham Rise.

Survey	Hoki	Hake	Ling
jco8101	4	39	0
oy78401	0	136	0
jco8913	0	26	0
aex8903	664	124	555
tan9106	654	176	508
tan9212	596	150	426
tan9401	443	136	475
tan9501	309	101	178
tan9601	636	49	280
tan9701	303	82	213
tan9801	399	63	154
tan9901	460	42	95
tan0001	971	78	714
tan0101	871	74	666
tan0201	1 553	87	556
tan0301	121	7	96
tan0401	182	36	583
tan0501	743	181	708
tan0601	337	156	337
tan0701	413	171	286
tan0801	970	46	360
tan0901	903	61	387

The geographical distributions of the sampled stomachs, relative to the distribution of all tows in the surveys, are presented in Appendices A (for hoki), B (for hake), and C (for ling). For hoki, the sampled stomachs were distributed throughout the survey area during the *Amaltal Explorer* survey and most of the *Tangaroa* survey series. However, tan0301 was clearly sampled inadequately.

For hake, the *Oyang 7* survey sampled only in a known hake spawning area; these data were therefore not included in the analysis as they are not likely to be representative of the hake population on the entire Chatham Rise. Stomach samples from the *Amaltal Explorer* and *Tangaroa* surveys had distributions comparable to the distribution of all hake catches in those surveys, except in tan0301 where sampling was inadequate. Some other *Tangaroa* surveys had relatively low numbers of sampled

stomachs (i.e., tan9601, tan9801, tan9901, tan0401, tan0801, tan0901), but this was because only small numbers of fish were caught during those surveys.

For ling, the sampled stomachs were distributed throughout the survey area for the *Amaltal Explorer* survey and most of the *Tangaroa* survey series. However, tan9901 and tan0301 were sampled inadequately.

The proportion of survey tows for which stomach content data were collected varied between surveys (Figure 1). In surveys before 1996, stomach information was recorded for most fish that were sampled for detailed biological data (e.g., length, weight, sex etc). However, since 1996, many fish examined for detailed biological information did not have their stomach sampled, although for most species and surveys less than 40% of fish fell into this category. But on some surveys (e.g., tan0301) hoki, hake, and ling were particularly poorly sampled for stomach information.

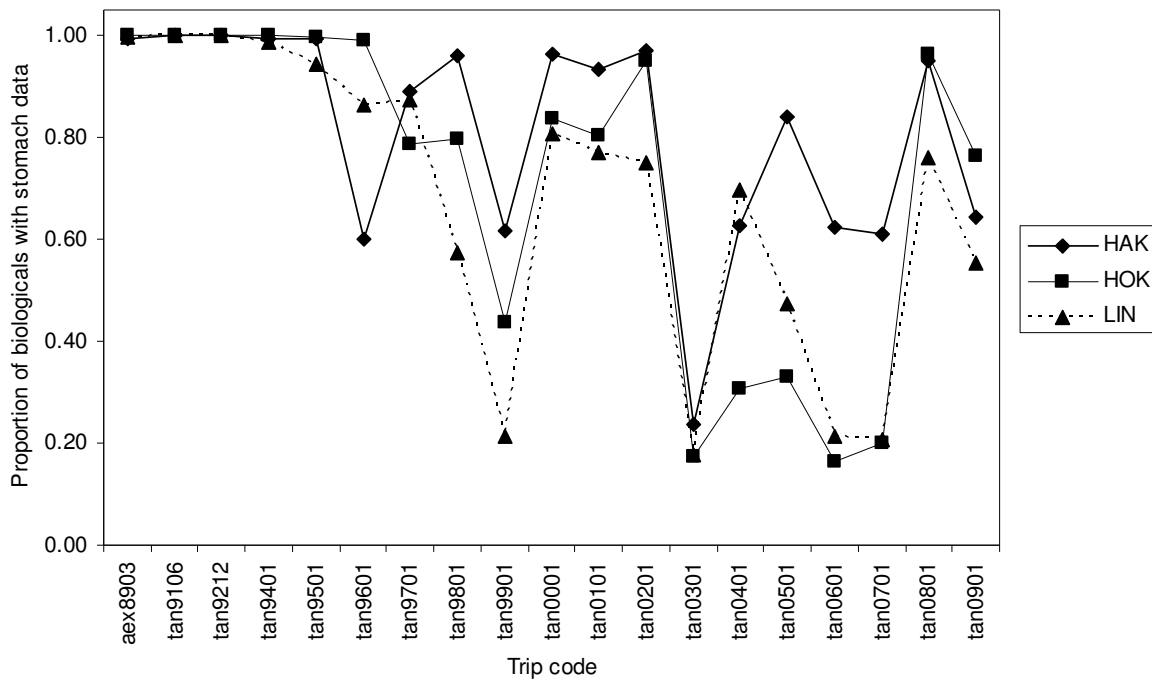


Figure 1: Proportions of fish where biological data included information on stomach contents, by species and survey. HAK, hake; HOK, hoki; LIN, ling.

The numbers of stomachs for which data were available are shown in Figure 2. Note that this plot shows all stomachs that were examined, including those found to be either empty or everted.

The proportion of examined stomachs that were classified as empty was relatively consistent (by species) throughout 1990 to 2009 (Figure 3). There were differences between species; on average, 72% of examined hake stomachs were empty, compared with 56% of ling stomachs and 53% of hoki stomachs. However, these data suggest that the method used to select stomachs for examination was generally consistent between surveys, i.e., in any one year there had not been a preferential selection of only full stomachs for stomach contents analysis. When biological data were collected for a species at a particular trawl station, it was usual for 20 specimens to be examined (or the entire catch, if it comprised fewer than 20 specimens, as was often the case for hake). An examination of the data indicated that when stomach content data were recorded for one fish in a biological sample, it was usually recorded for all fish in that sample.

Each stomach was classified as either containing some food, being empty, or being everted. Eversion occurs when an inflating swim bladder (a consequence of the fish being rapidly brought up from depth) forces the stomach (and most or all of its contents) out through the mouth of the fish. The

proportion of stomachs that were recorded as everted varied between species, but were low for all, at 3.4% for hake, 1.5% for hoki, and 1.0% for ling.

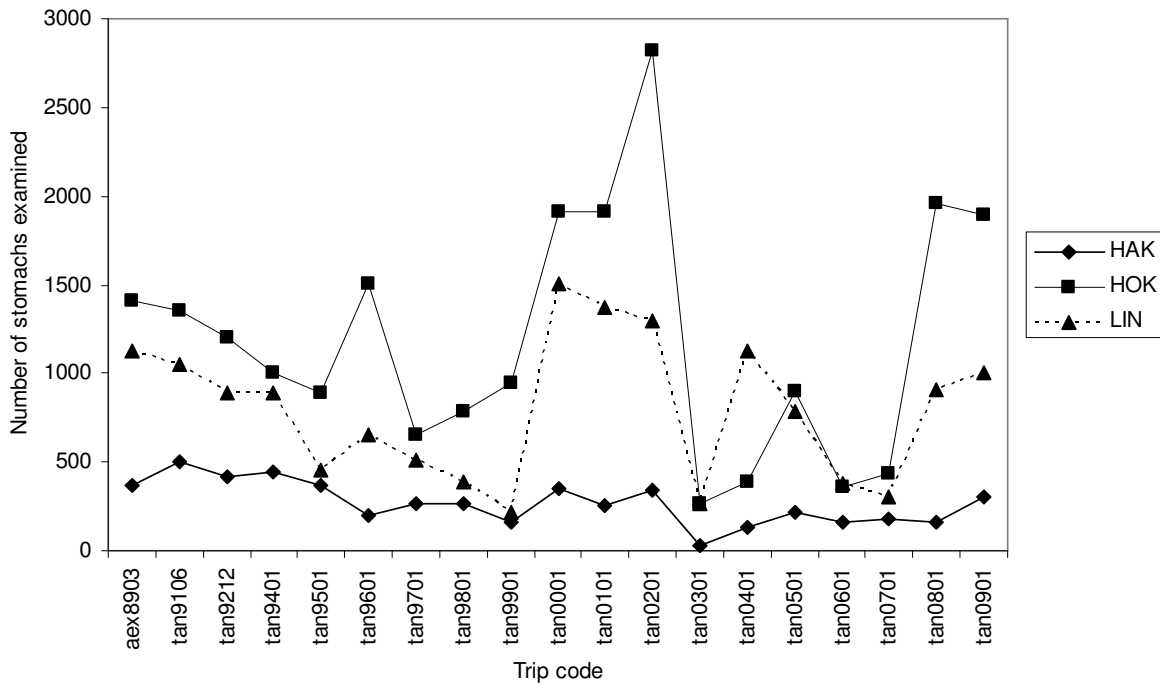


Figure 2: Numbers of fish for which stomach state was recorded, by species and survey. HAK, hake; HOK, hoki; LIN, ling.

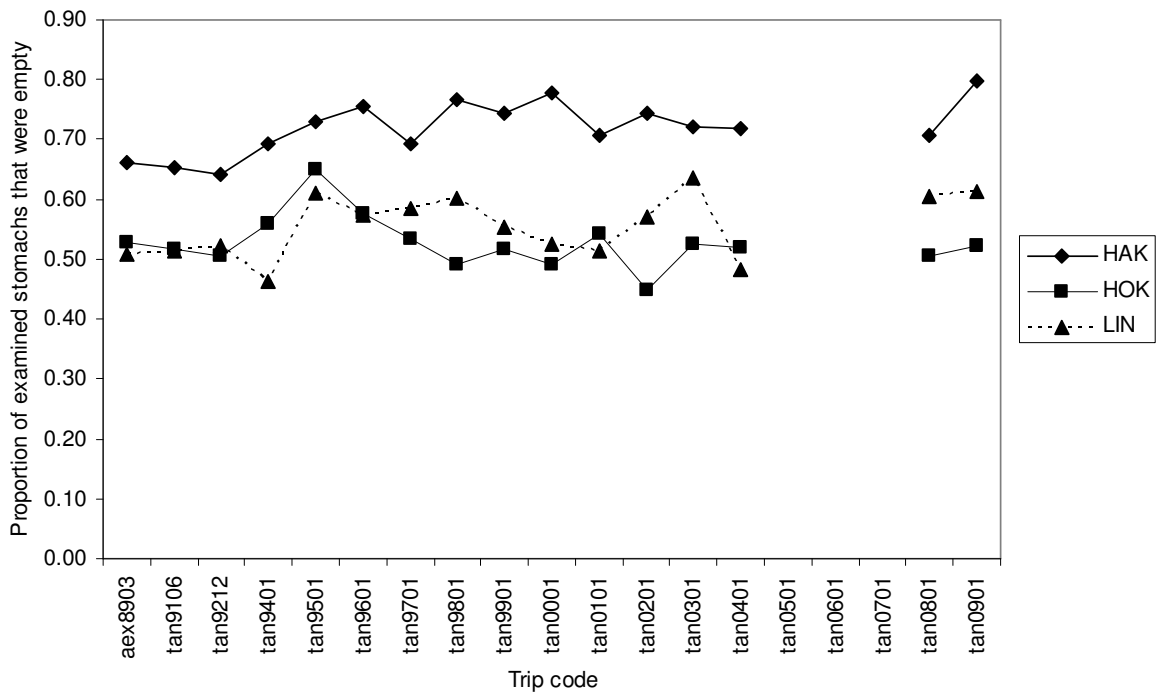


Figure 3: Proportions of examined stomachs that were classified as empty, by species and survey. HAK, hake; HOK, hoki; LIN, ling. Proportions are not shown for tan0501, tan0601, and tan0701 because little 'at sea' stomach fullness information was collected during these surveys.

In conclusion, it is apparent that stomach content data from individual tows were recorded in a consistent manner across surveys, and were not biased by the preferential selection of full stomachs. Surveys providing suitable quantities of comprehensive and consistently collected data from the

Chatham Rise were limited to the December 1989 *Amaltal Explorer* survey, the December 1989 *James Cook* survey (for hake only), and the *Tangaroa* summer series conducted each year from 1992 to 2009.

Analyses of detailed stomach contents (Dunn et al. 2009) has indicated that the approximate numbers of stomachs required to describe the diets of hoki, hake, and ling were roughly 100, 125, and 200, respectively, although the amount required depends on the level of taxonomic identification of prey (coarser identification requires fewer samples). Hence, it was considered desirable that each ‘annual’ sample in the current study should comprise at least those numbers of stomachs. Because of the relatively low numbers of examined stomachs available in some years, and the requirement of the minimum sample sizes noted above, we either excluded data from some years or combined data from adjacent years. For hoki, one combination was necessary (tan0301 + tan0401), owing to the inadequate size and distribution of the tan0301 samples. For ling, two combinations were necessary (tan9801 + tan9901, and tan0201 + tan0301), owing to the low sample numbers in tan9901 and tan0301. For hake, it was necessary to pair and combine most surveys after tan0501, owing to low numbers of fish caught in individual surveys. The resulting sample sizes, as used in the following analyses, are shown in Table 2.

Table 2: Sample structure used in the current analysis of hoki, hake and ling stomach contents on the Chatham Rise. *N*, sample size.

<u>Hoki</u>		<u>Hake</u>		<u>Ling</u>	
Survey(s)	<i>N</i>	Survey(s)	<i>N</i>	Survey(s)	<i>N</i>
aex8903	664	aex8903 + jco8913	150	aex8903	555
tan9106	654	tan9106	176	tan9106	508
tan9212	596	tan9212	150	tan9212	426
tan9401	443	tan9401	136	tan9401	475
tan9501	309	tan9501	101	tan9501	178
tan9601	636	tan9601 + tan9701	131	tan9601	280
tan9701	303	tan9801 + tan9901	105	tan9701	213
tan9801	399	tan0001 + tan0101	152	tan9801 + tan9901	249
tan9901	460	tan0201 + tan0301	94	tan0001	714
tan0001	971	tan0401 + tan0501	217	tan0101	666
tan0101	871	tan0601	156	tan0201 + tan0301	652
tan0201	1 553	tan0701	171	tan0401	583
tan0301 + tan0401	303	tan0801 + tan0901	107	tan0501	708
tan0501	743			tan0601	337
tan0601	337			tan0701	286
tan0701	413			tan0801	360
tan0801	970			tan0901	387
tan0901	903				

3.2 Hoki diet analysis

Of the 11 528 non-empty stomachs examined, 373 (3.2%) contained only unidentifiable material and 174 (1.5%) contained crustacean prey that could only be broadly classified (i.e., unidentified crustacean or unidentified euphausiid/prawn/mysid), leaving 10 981 for analyses of diet (95.3%). Stomachs were sampled from hoki 34–114 cm TL.

Two analyses of diet variability were completed, with different levels of prey identification:

(1) In an initial general analysis of hoki diet, prey items were aggregated into broad taxonomic groups (Table 3). Fish were aggregated at a phylum level. Of the 7888 records of fish prey, 4182 (53%) were unidentified fish (FIS), unidentified mesopelagic fish (MES), unidentified rattail (RAT), otoliths (OTO), or scales (SCL). Because fish were the most frequent prey group for hoki, we included all items at the phylum classification level, rather than excluding these broad categories and thus deleting about 30% of the data set. Natant decapods were grouped together as ‘prawns’. Most of this group had been originally classified as either NAT (“natant decapod”) or PRA (“prawn”) (68%). Of the

“prawns”, 17% were identified as *Pasiphaea* spp., and 13% were *Sergestes* spp. Other arthropod prey were aggregated at the order level, and all other prey groups at the class level, except Cephalopoda which were split into squids and octopods. It is possible that some of the minor prey groups (e.g., mollusc shell fragments) observed in the hoki stomachs were secondary prey, or were accidentally ingested along with a target prey item. Nevertheless they were included as they would have formed part of the diet. These items were rare and had little or no influence on the results.

(2) Because fish and ‘prawns’ were such important prey categories, a second more detailed analysis was completed using the same data set but excluding the 4182 fish prey (unidentified fish, otoliths, scales, mesopelagic fish, and rattails) and 2142 crustacean prey (unidentified prawns) records that had been only broadly classified. The remaining prey were identified to order, family, genus, or species, as shown in Table 3, except that all lanternfish (Myctophidae) were included as a single prey group. This subsample comprised 6178 stomachs, with the number of samples per year ranging from 109 to 930.

3.2.1 Overall diet

Unidentified fish was the most commonly recorded prey item, occurring in 35% of stomachs (Table 3). Unidentified myctophids were the next most important prey items, occurring in 22% of stomachs (26% of stomachs when all family Myctophidae were combined). Unidentified prawns occurred in 19% of stomachs, increasing to 27% when all prawn prey were combined. Euphausiids were also an important prey group, occurring in 18% of stomachs. Cephalopod prey were relatively infrequent and were almost entirely squid, which occurred in 3% of stomachs.

Table 3: Hoki overall stomach contents composition from the Chatham Rise summer trawl surveys. Prey sorted by taxonomic group. Point estimate of percentage frequency of occurrence (%F), with 95% confidence intervals from bootstrap re-sampling. Statistics in bold are estimates by taxonomic group as used in the initial multivariate analysis.

Prey items	%F	Lower 95%	Upper 95%
Arthropoda			
Galatheidae	0.036	0	0.089
Galatheidae	0.035	0	0.060
Metanephrops challengeri	0.009	0	0.045
<i>Metanephrops challengeri</i>	0.009	0	0.059
Crabs	0.027	0	0.084
Unidentified crab	0.026	0	0.062
Prawns	26.855	21.236	31.419
<i>Funchalia</i> sp	0.017	0	0.112
<i>Sergestes</i> sp	3.175	2.008	3.041
<i>Camplyonotus rathbonae</i>	0.009	0	0.035
<i>Lipkius holthuisi</i>	0.043	0	0.106
<i>Oplophorus novaezeelandiae</i>	0.208	0.078	0.319
<i>Oplophorus spinosus</i>	0.026	0	0.043
<i>Systellaspis debilis</i>	0.035	0	0.052
<i>Acanthephyra pelagica</i>	0.026	0	0.044
<i>Acanthephyra</i> sp	0.052	0	0.062
<i>Notopandalus magnoculus</i>	0.165	0.034	0.247
<i>Pasiphaea</i> sp	4.189	2.539	3.728
Unidentified prawn	18.581	17.877	21.491
Euphausiacea	18.805	13.920	25.388
<i>Nematoscelis megalops</i>	0.009	0	0.035
<i>Nyctiphanes</i> sp	0.017	0	0.042
Euphausiid	17.904	15.163	18.480
Amphipoda	2.122	0.856	3.742
<i>Cylopus magellanicus</i>	0.009	0	0.027
<i>Vibilia</i> sp	0.095	0.009	0.154

Phronimidae	0.009	0	0.051
<i>Themisto gaudichaudi</i>	0.278	0.097	0.358
Pelagic (hyperiid) amphipod	0.026	0	0.052
Amphipod	1.648	1.107	2.308
Isopoda	0.009	0	0.045
Isopod	0.009	0	0.060
Mysidacea	0.792	0.137	1.808
<i>Gnathophausia</i> sp	0.009	0	0.026
Mysid	0.746	0.390	1.066
Copepoda	0.118	0	0.276
Copepod	0.113	0.026	0.157
Unident. euphausiid/prawn/mysid	0.633	0.267	0.674
Unidentified crustacea	1.804	1.066	2.122
Actinopterygii			
Fish	66.761	61.965	70.654
<i>Gnathophis habenatus</i>	0.009	0	0.026
<i>Simenchelys parasiticus</i>	0.017	0	0.035
<i>Serrivomer</i> sp	0.009	0	0.044
<i>Nemichthys scolapaceus</i>	0.018	0	0.035
Nemichthyidae	0.017	0	0.042
Anguilliformes	0.009	0	0.033
<i>Argentina elongata</i>	0.095	0.025	0.175
<i>Bathylagus</i> sp	0.182	0.116	0.384
<i>Gonostoma elongatum</i>	0.035	0	0.096
<i>Cyclothone</i> sp	0.009	0	0.018
Melanostomiidae	0.017	0	0.041
Malacosteidae	0.052	0.009	0.161
<i>Alepocephalus australis</i>	0.009	0	0.035
<i>Xenodermichthys</i> sp	0.035	0	0.069
Alepocephalidae	0.009	0	0.027
<i>Magnisudis prionosa</i>	0.017	0	0.034
<i>Alepisaurus ferox</i>	0.009	0	0.018
<i>Macroparalepis macrugeneion</i>	0.009	0	0.034
Paralepididae	0.104	0	0.141
<i>Scopelarchus</i> sp	0.017	0	0.043
<i>Scopelosaurus</i> sp	0.095	0.009	0.110
<i>Luciosudus</i> sp	0.009	0	0.035
<i>Anotopterus pharao</i>	0.009	0	0.026
<i>Diaphus danae</i>	0.087	0.017	0.139
<i>Diaphus</i> sp	0.104	0.026	0.170
<i>Electrona</i> sp	0.130	0.017	0.186
<i>Gymnoscopelus</i> sp	0.061	0.009	0.097
<i>Lampanyctodes hectoris</i>	3.140	2.000	3.045
<i>Lampichthys procerus</i>	0.052	0	0.093
<i>Lampanyctus</i> sp	0.130	0.035	0.276
<i>Lampadena</i> sp	0.026	0	0.052
<i>Loweina rara</i>	0.009	0	0.026
<i>Myctophum</i> sp	0.026	0	0.052
<i>Protomyctophum</i> sp	0.009	0	0.035
<i>Symbolophorus</i> sp	0.043	0	0.078
Myctophidae	21.782	18.962	22.958
<i>Chauliodus sloani</i>	0.130	0.053	0.237
<i>Stomias</i> sp	0.026	0	0.062
<i>Maurolicus australis</i>	1.674	1.368	2.653
Sternoptychidae	0.095	0.008	0.216
<i>Photichthys argenteus</i>	1.180	0.988	1.830
<i>Vinciguerrria</i> sp	0.026	0	0.053
Gonostomatidae	0.017	0	0.060

Unidentified mesopelagic fish	0.703	0.405	0.786
<i>Gonorynchus gonorynchus</i>	0.017	0	0.078
<i>Nansenia</i> sp	0.026	0	0.069
<i>Persparsia kopua</i>	0.043	0.026	0.169
Platyroctidae	0.009	0	0.026
<i>Austrophycis marginata</i>	0.026	0	0.112
<i>Macruronus novaezelandiae</i>	0.017	0	0.053
<i>Coryphaenoides serrulatus</i>	0.009	0	0.027
<i>Coryphaenoides subserrulatus</i>	0.026	0	0.061
<i>Coryphaenoides</i> sp	0.017	0	0.052
<i>Coelorinchus oliverianus</i>	0.390	0.250	0.518
<i>Coelorinchus innotabilis</i>	0.009	0	0.043
<i>Coelorinchus aspercephalus</i>	0.009	0	0.034
<i>Coelorinchus</i> sp	0.043	0	0.071
<i>Lepidorhynchus denticulatus</i>	0.538	0.294	0.627
Unidentified rattails	0.304	0.164	0.439
<i>Diretmus argenteus</i>	0.017	0	0.052
<i>Capromimus abbreviatus</i>	0.052	0	0.095
Syngnathidae	0.009	0	0.035
<i>Hoplichthys haswelli</i>	0.009	0	0.026
<i>Ambophthalmos</i> sp	0.009	0	0.027
Apogonidae	0.009	0	0.035
<i>Chiasmodon niger</i>	0.017	0	0.092
<i>Paradiplospinus gracilis</i>	0.009	0	0.035
<i>Lepidopus caudatus</i>	0.017	0	0.084
<i>Benthodesmus</i> sp	0.009	0	0.018
<i>Seriolella punctata</i>	0.009	0	0.026
<i>Seriolella caerulea</i>	0.009	0	0.026
<i>Cubiceps</i> sp	0.017	0	0.059
<i>Azygopus pinnifasciatus</i>	0.009	0	0.035
Unidentified otoliths	0.026	0	0.060
Unidentified fish	35.088	33.236	35.985
Cephalopoda			
Octopoda	0.109	0.029	0.221
<i>Pinnoctopus cordiformis</i>	0.035	0	0.096
Octopoda	0.069	0.017	0.187
Squids	3.397	2.847	4.020
<i>Iridoteuthis</i> sp	0.009	0	0.034
Sepiolidae	0.052	0.009	0.115
<i>Mastigoteuthis</i> sp	0.009	0	0.035
<i>Chiroteuthis</i> sp	0.009	0	0.026
<i>Histioteuthis</i> sp	0.173	0.035	0.234
Cranchiidae	0.078	0.009	0.129
<i>Nototeuthis dimegacotyle</i>	0.009	0	0.035
Octopoteuthidae	0.026	0	0.070
<i>Moroteuthis ingens</i>	0.043	0.025	0.211
<i>Moroteuthis</i> sp	0.043	0.009	0.124
<i>Todarodes filippovae</i>	0.026	0	0.053
<i>Nototodarus sloanii</i>	0.121	0.026	0.215
<i>Nototodarus</i> sp	0.356	0.119	0.463
Teuthoidea	2.177	1.948	2.936
Unidentified squid	0.113	0.017	0.153
Other Mollusca			
Shell fragments	0.018	0	0.067
Shell fragments	0.017	0	0.043
Tunicata			
Salpidae	1.730	1.126	2.408
Salpidae	1.648	1.489	2.252

Porifera			
Porifera	0.009	0	0.043
<i>Lissodendoryx</i> sp	0.009	0	0.051
Cnidaria			
Cnidaria	0.036	0	0.101
<i>Leiopathes secunda</i>	0.017	0	0.043
Hydrozoa	0.009	0	0.026
Anthozoa	0.009	0	0.026
Echinodermata			
Echinodermata	0.009	0	0.047
Gorgonocephalidae	0.009	0	0.033
Annelida			
Polychaeta	0.018	0	0.064
<i>Hyalinoecia tubicola</i>	0.009	0	0.026
Polychaeta	0.009	0	0.042
Chaetognatha			
Chaetognatha	0.009	0	0.039
Chaetognatha	0.009	0	0.027
Other			
Unidentified material	4.051	2.868	4.233

3.2.2 Broad analysis of hoki diet

The three-dimensional PCA indicated significant relationships between hoki diet and the predictors bottom depth, fish length, and year (Table 4). Fish weight also provided a relatively high level of explanatory power, but because weight was strongly correlated with length ($r^2=0.97$), and length was the better predictor, weight was excluded.

Table 4: Pearson correlations attributable to the variables offered in a three-dimensional PCA of hoki diet. Total values for the chosen explanatory variables are in bold.

	Year	bot_temp	time	latitude	longitude	depth	length	weight	Sex
PC1	0.125	-0.073	-0.036	-0.070	-0.002	0.031	-0.047	-0.036	-0.009
PC2	0.117	-0.108	0.017	0.045	0.003	0.176	0.158	0.151	0.055
PC3	0.005	-0.058	-0.054	0.010	0.054	0.116	0.099	0.100	0.032
PC1–3	0.171	0.142	0.067	0.084	0.054	0.213	0.192	0.184	0.064

Non-parametric MDS indicated no clear groupings of depth classes and no patterns of similarity between adjacent depth classes (plot not shown). The SIMPER analysis showed that fish, prawns, and euphausiids contributed at least 95% of the dietary similarity in all depth groups, and did so in a relatively consistent manner. The percentage volumes by depth group for these three prey categories are shown in Figure 4. There are only weak changes in prey with depth; prawns possibly decrease in importance in deeper water (over 531 m).

Non-parametric MDS indicated no clear groupings of length classes and no patterns of similarity between adjacent length classes (plot not shown). The SIMPER analysis showed that fish, prawns, and euphausiids contributed at least 95% of the dietary similarity in all length groups. The percentage volumes by length group for the three prey categories are shown in Figure 5. There are only weak patterns in prey with fish length; euphausiids may be relatively important in hoki 34–47 cm and 69.1–82 cm long.

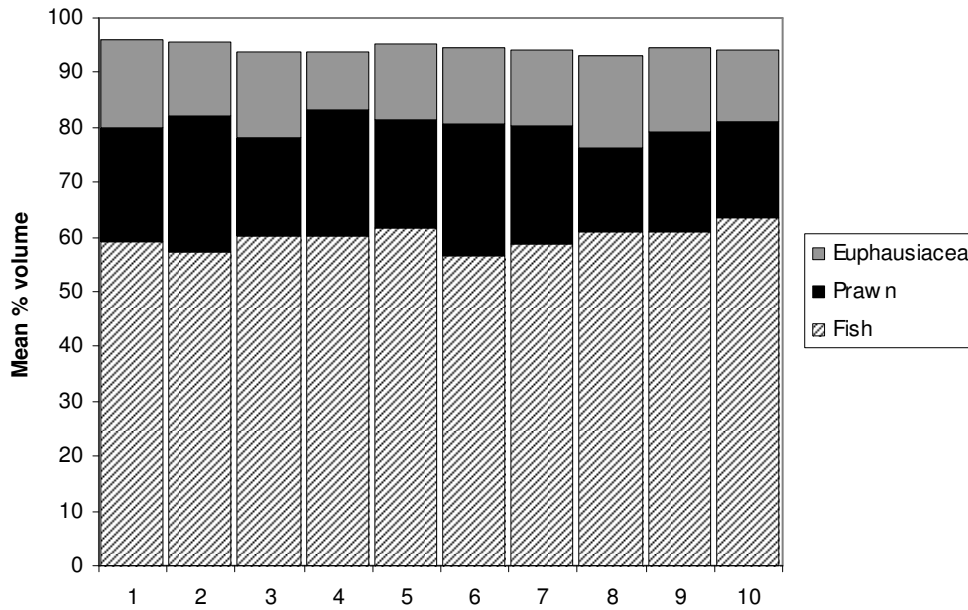


Figure 4: Hoki diet. Mean percentage prey volume for the main prey types contributing to at least 95% of the SIMPER similarity within each group, for each of the 10 depth groups: 1, 200–320 m; 2, 321–370 m; 3, 371–410 m; 4, 411–440 m; 5, 441–465 m; 6, 466–500 m; 7, 501–530 m; 8, 531–590 m; 9, 591–690 m; 10, 691–940 m.

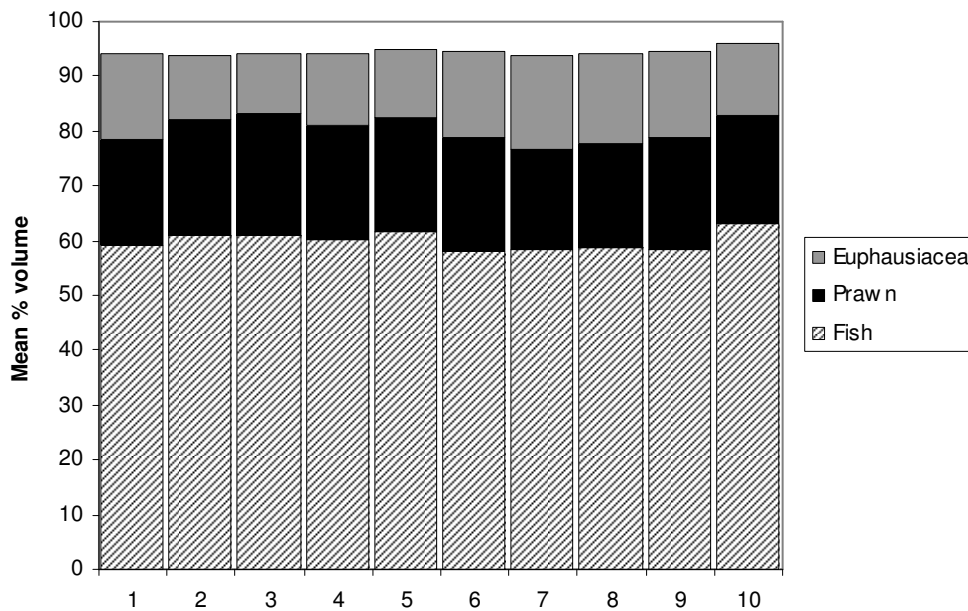


Figure 5: Hoki diet. Mean percentage prey volume for the main prey types contributing to at least 95% of the SIMPER similarity within each group, for each of the 10 length groups: 1, 34–47 cm; 2, 47.1–56 cm; 3, 56.1–61 cm; 4, 61.1–65 cm; 5, 65.1–69 cm; 6, 69.1–73 cm; 7, 73.1–77 cm; 8, 77.1–82 cm; 9, 82.1–90 cm; 10, 90.1–114 cm.

Non-parametric MDS indicated two clear groupings of years; 1990, and all other years (Figure 6). The SIMPER analysis showed that fish, prawns, and euphausiids contributed at least 95% of the dietary similarity between years. Mean percentage volumes by year for these three prey categories are shown in Figure 7, and some weak trends are apparent. Fish prey contributed the most to diet in all years, and apparently slowly increased in importance over time, with a possible peak every 3 or 4 years. Prawns were the second most important prey, contributing substantially in all years except 1990; they appeared to have slightly decreased in importance over time (since 1992). Euphausiids contributed

much of the remainder, and were relatively variable, but exhibited no obvious trends other than a very high abundance in 1990.

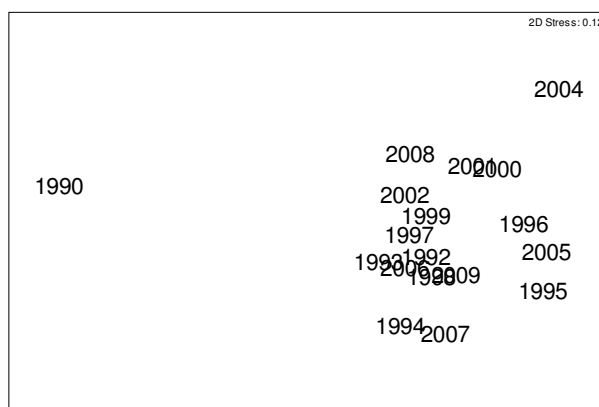


Figure 6: Hoki diet. NMDS based on percentage by volume (% V) of the 18 year groups.

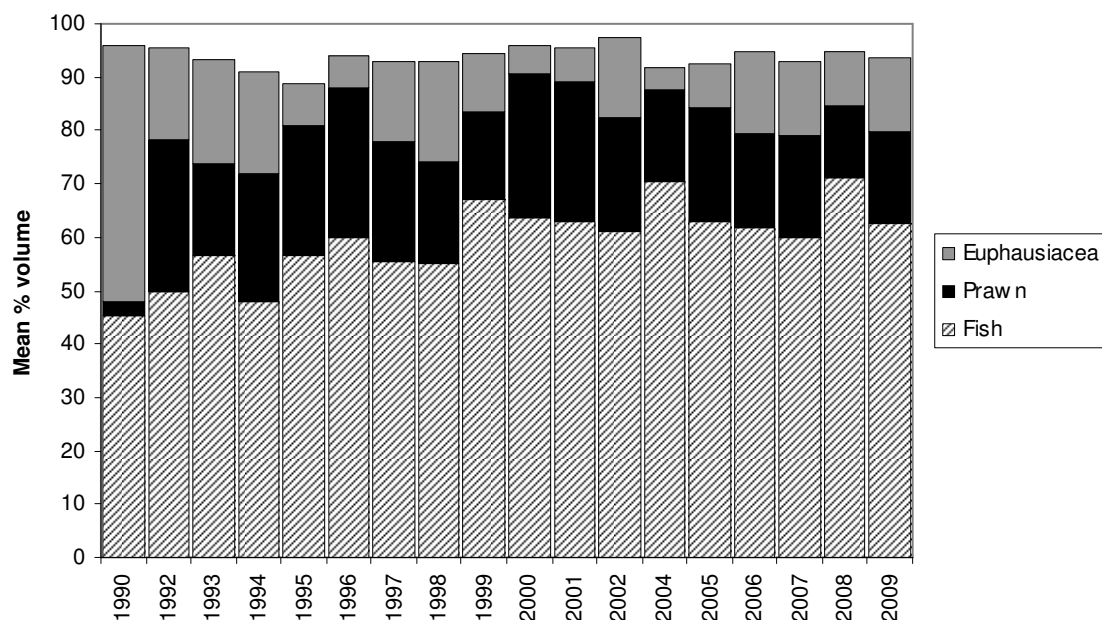


Figure 7: Hoki diet. Mean percentage prey volume for the main prey types contributing to at least 95% of the SIMPER similarity within each group for each of the 18 year groups.

3.2.3 Detailed analysis of hoki diet

The three-dimensional PCA indicated significant relationships between hoki diet and the predictors year, fish weight, and bottom depth (Table 5). Length was strongly correlated with weight ($r^2=0.97$), and was a marginally poorer explanatory variable and so was excluded.

Table 5: Pearson correlations attributable to the variables offered in a three-dimensional PCA of hoki detailed diet. Values for the chosen explanatory variables are in bold.

	year	Bot_temp	time	latitude	longitude	depth	length	weight	sex
PC1	0.250	-0.098	0.017	-0.089	0.014	0.024	-0.049	-0.053	-0.027
PC2	-0.188	0.140	0.005	-0.082	-0.037	-0.286	-0.308	-0.307	-0.124
PC3	0.096	-0.017	0.084	-0.013	-0.065	-0.042	-0.040	-0.048	-0.008
PC1-3	0.327	0.172	0.086	0.122	0.076	0.290	0.314	0.315	0.127

Non-parametric MDS indicated two groups of years; 1990, and all other years (Figure 8). ANOSIM confirmed the significant effect of year on diet (overall $R=0.078$, $P<0.01$). However, for 1992–2009, low R -statistics from pair-wise tests ($R=0.000$ – 0.245) indicated a high degree of dietary overlap. Only 1990 was clearly different from most other years (i.e., most $R>0.3$).

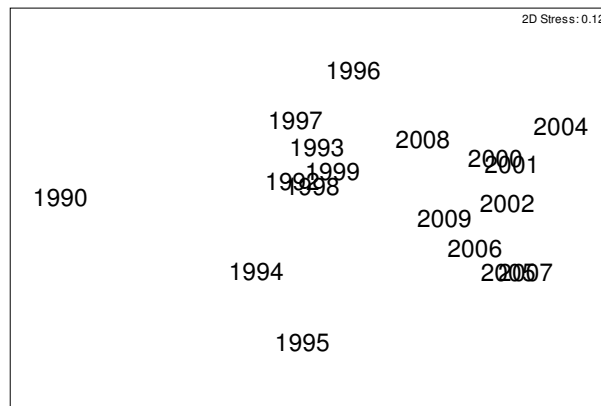


Figure 8: Hoki detailed diet. NMS based on percentage by volume (%V) of the 18 year groups. Note that ‘2004’ combines 2003 and 2004.

The SIMPER analysis identified that myctophids, euphausiids, *Pasiphaea* spp prawns, amphipods, pearlside (*Maurollicus australis*), and lighthouse fish (*Photichthys argenteus*) contributed most to dietary similarity. Mean percentage volumes of the most frequently recorded prey exhibited some trends (Figure 9). Myctophids were the most important prey group in all years from 1996 to 2009. Euphausiids were the second most important prey, contributing substantially in most years, but particularly from 1990 to 1995. *Pasiphaea* spp prawns were important after 2000, except in 2008, but it should be noted that three of the years when it contributed significantly were when the stomach contents were analysed in the laboratory rather than at sea (i.e., 2005–07). In common with *Pasiphaea* spp., the *Sergestes* spp prawns were recorded only from 2000 onwards. Squid was the third most frequent group, recorded in all years and contributing an average of about 6% of records annually. Other prey groups identified by the SIMPER analysis (amphipods, pearlside, and lighthouse fish) contributed little to the diet in most years.

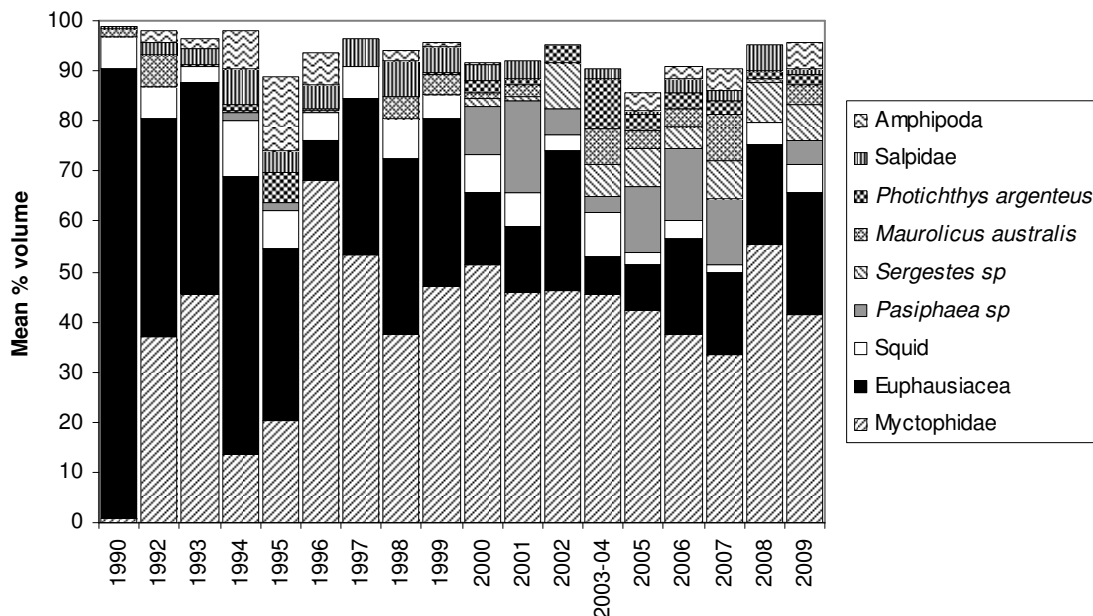


Figure 9: Hoki detailed diet. Mean percentage prey volume for the main prey types contributing to at least 90% of the SIMPER similarity within each group for each of the 17 year groups.

Both the broad and detailed diet analyses of percentage prey volume indicated a weak trend suggesting that fish prey were less important at the start of the time series. A plot of the percentage of stomachs containing fish, prawns, and euphausiids, by year, supports this conclusion (Figure 10). The percentage of stomachs containing fish has steadily increased over time ($R^2 = 0.67$), while the percentage of stomachs with the other two important prey groups have fluctuated without any apparent trend.

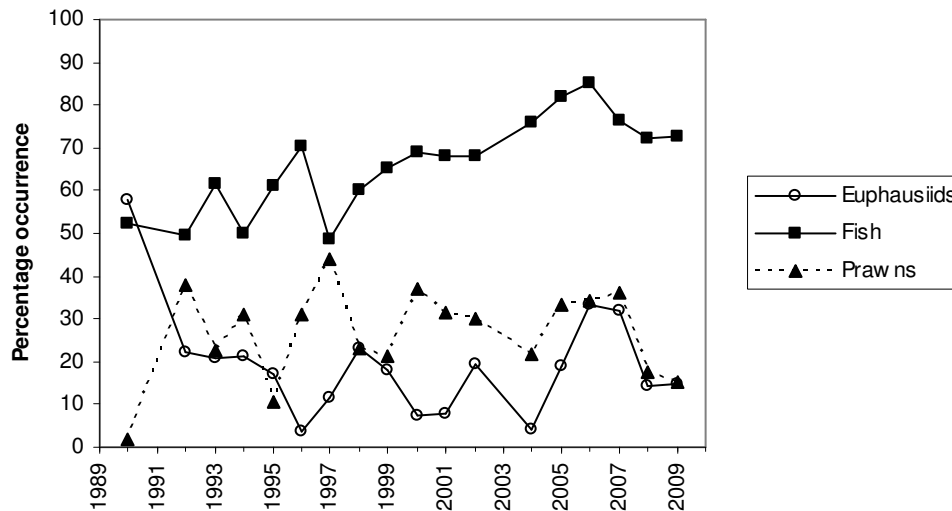


Figure 10: Percentages of hoki stomachs containing fish, prawns, or euphausiids, by year.

Non-parametric MDS indicated possible clusters of fish weight classes, but the most obvious result was a general transition in diet from small to large fish (Figure 11). ANOSIM confirmed the significant effect of weight on diet (overall $R=0.049$, $P<0.01$), but low R -statistics from pair-wise tests ($R=0.000-0.215$) indicated a high degree of dietary overlap between weight groups.

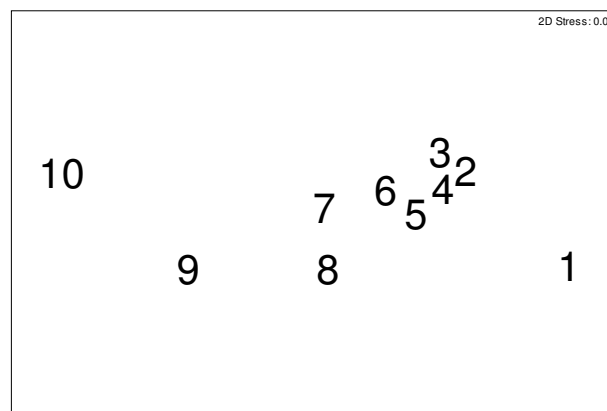


Figure 11: Hoki detailed diet. NMDS based on percentage by volume (%V) of the ten fish weight classes: 1, 100–350 g; 2, 351–520 g; 3, 521–640 g; 4, 641–820 g; 5, 821–960 g; 6, 961–1120 g; 7, 1121–1350 g; 8, 1351–1600 g; 9, 1601–2100 g; 10, 2101–5170 g.

SIMPER indicated myctophids and euphausiids contributed the most to dietary similarity. Mean percentage volumes showed that myctophids contributed the most to prey volume, but with an increasing and then decreasing importance with increasing predator size (Figure 12). Their peak contribution is for predators from 520 to 640 g (weight group 3). Euphausiids exhibited the opposite relationship, being most important for the smallest size group, reducing in importance to size group 3, and then increasing in importance again for all size groups except 10. Squid and *Pasiphaea* spp. prawns increased in importance as predator size increased, and javelinfish were important only for the largest predator groups.

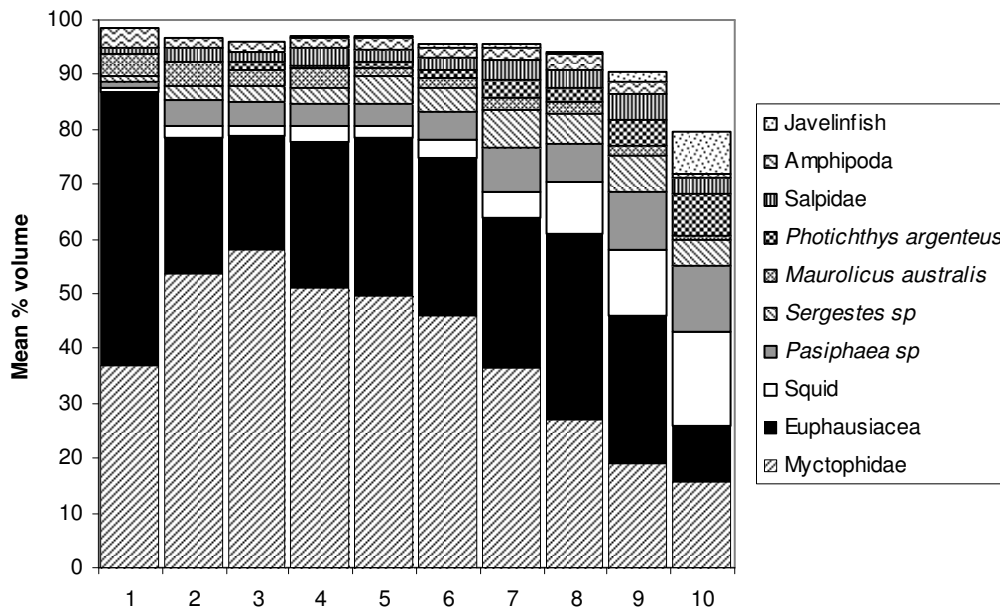


Figure 12: Hoki detailed diet. Mean percentage prey volume for the main prey types contributing to at least 90% of the SIMPER similarity within each group for each of 10 fish weight classes: 1, 100–350 g; 2, 351–520 g; 3, 521–640 g; 4, 641–820 g; 5, 821–960 g; 6, 961–1120 g; 7, 1121–1350 g; 8, 1351–1600 g; 9, 1601–2100 g; 10, 2101–5170 g.

Non-parametric MDS suggested a gradual change in diet with depth, with groups 1 and 2 dissimilar from the remainder (Figure 13). ANOSIM confirmed the significant effect of depth on diet (overall $R=0.031$, $P<0.01$), but low R -statistics from pair-wise tests ($R=0.000$ – 0.152) indicated a high degree of dietary overlap between depth groups.

A SIMPER analysis indicated that myctophids, euphausiids, and squid contributed most to the dietary similarity by depth group. The mean percentage volume of myctophids increased as depth increased from 200 m to 530 m, and then declined (Figure 14). The volume of euphausiids was relatively consistent over the entire depth range investigated. Squids and *Pasiphaea* spp. prawns were most important in shallower waters (less than 370 m), although *Pasiphaea* spp. contributed substantially in the deepest stratum.

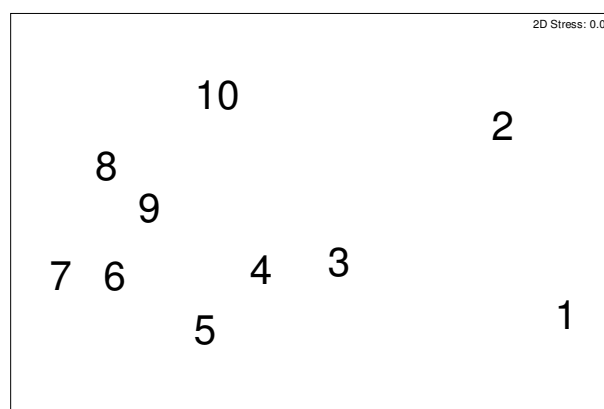


Figure 13: Hoki detailed diet. NMDS based on percentage by volume (% V) of the 10 depth groups: 1, 200–320 m; 2, 321–370 m; 3, 371–410 m; 4, 411–440 m; 5, 441–465 m; 6, 466–500 m; 7, 501–530 m; 8, 531–590 m; 9, 591–690 m; 10, 691–940 m.

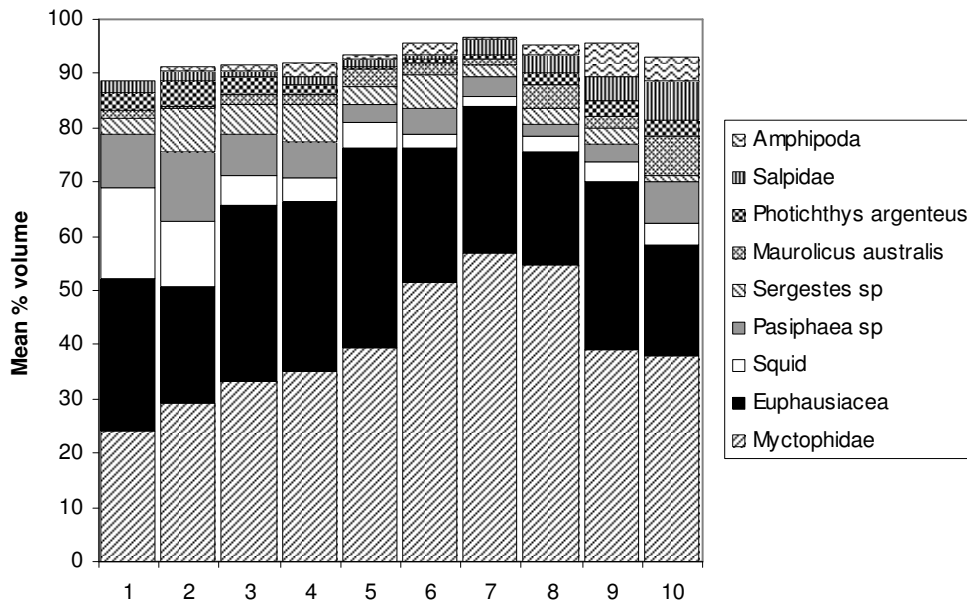


Figure 14: Hoki detailed diet. Mean percentage prey volume for the main prey types contributing to at least 90% of the SIMPER similarity within each group for each of the 10 depth groups: 1, 200–320 m; 2, 321–370 m; 3, 371–410 m; 4, 411–440 m; 5, 441–465 m; 6, 466–500 m; 7, 501–530 m; 8, 531–590 m; 9, 591–690 m; 10, 691–940 m.

3.3 Hake diet analysis

Of the 1847 non-empty stomachs examined, 24 (1.3%) contained only unidentifiable material and 7 (0.4%) contained crustacean prey that could only be broadly classified (i.e., CRU or EPN), leaving 1816 for detailed analyses of diet (98.3%). Stomachs were sampled from hake 37–133 cm TL.

Two analyses of diet variability were completed, with different levels of prey identification.

(1) Prey items were aggregated into the following broad taxonomic groups. Fish were aggregated at the phylum level. Of the 1635 records of fish prey, 992 (61%) had been classified initially only as unidentified fish (FIS), unidentified mesopelagic fish (MES), or unidentified rattail (RAT). Because fish were clearly the most important prey group for hake it was desirable to include all items at the phylum classification level, rather than deleting about half of the data set. Natant decapods were grouped together as “prawns”. Most of this group had been originally classified as either NAT or PRA, but 36% of ‘prawns’ were identified as *Pasiphaea* spp., and 10% were *Sergestes* spp. Other arthropods, cephalopods, and salps were aggregated at the order level. It is possible that the copepods, isopods, mollusc shell fragments, and salps observed in the hake stomachs could have been secondary prey, or were accidentally ingested along with a target prey item. Nevertheless they were included as they would have formed part of the diet, and because they were rare they had little influence in the analysis.

(2) Because fish were such an important prey category, a second more detailed analysis was completed using only the 643 fish prey that were identified to family or more detailed level. The fish were analysed in the species groups as shown in Table 6, except that all lanternfish (Myctophidae) and Apogonidae were each aggregated into single groups. This sub sample comprised 625 stomachs, with the number of samples per year ranging from 24 to 81.

3.3.1 Overall diet

Fish was the most important prey item, occurring in 51% of stomachs (Table 6), but most were unidentified beyond phylum level. Hoki and javelinfish were the next most important fish prey items,

occurring in 19% and 9% of stomachs, respectively. Oliver's rattail (*Caelorinchus oliverianus*) was the only other fish species identified in more than 1% of stomachs. Prawns (all species combined) occurred in 11% of stomachs. Euphausiids were the only other crustacean group identified in more than 1% of stomachs. Squids occurred in 6% of stomachs.

Table 6: Hake overall stomach contents composition from the Chatham Rise summer trawl surveys. Prey sorted by taxonomic group. Point estimate of percentage frequency of occurrence (%F), with 95% confidence intervals from bootstrap re-sampling. Statistics in bold are estimates by taxonomic group as used in the initial multivariate analysis.

Prey items	%F	Lower 95%	Upper 95%
Arthropoda			
Prawns	11.068	7.756	12.430
<i>Sergestes</i> sp	0.975	0.337	1.614
<i>Sergia potens</i>	0.054	0	0.236
<i>Oplophorus novaezeelandiae</i>	0.054	0	0.177
<i>Pasiphaea</i> spp	3.846	2.135	5.363
<i>Lipkius holthuisi</i>	0.108	0	0.389
Unidentified prawn	6.230	3.827	7.006
Euphausiacea	1.487	0.499	2.252
Euphausiacea	1.463	0.497	2.273
Amphipoda	0.385	0.057	0.773
<i>Themisto gaudichandi</i>	0.217	0	0.489
Vibiliidae	0.054	0	0.232
Amphipoda	0.108	0	0.369
Isopoda	0.055	0	0.176
Isopoda	0.054	0	0.174
Mysidae	0.275	0	0.675
<i>Gnathopausia</i> sp	0.054	0	0.227
Mysidae	0.217	0	0.534
Copepoda	0.165	0	0.419
Copepoda	0.163	0	0.405
Unidentified crab	0.054	0	0.177
Unident. Euphausid/prawn/mysid	0.488	0.109	0.840
Unidentified crustacea	0.975	0.221	1.651
Chordata			
Fish	86.289	84.843	89.477
Nemichthyidae	0.054	0	0.233
<i>Nansenia</i> sp	0.054	0	0.235
<i>Xenodermichthys</i> sp	0.054	0	0.271
Malacosteidae	0.054	0	0.286
<i>Argentina elongata</i>	0.488	0.168	0.895
<i>Photichthys argenteus</i>	0.271	0.053	0.680
<i>Stomias</i> sp	0.054	0	0.335
<i>Lampanyctodes hectoris</i>	0.163	0	0.583
<i>Lampanyctus</i> sp	0.054	0	0.235
Myctophidae	0.921	0.236	1.396
<i>Austrophycis marginata</i>	0.163	0	0.398
<i>Halargyreus johnsonii</i>	0.054	0	0.179
<i>Mora moro</i>	0.054	0	0.228
<i>Euclichthys polynemus</i>	0.054	0	0.232
<i>Macruronus novaezeelandiae</i>	19.014	16.378	21.345
<i>Caelorinchus bollonsi</i>	0.379	0.385	1.421
<i>Caelorinchus innotabilis</i>	0.108	0	0.439
<i>Caelorinchus oliverianus</i>	1.896	1.573	3.544
<i>Coryphaenoides subserrulatus</i>	0.108	0	0.347
<i>Ventrifossa nigromaculata</i>	0.054	0	0.547
<i>Lepidorhynchus denticulatus</i>	8.884	9.983	14.18

Macrouridae	1.517	0.830	2.142
<i>Beryx</i> sp	0.325	0	0.375
<i>Neocyttus rhomboidalis</i>	0.054	0	0.172
Oreosomatidae	0.054	0	0.174
<i>Centriscopus humerosus</i>	0.163	0	0.436
<i>Helicolenus</i> sp	0.379	0.165	1.005
<i>Epigonus lenimem</i>	0.163	0.054	0.728
<i>Epigonus robustus</i>	0.054	0	0.275
<i>Epigonus telescopus</i>	0.108	0	0.236
Apogonidae	0.054	0	0.229
<i>Trachurus symmertricus murphyi</i>	0.054	0	0.184
<i>Cepola aotea</i>	0.054	0	0.329
<i>Centrolophus niger</i>	0.054	0	0.173
<i>Cubiceps</i> sp	0.217	0	0.581
<i>Tetragonurus cuvieri</i>	0.163	0	0.453
Unidentified mesopelagic fish	0.813	0.175	1.463
Unidentified fish	50.921	45.418	51.780
Commercial discard fish	0.220	0	0.537
Commercial discard fish	0.216	0	0.497
Cephalopoda			
Squids	6.057	4.697	7.502
Cranchiidae	0.054	0	0.231
<i>Histioteuthis</i> sp	0.217	0	0.564
<i>Moroteuthis ingens</i>	0.325	0.055	0.712
<i>Nototodarus sloanii</i>	0.542	0.269	1.080
<i>Ommastrephes bartrami</i>	0.108	0	0.353
<i>Moroteuthis</i> sp	0.163	0	0.330
<i>Todarodes filippovae</i>	0.217	0.055	0.587
<i>Nototodarus</i> sp	0.975	0.216	1.420
<i>Teuthoidea</i>	3.467	2.367	4.431
Octopods	0.055	0	0.174
<i>Pinnoctopus cordiformis</i>	0.054	0	0.168
Mollusca other			
Shell fragments	0.275	0	0.650
Shell fragments	0.271	0	0.634
Tunicata			
Salpidae	0.220	0	0.516
Salpidae	0.217	0	0.526
Porifera			
Porifera	0.055	0	0.174
Porifera	0.054	0	0.172
Echinodermata			
Echinoidea	0.110	0	0.392
Echinoidea	0.108	0	0.348
Other			
Unidentified material	3.900	2.079	5.178

3.3.2 Broad analysis of hake diet

The three-dimensional PCA indicated significant relationships between hake diet and the predictors fish weight, latitude, and depth (Table 7). Length and sex also provided relatively high levels of explanatory power, but both these variables were strongly correlated with weight ($r^2=0.98$ for length-weight; mean weights by sex were 2.8 kg for males and 5.7 kg for females), so they were excluded. Year provided no significant explanatory power.

Table 7: Pearson correlations attributable to the variables offered in a three-dimensional PCA of hake diet. Values for the chosen explanatory variables are in bold.

	year	bot_temp	time	latitude	longitude	depth	length	weight	sex
PC1	0.051	0.014	0.065	0.223	-0.118	0.156	-0.214	-0.228	-0.178
PC2	-0.047	0.038	-0.013	-0.050	0.044	-0.079	0.139	0.151	0.080
PC3	0.073	-0.032	-0.012	-0.055	0.013	-0.013	0.021	0.022	-0.012
PC1-3	0.100	0.052	0.067	0.235	0.126	0.175	0.256	0.274	0.195

Non-parametric MDS indicated a strong similarity between fish weight classes 1 and 2 (260–2100 g), 3 and 4 (2101–5600 g), and 5 and 6 (5601–19 500 g) (Figure 15). ANOSIM confirmed the significant effect of weight on diet (overall $R=0.019$, $P<0.01$), but low R -statistics from pair-wise tests ($R=0.001–0.080$) indicated a high degree of dietary overlap between weight groups.

The differences in diet between weight groups were dominated by increasing volumes of fish prey, coinciding with decreasing volumes of prawns, as predator size increased (Figure 16). Squid contributed to the diet across all predator size classes.

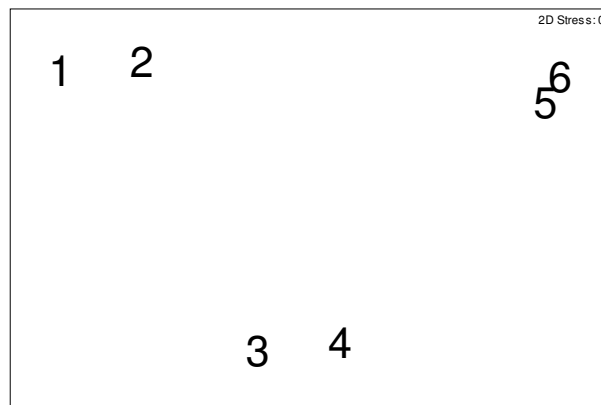


Figure 15: Hake diet. NMDS based on percentage by volume (%V) of the six fish size classes: 1, 260–1150 g; 2, 1151–2100 g; 3, 2101–3500 g; 4, 3501–5600 g; 5, 5601–9000 g; 6, 9001–19 500 g.

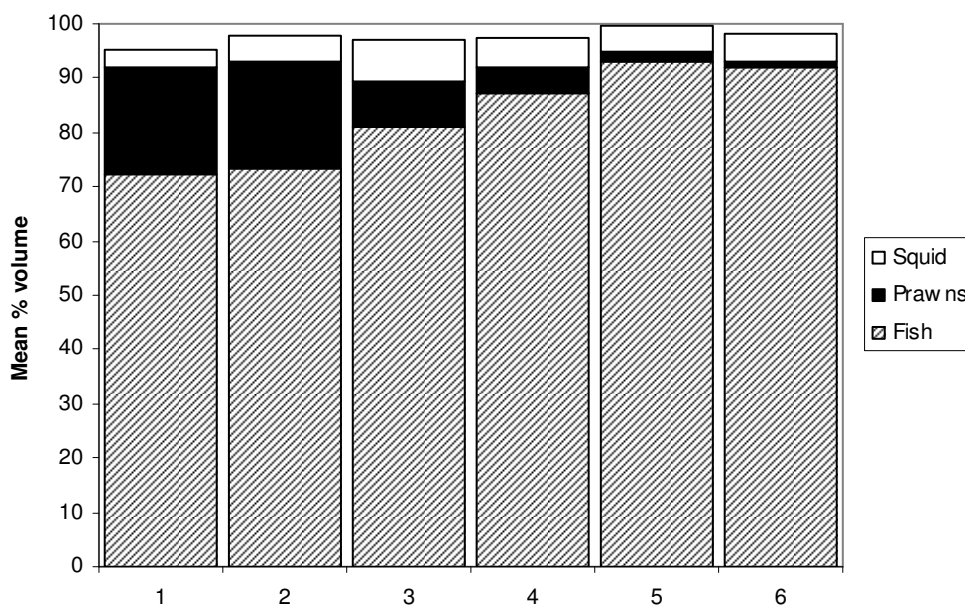


Figure 16: Hake diet. Mean percentage prey volume for the main prey types contributing to at least 95% of the SIMPER similarity within each group for each of the six fish weight classes: 1, 260–1150 g; 2, 1151–2100 g; 3, 2101–3500 g; 4, 3501–5600 g; 5, 5601–9000 g; 6, 9001–19 500 g.

Non-parametric MDS indicated a north-south dissimilarity in diet occurring between latitude groups 4 and 5 (i.e., at about 43.55° S), as well as a transition in diet from north to south (Figure 17). ANOSIM confirmed the significant effect of latitude on diet (overall $R=0.01$, $P<0.01$), but R -statistics from pair-wise tests ($R=0.000$ – 0.023) indicated a high degree of dietary overlap between latitude groups. Fish had a lower importance, and prawns higher importance, in the north (Figure 18).



Figure 17: Hake diet. N-MDS based on percentage by volume (%V) of the six latitude classes (all in °S): 1, 42.72–42.91; 2, 42.92–43.08; 3, 43.09–43.30; 4, 43.31–43.55; 5, 43.56–43.88; 6, 43.89–44.65.

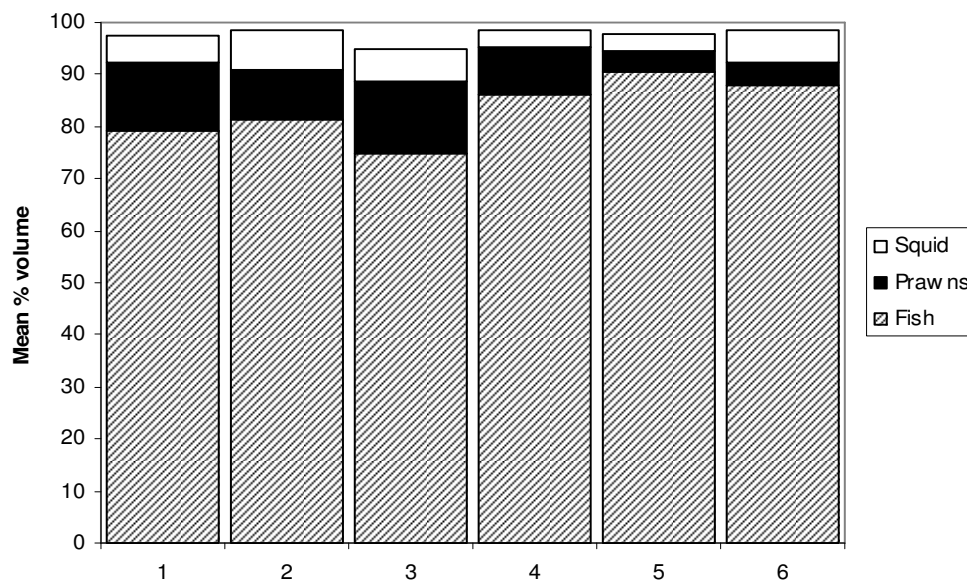


Figure 18: Hake diet. Mean percentage prey volume for the main prey types contributing to at least 95% of the SIMPER similarity within each group for each of the six latitude classes (all in °S): 1, 42.72–42.91; 2, 42.92–43.08; 3, 43.09–43.30; 4, 43.31–43.55; 5, 43.56–43.88; 6, 43.89–44.65.

Non-parametric MDS indicated three relatively distinct depth groups: 1–3 (290–495 m), 4 (496–550 m), and 5–6 (551–900 m) (Figure 19). ANOSIM confirmed the significant effect of depth on diet (overall $R=0.018$, $P<0.01$), but very low R -statistics from pair-wise tests ($R=0.003$ – 0.091) indicated a high degree of dietary overlap.

Fish increased in importance, and prawns decreased in importance, as depth increased (Figure 20). This result was similar to the results of the SIMPER analysis on weight (see Figure 16), and suggests prawns contributed more to the diet of the smaller and shallower fish. However, there was no significant relationship between fish weight and depth ($R^2=0.01$, $p\leq 0.15$), so it is unlikely that the depth effect is aliasing for fish weight, and both fish weight and depth effects are valid.

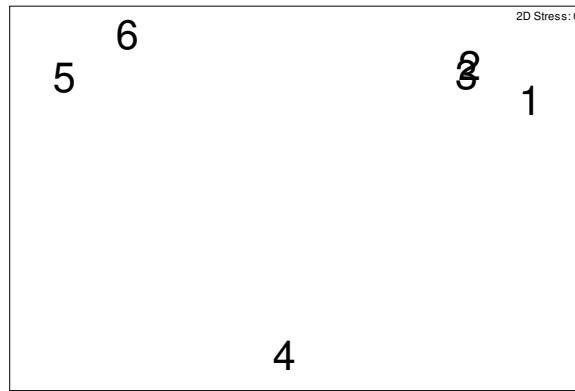


Figure 19: Hake diet. NMDS based on percentage by volume (%V) of the six depth classes: 1, 290–420 m; 2, 421–455 m; 3, 456–495 m; 4, 496–550 m; 5, 551–640 m; 6, 641–900 m.

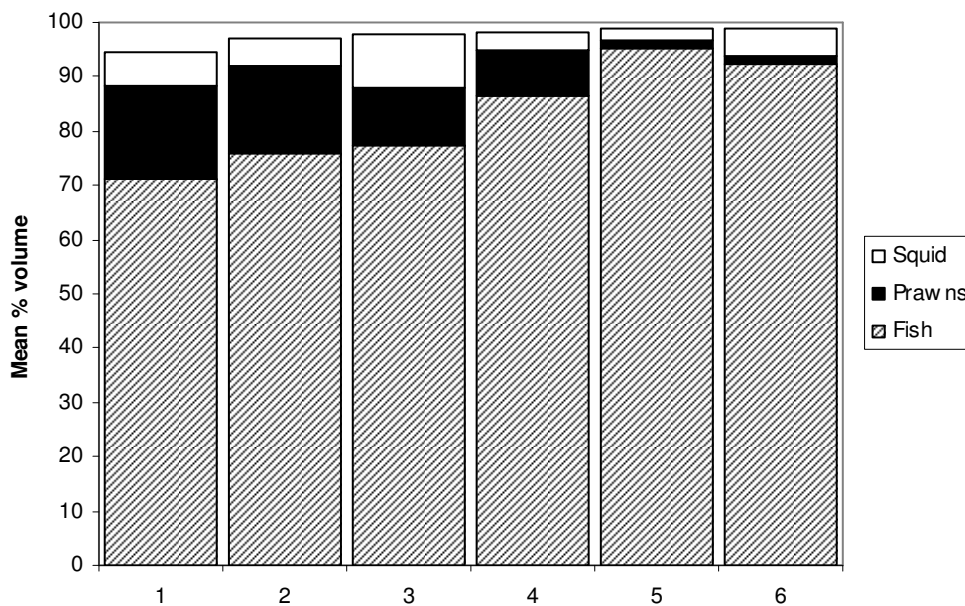


Figure 20: Hake diet. Mean percentage prey volume for the main prey types contributing to at least 95% of the SIMPER similarity within each group for each of the six depth classes: 1, 290–420 m; 2, 421–455 m; 3, 456–495 m; 4, 496–550 m; 5, 551–640 m; 6, 641–900 m.

3.3.3 Detailed analysis of hake fish diet

A second analysis used only the fish prey items that were identified at least to family. The three-dimensional PCA indicated significant relationships between hake fish diet and the predictors fish weight, depth, and year (Table 8). Length also provided a high level of explanatory power, but it was strongly correlated with weight ($r^2=0.98$), with weight the better predictor, and so was excluded.

Table 8: Pearson correlations attributable to the variables offered in a three-dimensional PCA of hake fish diet. Values for the chosen explanatory variables are in bold.

	year	bot_temp	time	latitude	longitude	depth	length	weight	sex
PC1	0.248	-0.145	-0.007	0.073	-0.009	0.083	-0.334	-0.373	-0.182
PC2	0.172	-0.254	-0.100	0.016	-0.246	0.298	-0.261	-0.277	-0.164
PC3	-0.069	-0.010	0.057	-0.181	-0.075	-0.115	0.015	0.016	0.052
PC1–3	0.310	0.292	0.116	0.196	0.258	0.330	0.424	0.465	0.251

Non-parametric MDS showed a similar dissimilarity between groups, indicating a steady change in diet as fish weight increased, with only classes 5 and 6 (5601–19 500 g) appearing closely similar (Figure 21). ANOSIM confirmed the significant effect of weight on diet (overall $R=0.137$, $P<0.01$),

and the R statistics from the pair-wise tests also indicated distinct differences between small fish (groups 1 and 2) and large fish (groups 5 and 6) (Table 9).

The SIMPER analysis indicated that the dietary dissimilarity between different hake size groups was largely explained by changes in proportions of hoki, javelinfish, Oliver's rattail, and myctophid prey. The diet of smaller hake was dominated by small rattail species and javelinfish (Figure 22). Medium-sized hake had a diet transitioning between javelinfish and hoki, with reducing volumes of the smaller rattails. Large hake had a diet dominated by hoki, with javelinfish comprising much of the remainder.

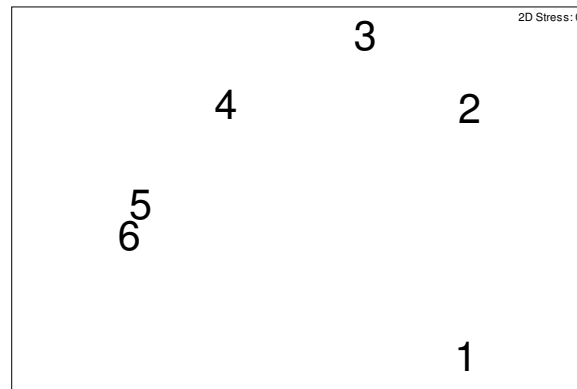


Figure 21: Hake fish diet. NMS based on percentage by volume (% V) of the six fish size classes: 1, 260–1150 g; 2, 1151–2100 g; 3, 2101–3500 g; 4, 3501–5600 g; 5, 5601–9000 g; 6, 9001–19 500 g.

Table 9: Hake fish diet. R statistic from the ANOSIM pair-wise tests based on percentage by volume (% V) of the six fish size classes: 1, 260–1150 g; 2, 1151–2100 g; 3, 2101–3500 g; 4, 3501–5600 g; 5, 5601–9000 g; 6, 9001–19 500 g.

	1	2	3	4	5	6
1	0					
2	0.028	0				
3	0.124	0.033	0			
4	0.255	0.148	0.044	0		
5	0.484	0.363	0.199	0.049	0	
6	0.451	0.330	0.164	0.031	0.003	0

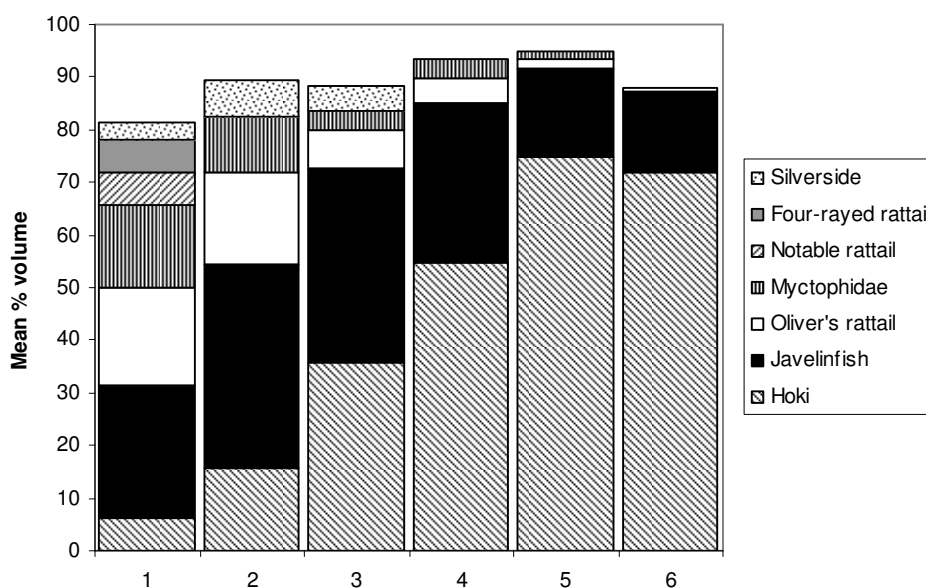


Figure 22: Hake fish diet. Mean percentage prey volume for the main prey types contributing to at least 95% of the SIMPER similarity within each group for each of the six fish weight classes: 1, 260–1150 g; 2, 1151–2100 g; 3, 2101–3500 g; 4, 3501–5600 g; 5, 5601–9000 g; 6, 9001–19 500 g.

Non-parametric MDS indicated three relatively distinct depth groups: 1 (290–420 m), 2 (421–455 m), and 4–6 (456–900 m) (Figure 23). ANOSIM confirmed the significant effect of depth on diet (overall $R=0.031$, $P<0.01$), but low R -statistics from pair-wise tests ($R=0.004$ – 0.162) indicated a high degree of dietary overlap between depth groups.

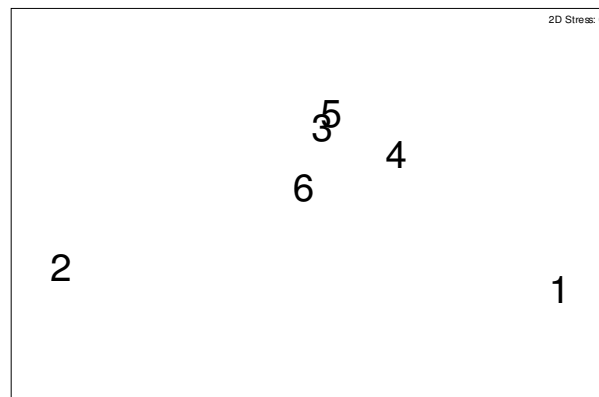


Figure 23: Hake fish diet. NMDS based on percentage by volume (%V) of the six depth classes: 1, 290–420 m; 2, 421–455 m; 3, 456–495 m; 4, 496–550 m; 5, 551–640 m; 6, 641–900 m.

There were no clear patterns in dietary similarity as depth increased, other than a lower importance of hoki at depths 290–420 m (Figure 24). Hoki and javelinfish contributed to the diet in all depth groups, but not in any consistent way. Oliver’s rattail contributed mainly in the deepest and shallowest groups.

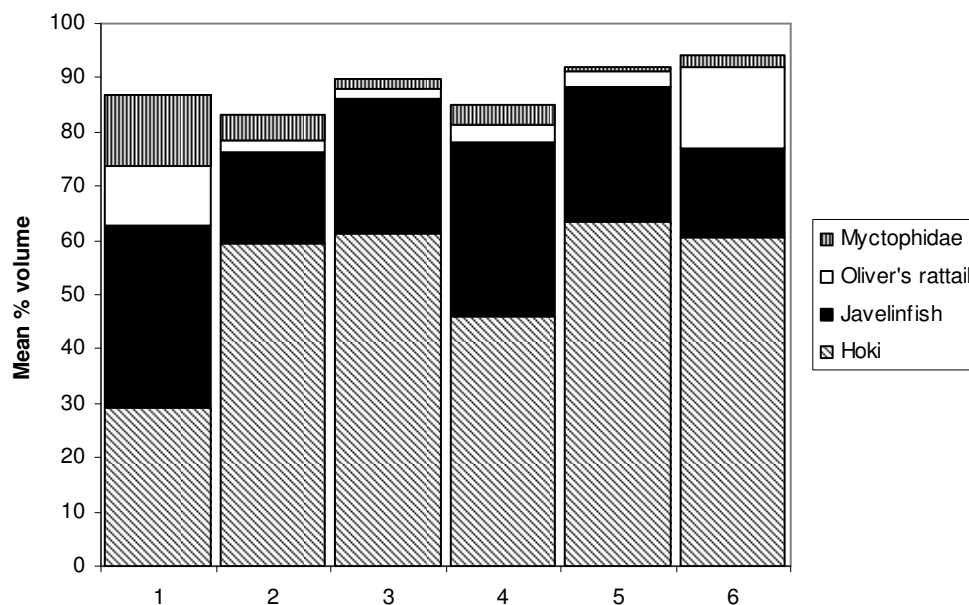


Figure 24: Hake fish diet. Mean percentage prey volume for the main prey types contributing to at least 95% of the SIMPER similarity within each group for each of the six depth classes: 1, 290–420 m; 2, 421–455 m; 3, 456–495 m; 4, 496–550 m; 5, 551–640 m; 6, 641–900 m.

Year was the third most influential variable in the model. Non-parametric MDS indicated three loosely similar year groups: 2004–07 and 1995–96 as relative outliers, and all other years (Figure 25). ANOSIM confirmed the significant effect of depth on diet (overall $R=0.083$, $P<0.01$). The R -statistics from pair-wise tests were generally low (i.e., $R<0.3$), but there were some differences between some pairings of the 2004–2007 years with 1992, 1995, and 1996 ($R=0.320$ – 0.394).

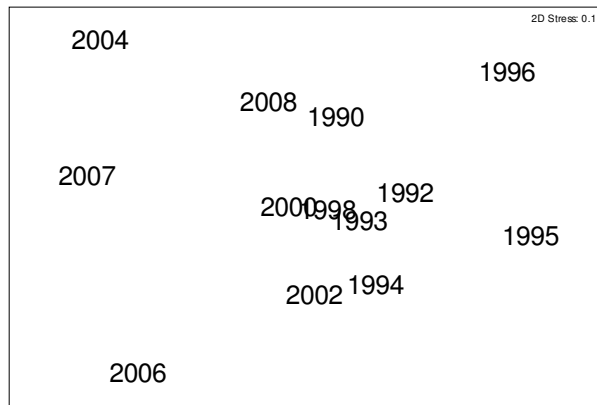


Figure 25: Hake fish diet. NMS based on percentage by volume (%V) of the 13 year classes. Note that ‘1996’ combines 1997 and 1997 data, ‘1998’ combines 1998 and 1999, ‘2000’ combines 2000 and 2001, ‘2002’ combines 2002 and 2003, ‘2004’ combines 2004 and 2005, and ‘2008’ combines 2008 and 2009.

There were some trends in diet apparent across years (Figure 26). Abundance of hoki in the diet was high until about 1998–99, but it then declined steadily to 2006 and 2007, before again increasing in 2008–09. Javelinfish contributed to the diet in most years, but particularly in two of the year groups when the abundance of hoki in stomachs was low (2004–05 and 2007). In 2004–05, 2006, and 2007, hoki were at their lowest abundance in the hake diet; those were the same years when most of the stomach content data were derived from laboratory analysis, rather than from at-sea examinations. However, it is also apparent that the mean size of hake used in this analysis has varied markedly over time (Figure 27). The abundance of hoki in the diet appears to be correlated with the mean size of the hake examined, so year will be aliasing, at least in part, for hake size.

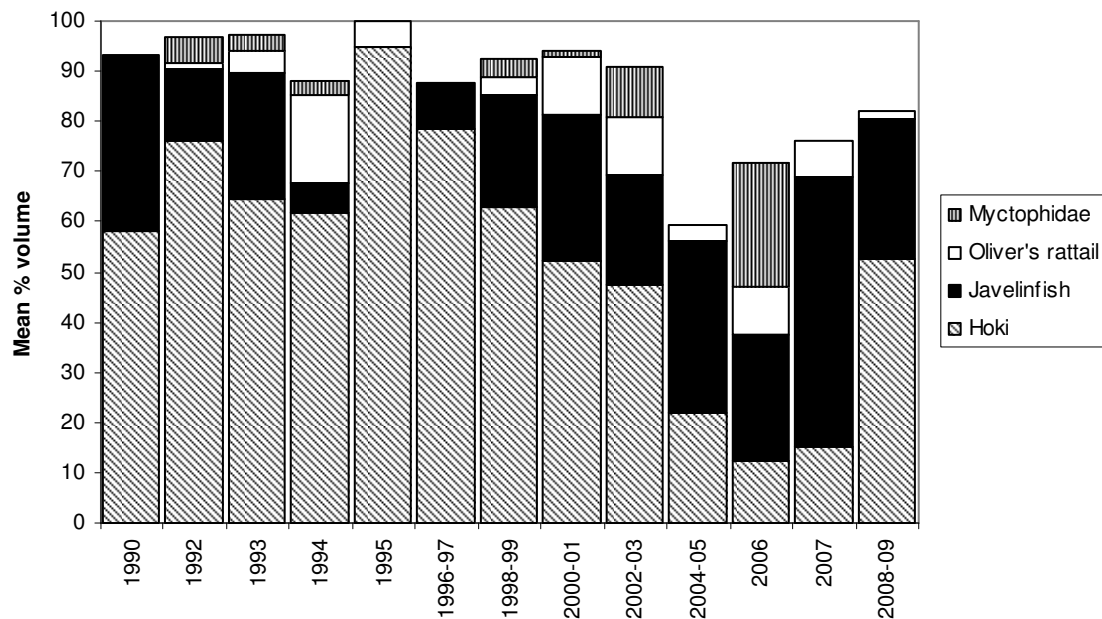


Figure 26: Hake fish diet. Mean percentage prey volume for the main prey types contributing to at least 95% of the SIMPER similarity within each group for each of the 13 year groups.

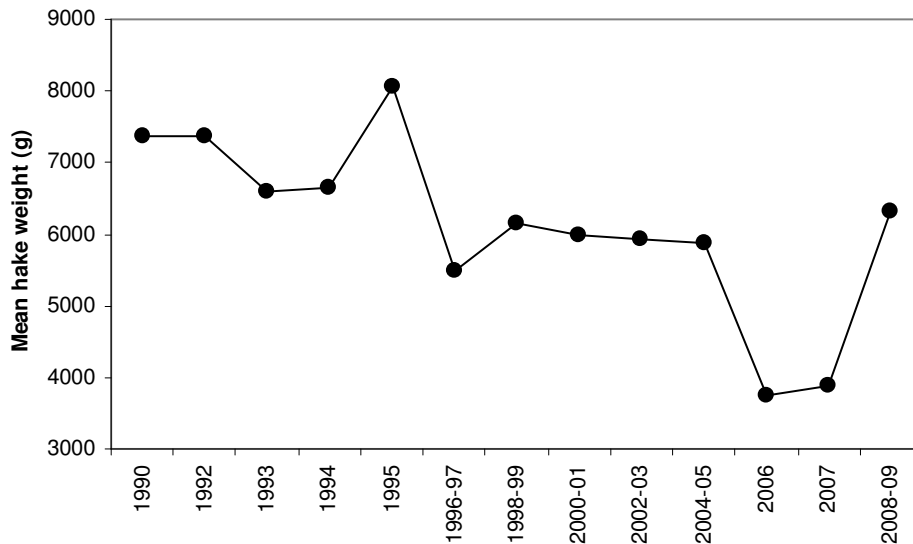


Figure 27: Mean weight of hake used in the ‘hake fish diet’ analysis, by year group.

3.4 Ling diet analysis

Of the 7576 non-empty stomachs examined, 146 (1.9%) contained only unidentifiable material and 235 (3.1%) contained crustacean prey that could only be broadly classified (i.e., CRU or EPN), leaving 7195 for detailed analyses of diet (95%). Stomachs were sampled from ling 28–170 cm TL.

Two analyses of diet variability were completed, with different levels of prey identification.

(1) Prey items were aggregated into the broad taxonomic groups shown in Table 10. Fish were aggregated at a phylum level. Of the 3966 records of fish prey, 2996 (76%) had been classified only as unidentified fish (FIS) or unidentified rattail (RAT). Because fish were the most important prey group for ling, it was desirable to include all items at the phylum classification level, rather than deleting about a third of the data set. Natant decapods were grouped together as “prawns”. Most of this group (64%) had been originally classified as either NAT or PRA, but 16% of prawns were identified as the sabre prawn, *Camplyonotus rathbonae*, and 5% as Crangonidae. All crabs were grouped together, as 68% had been identified only as CRB. All galatheids (i.e., *Munida* spp. and Galatheidae) were combined. Scampi were included as a separate prey group. Octopoda and squids were included as two separate groups. Other arthropods, molluscs, sponges, corals, echinoderms, worms, and salps were aggregated at the order level; it is possible that some of these items were secondary prey or accidentally ingested. Nevertheless they were included as diet, and being rare had little or no influence in the diet analysis.

(2) Because fish were such an important prey category, a second detailed analysis was completed using only fish prey that were identified to family or higher. Some species were aggregated into groups by order, genus, or family (Table 11). This subsample comprised 869 stomachs, with the number of samples per year ranging from 16 to 77.

3.4.1 Overall diet

Unidentified fish was the most important prey item, occurring in 37% of stomachs (see Table 10). When all fish species are combined, they occurred in 52% of stomachs. *Munida gracilis* was the next most important prey item, occurring in 32% of stomachs (as a group, galatheids occurred in 36% of stomachs). Scampi (*Metanephrops challengerii*) occurred in 8% of stomachs, and prawns (all species combined) occurred in 10%. The only other groups to occur in more than 1% of stomachs were crabs (4%), squids (2%), and isopods (1%).

Table 10: Ling overall stomach contents composition from the Chatham Rise summer trawl surveys. Prey sorted by taxonomic group. Point estimate of percentage frequency of occurrence (%F), with 95% confidence intervals from bootstrap re-sampling. Statistics in bold are estimates by taxonomic group as used in the initial multivariate analysis.

Prey items	%F	Lower 95%	Upper 95%
Arthropoda			
Galatheidae	36.192	33.896	38.388
<i>Munida gracilis</i>	32.074	31.108	35.512
Galatheidae	3.458	2.050	3.880
Scampi	8.659	7.379	9.893
<i>Metanephrops challengeri</i>	8.223	6.816	9.467
Crabs	4.211	3.307	5.054
<i>Sympagurus dimorphous</i>	0.013	0	0.056
Unidentified hermit crabs	0.026	0	0.057
<i>Leptomithrax longipes</i>	0.013	0	0.042
<i>Leptomithrax australis</i>	0.013	0	0.055
<i>Carcinoplax victoriensis</i>	0.818	0.474	1.033
<i>Neommatocarcinus huttoni</i>	0.290	0.094	0.464
Unidentified crabs	2.851	2.098	3.673
Prawns	10.188	8.458	10.865
<i>Sergia potens</i>	0.013	0	0.068
<i>Sergestes</i> sp	0.092	0	0.174
<i>Camplyonotus rathbonae</i>	1.610	0.891	1.761
<i>Metacrangon knoxi</i>	0.013	0	0.054
<i>Prionocrangon curvicaulis</i>	0.013	0	0.056
Crangonidae	0.462	0.196	0.641
<i>Lipkius holthuisi</i>	0.158	0.058	0.296
<i>Notopandalus magnoculus</i>	1.030	0.530	1.344
<i>Pasiphaea</i> sp	0.079	0	0.168
<i>Polycheles suhmi</i>	0.026	0	0.091
Unidentified prawn	6.481	5.578	7.660
Prawn killer	0.028	0	0.090
<i>Ibacus alticrenatus</i>	0.026	0	0.094
Euphausiacea	0.959	0.620	1.324
Euphausiacea	0.911	0.649	1.306
Amphipoda	0.334	0.129	0.497
<i>Themisto gaudichandi</i>	0.013	0	0.057
Gammarid amphipod	0.013	0	0.068
Amphipoda	0.290	0.096	0.403
Cumacea	0.014	0	0.056
Cumacea	0.013	0	0.055
Isopoda	1.001	0.617	1.243
<i>Acutiserolis</i> sp	0.224	0.080	0.356
<i>Aega monophthalma</i>	0.013	0	0.043
Isopoda	0.739	0.434	0.961
Mysidae	0.903	0.457	1.243
Mysidae	0.858	0.447	1.108
Copepoda	0.042	0	0.114
Copepoda	0.040	0	0.109
Unident. euphausiid/prawn/mysid	0.251	0.084	0.383
Unidentified crustacea	4.277	3.462	5.089
Chordata			
Fish	51.953	49.507	54.184
<i>Squalus acanthias</i>	0.053	0.014	0.209
<i>Echinorhinus cookei</i>	0.040	0	0.202
<i>Brochiraja asperula</i>	0.026	0	0.083
<i>Hydrolagus novaezelandiae</i>	0.040	0	0.123

<i>Hydrolagus bemisi</i>	0.053	0	0.136
<i>Hydrolagus</i> sp	0.040	0	0.107
<i>Harriotta raleighana</i>	0.013	0	0.053
Chondrichthyes	0.013	0	0.055
Shark egg case	0.145	0.083	0.313
Glass eels	0.013	0	0.055
<i>Bassanago hirsutus</i>	0.198	0.053	0.295
<i>Bassanago bulbiceps</i>	0.066	0	0.135
<i>Gnathophis habenatus</i>	0.013	0	0.042
<i>Conger</i> sp	0.013	0	0.056
<i>Serrivomer</i> sp	0.013	0	0.055
Nemichthyidae	0.013	0	0.069
Anguilliformes	0.158	0.042	0.244
<i>Notacanthus sexspinis</i>	0.290	0.112	0.391
<i>Argentina elongata</i>	0.026	0	0.137
<i>Xenodermichthys</i> sp	0.013	0	0.108
<i>Alepisaurus ferox</i>	0.026	0	0.057
<i>Gonostoma elongatum</i>	0.013	0	0.069
<i>Maurolicus australis</i>	0.040	0	0.100
<i>Photichthys argenteus</i>	0.040	0	0.125
<i>Lampanyctodes hectoris</i>	0.013	0	0.055
Myctophidae	0.158	0.041	0.262
<i>Gonorynchus gonorynchus</i>	0.013	0	0.082
<i>Auchenoceros punctatus</i>	0.013	0	0.055
<i>Pseudophycis bachus</i>	0.132	0.040	0.297
<i>Austrophycis marginata</i>	1.650	1.192	2.014
<i>Mora moro</i>	0.013	0	0.054
<i>Halargyreus johnsonii</i>	0.026	0	0.084
<i>Antimora rostrata</i>	0.013	0	0.058
Moridae	0.026	0	0.081
<i>Macruronus novaezelandiae</i>	1.795	1.342	2.307
<i>Brotulotaenia crassa</i>	0.013	0	0.055
<i>Genypterus blacodes</i>	0.092	0.040	0.252
<i>Caelorinchus aspercephalus</i>	0.198	0.097	0.385
<i>Caelorinchus bollonsi</i>	0.343	0.175	0.488
<i>Caelorinchus parvifasciatus</i>	0.026	0	0.109
<i>Caelorinchus fasciatus</i>	0.343	0.148	0.489
<i>Caelorinchus innotabilis</i>	0.370	0.280	0.714
<i>Caelorinchus acanthiger</i>	0.013	0	0.042
<i>Caelorinchus matamua</i>	0.026	0	0.067
<i>Caelorinchus oliverianus</i>	2.112	1.546	2.521
<i>Lepidorhynchus denticulatus</i>	0.620	0.390	0.850
<i>Ventrifossa nigromaculata</i>	0.026	0	0.071
Macrouridae	2.759	2.096	3.252
<i>Euclichthys polynemus</i>	0.053	0	0.123
<i>Beryx splendens</i>	0.040	0	0.084
<i>Capromimus abbreviatus</i>	0.013	0	0.053
<i>Cyttus traversi</i>	0.013	0	0.055
<i>Neocyttus rhomboidalis</i>	0.013	0	0.053
<i>Alloctytus niger</i>	0.079	0.014	0.176
Oreosomatidae	0.013	0	0.068
<i>Regalecus glesne</i>	0.013	0	0.085
<i>Macrorhamphosodes uradoi</i>	0.013	0	0.068
<i>Centriscops humerosus</i>	0.146	0.014	0.189
<i>Solegnathus spinosissimus</i>	0.013	0	0.082
Syngnathiformes	0.013	0	0.068
<i>Helicolenus spp</i>	0.290	0.097	0.428
<i>Hoplichthys haswelli</i>	0.422	0.204	0.591

<i>Alertichthys blacki</i>	0.026	0	0.113
<i>Antipodocottus galathea</i>	0.013	0	0.084
<i>Neophrynichthys angustus</i>	0.146	0.026	0.238
<i>Lepidoperca aurantia</i>	0.013	0	0.072
<i>Epigonus lenimem</i>	0.013	0	0.055
<i>Caristius</i> sp	0.013	0	0.055
<i>Cepola aotea</i>	0.013	0	0.056
<i>Hemerocoetes</i> sp	0.370	0.167	0.676
<i>Kathetostoma giganteum</i>	0.013	0	0.055
<i>Benthodesmus</i> sp	0.013	0	0.070
<i>Seriolella punctata</i>	0.013	0	0.055
<i>Seriolella caerulea</i>	0.040	0	0.096
<i>Arnoglossus scapha</i>	0.106	0.014	0.222
<i>Peltorhamphus latus</i>	0.026	0	0.096
<i>Azygopus pinnifasciatus</i>	0.224	0.095	0.359
<i>Pelotretis flavilatus</i>	0.013	0	0.094
Pleuronectiformes	0.159	0.034	0.222
Unidentified fish	36.655	34.743	38.614
Chondrichthyes egg case	0.181	0.086	0.401
Egg case	0.176	0.080	0.391
Commercial discard fish	0.876	0.589	1.355
Commercial discard fish	0.853	0.546	1.248
Cephalopoda			
Squids	1.932	1.620	2.526
<i>Sepioloidea loulouae</i>	0.013	0	0.068
Sepiolidae	0.026	0	0.068
<i>Nototodarus sloanii</i>	0.092	0.014	0.198
<i>Nototodarus</i> sp	0.145	0.014	0.209
<i>Amphitretus</i> sp	0.013	0	0.100
Teuthoidea	1.465	1.238	2.074
Cephalopoda	0.092	0	0.177
Octopoda	0.764	0.585	1.198
<i>Pinnoctopus cordiformis</i>	0.343	0.280	0.730
<i>Graneledone</i> sp	0.013	0	0.055
Octopoda	0.370	0.151	0.517
Other Mollusca			
Shelled molluscs	0.347	0.126	0.504
<i>Lunella</i> sp	0.066	0	0.135
Aplysiidae	0.026	0	0.069
Gastropoda	0.106	0.014	0.186
Bivalvia	0.052	0	0.097
Shell fragments	0.079	0	0.175
Tunicata			
Salpidae	0.125	0.029	0.243
Salpidae	0.119	0.027	0.221
Porifera			
Porifera	0.028	0	0.085
<i>Lissodendoryx</i> sp	0.026	0	0.080
Cnidaria			
Hydrozoa	0.014	0	0.071
Hydrozoa	0.013	0	0.055
Echinodermata			
Cidaridae	0.014	0	0.071
Cidaridae	0.013	0	0.055
Annelida			
Polychaeta	0.292	0.112	0.417
<i>Eunice</i> sp	0.013	0	0.068
<i>Hyalinoecia tubicola</i>	0.013	0	0.056

	Polynoidae	0.026	0	0.084
	Terebellidae	0.013	0	0.055
	Polychaeta	0.211	0.056	0.311
Other				
	Unidentified material	4.079	2.806	4.420

Table 11: Ling stomach contents composition data used for the detailed analysis of fish prey. Point estimate of percentage frequency of occurrence (%F), with 95% confidence intervals from bootstrap re-sampling. Statistics in bold are estimates by taxonomic group as used in the detailed multivariate analysis.

Prey items	%F	Lower 95%	Upper 95%
Elasmobranchii	1.151	0.793	3.406
Chimaeriformes	1.266	0.477	2.169
Conger eels	2.532	0.938	3.079
Spineback eel	2.532	1.056	3.180
Myctophiformes	2.301	0.994	3.456
Dwarf cod	14.384	8.922	14.706
Moridae (excluding dwarf cod)	2.417	1.302	3.955
Hoki	15.650	14.086	21.704
Ling	0.806	0.468	2.007
Oblique banded rattail	1.726	1.027	3.746
Bollons's rattail	2.992	1.648	4.599
Banded rattail	2.992	1.285	3.783
Notable rattail	3.222	2.392	5.463
Olivers rattail	18.412	13.876	20.136
Javelinfish	5.409	3.869	7.692
Oreosomatidae (dorries)	0.921	0.241	1.835
Bellowsfish (Centriscidae)	1.611	0.577	2.400
Sea perch	2.532	0.965	3.452
Deepsea flathead	3.682	1.839	4.540
Opalfish	3.222	1.609	5.282
Toadfish	1.266	0.365	2.140
Flatfish (Pleuronectiformes)	4.603	3.503	6.845
Commercial discard fish	7.250	5.425	11.046

3.4.2 Broad analysis of ling diet

The three-dimensional PCA indicated significant relationships between ling diet and the predictors fish weight, depth, and latitude (Table 12). Length also had a relatively high level of explanatory power, but was strongly correlated with weight, so was excluded ($r^2=0.98$). Year provided relatively little explanatory power.

Table 12: Pearson correlations attributable to the variables offered in a three-dimensional PCA of hake diet. Values for the chosen explanatory variables are in bold.

	year	bot_temp	time	latitude	longitude	depth	length	weight	sex
PC1	-0.017	-0.227	-0.013	-0.126	-0.142	0.394	0.396	0.405	0.090
PC2	-0.071	-0.094	-0.034	-0.109	-0.026	0.021	-0.080	-0.080	0.019
PC3	-0.042	-0.081	-0.048	-0.097	0.011	0.056	-0.126	-0.129	-0.013
PC1-3	0.085	0.259	0.060	0.193	0.145	0.399	0.423	0.433	0.093

Non-parametric MDS did not indicate any clear clusters of fish weight classes, but rather a general transition in diet from small to large fish (Figure 28).

The SIMPER analysis showed that the prey groups fish, galatheids, and scampi explained most of the similarity between weight groups. There was a transition in diet from galatheids to fish as ling size increased (Figure 29). Fish dominated the diet of the two largest weight groups. The occurrence of scampi in the diet increased with predator size, while the occurrence of prawns declined.

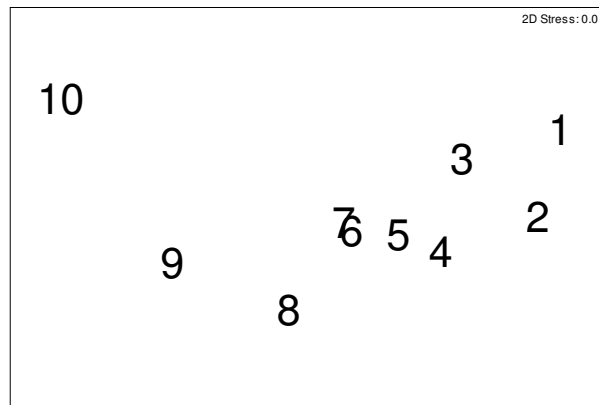


Figure 28: Ling diet. N-MDS based on percentage by volume (%V) of the 10 fish weight classes: 1, 80–520 g; 2, 521–920 g; 3, 921–1450 g; 4, 1451–2100 g; 5, 2101–2700 g; 6, 2701–3330 g; 7, 3331–4200 g; 8, 4201–5500 g; 9, 5501–9500 g; 10, 9501–28 600 g.

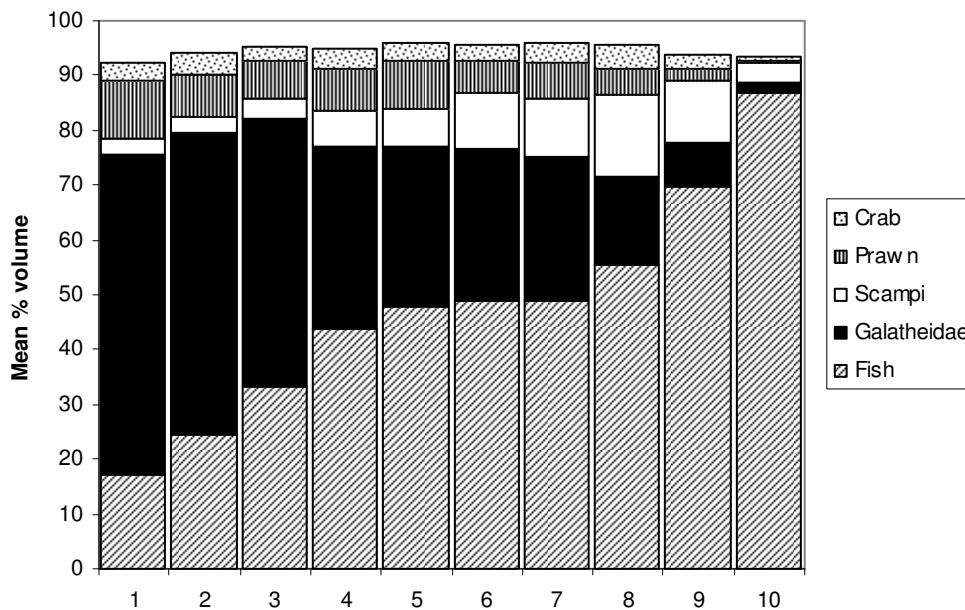


Figure 29: Ling diet. Mean percentage prey volume for the main prey types contributing to at least 95% of the SIMPER similarity within each group for each of the ten fish weight classes: 1, 80–520 g; 2, 521–920 g; 3, 921–1450 g; 4, 1451–2100 g; 5, 2101–2700 g; 6, 2701–3330 g; 7, 3331–4200 g; 8, 4201–5500 g; 9, 5501–9500 g; 10, 9501–28 600 g.

Non-parametric MDS indicated no clear groupings of depth classes, but rather a gradual change in diet with depth (Figure 30). The SIMPER analysis showed that the prey groups fish, galatheids, and scampi explained most of the similarity between depth groups. Fish prey were most important in the diet of the shallowest and three deepest groups (Figure 31). In the intermediate groups, both galatheids and fish were equally important. Scampi were relatively abundant in the diet of shallower ling.

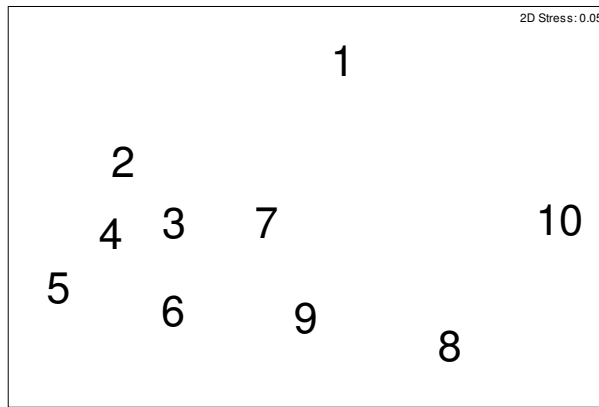


Figure 30: Ling diet. NMS based on percentage by volume (%V) of the 10 depth classes: 1, 215–350 m; 2, 351–380 m; 3, 381–411 m; 4, 412–430 m; 5, 431–452 m; 6, 453–478 m; 7, 479–510 m; 8, 511–554 m; 9, 555–624 m; 10, 625–850 m.

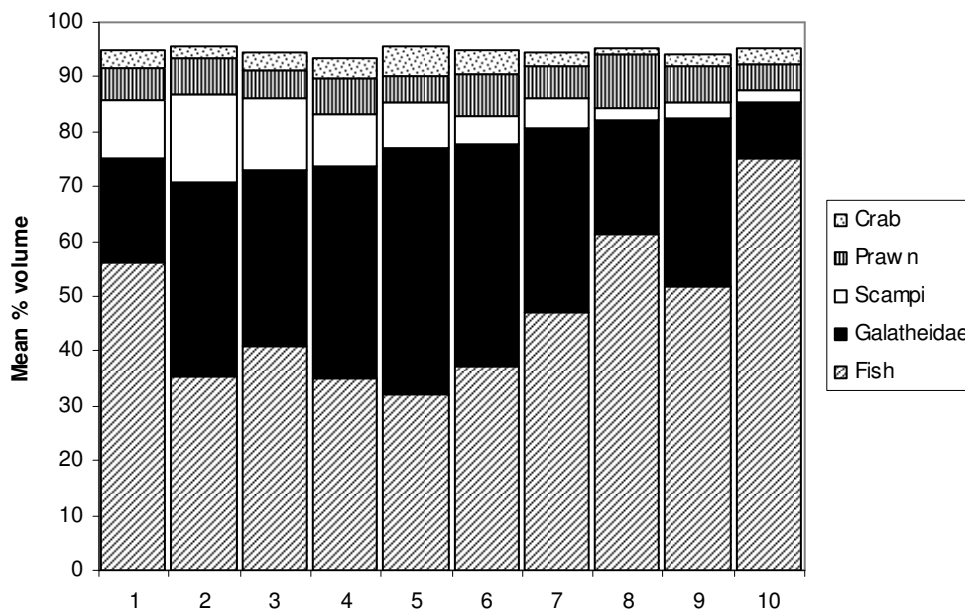


Figure 31: Ling diet. Mean percentage prey volume for the main prey types contributing to at least 95% of the SIMPER similarity within each group for each of the 10 depth classes: 1, 215–350 m; 2, 351–380 m; 3, 381–411 m; 4, 412–430 m; 5, 431–452 m; 6, 453–478 m; 7, 479–510 m; 8, 511–554 m; 9, 555–624 m; 10, 625–850 m.

Non-parametric MDS indicated similarity between adjacent latitude classes but no clear groups, suggesting a gradual change in diet with latitude (Figure 32). A SIMPER analysis indicated that fish, galatheids, prawns, and crabs explained most of the similarity between latitude groups. Fish was the most important prey group in the two most northern latitude groups; this prey category declined in importance with southward movement (except in the southernmost group where fish was again abundant) (Figure 33). Galatheids were dominant in latitude groups 5 to 9. Prawns and scampi were moderately important across the entire Rise, while crabs occurred more frequently on the south Rise.

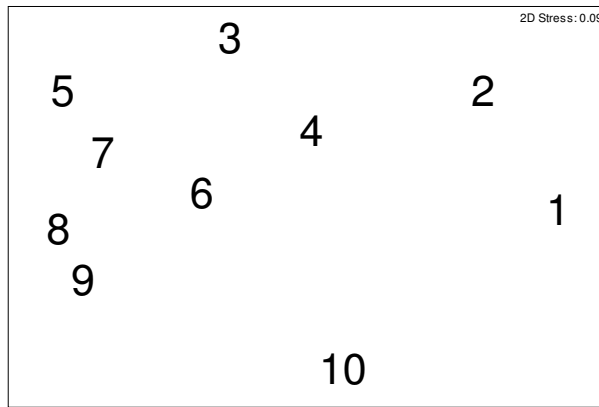


Figure 32: Ling diet. NMS based on percentage by volume (%V) of the 10 latitude groups (all in °S): 1, 42.74–43.00; 2, 43.01–43.16; 3, 43.17–43.30; 4, 43.31–43.46; 5, 43.47–43.62; 6, 43.63–43.75; 7, 43.76–43.88; 8, 43.89–44.02; 9, 44.03–44.19; 10, 44.20–44.65.

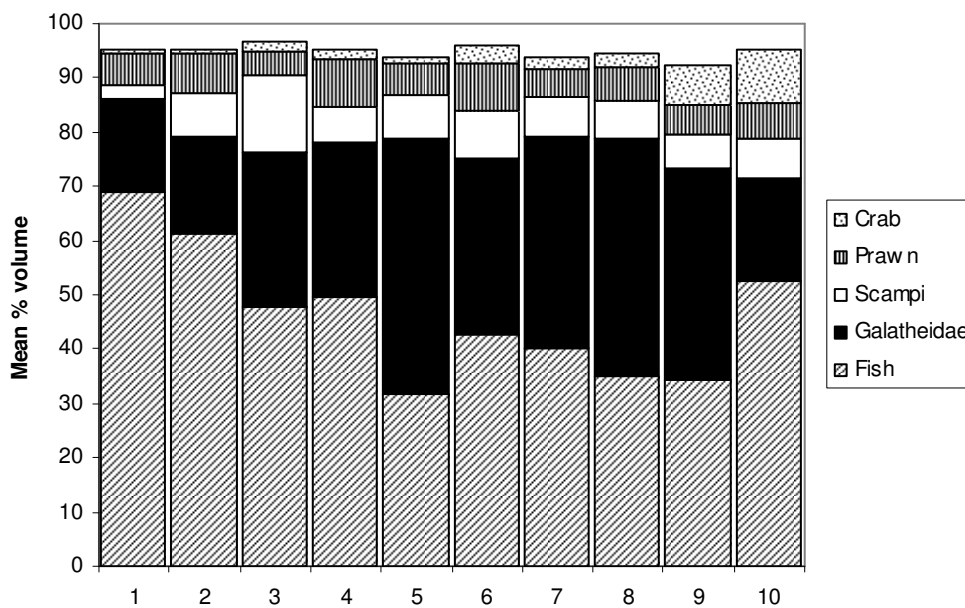


Figure 33: Ling diet. Mean percentage prey volume for the main prey types contributing to at least 95% of the SIMPER similarity within each group for each of the 10 latitude groups (all in °S): 1, 42.74–43.00; 2, 43.01–43.16; 3, 43.17–43.30; 4, 43.31–43.46; 5, 43.47–43.62; 6, 43.63–43.75; 7, 43.76–43.88; 8, 43.89–44.02; 9, 44.03–44.19; 10, 44.20–44.65.

Although ‘year’ explained little of the variance in the ling diet, an examination of the year effect is presented here (Figure 34). Fish accounted for more than 50% of the diet in 8 of the 17 year groups. Galatheids were the second most important contributor in all but two years (2000 and 2001) when they were slightly more common than fish. There was an indication of a decline in importance of fish prey from 1992 to 2000, followed by a subsequent recovery to 2009, with an inverse importance for galatheids.

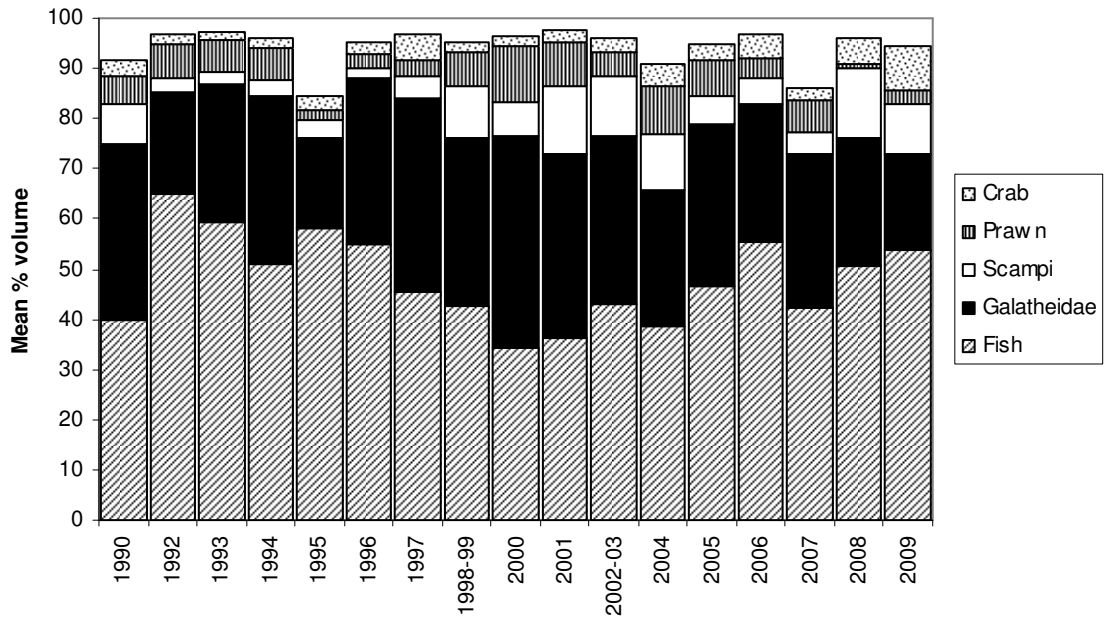


Figure 34: Ling diet. Mean percentage prey volume for the main prey types contributing to at least 95% of the SIMPER similarity within each year group.

3.4.2 Detailed analysis of ling fish diet

The second analysis used only the fish prey items that were identified at least to family. The 3-dimensional PCA indicated significant relationships between ling fish diet and the predictors fish weight, year, and longitude (Table 13). Length also provided a high level of explanatory power, but was strongly correlated with weight ($r^2=0.96$) and was excluded.

Table 13: Pearson correlations attributable to the variables offered in a three-dimensional PCA of ling fish diet. Values for the chosen explanatory variables are in bold.

	year	bot_temp	time	latitude	longitude	depth	length	weight	sex
PC1	-0.139	0.069	0.016	-0.028	0.061	-0.177	0.149	0.164	0.092
PC2	-0.289	0.028	0.001	0.035	-0.217	0.079	0.335	0.353	0.088
PC3	0.145	0.152	0.010	0.096	0.104	-0.093	0.221	0.218	0.079
PC1-3	0.352	0.169	0.018	0.106	0.248	0.215	0.428	0.446	0.150

Non-parametric MDS did not indicate any clear groups of fish weight classes, rather a general transition in diet from small to large fish (Figure 35). ANOSIM confirmed the significant effect of weight on diet (overall $R=0.034$, $P<0.01$), but low R -statistics from pair-wise tests ($R=0.001-0.100$) indicated a high degree of dietary overlap between weight groups.

The SIMPER analysis identified 15 prey groups that explained at least 90% of the similarities within each weight group. Oliver's rattail, dwarf cod, hoki, and commercial discards accounted for more than 50% of prey in all but the largest weight group (Figure 36). Dwarf cod decreased in importance as predator size increased, while hoki and discards increased in importance. Oliver's rattail was important in all but the two largest weight groups. Javelinfish were moderately important prey for medium to large ling.

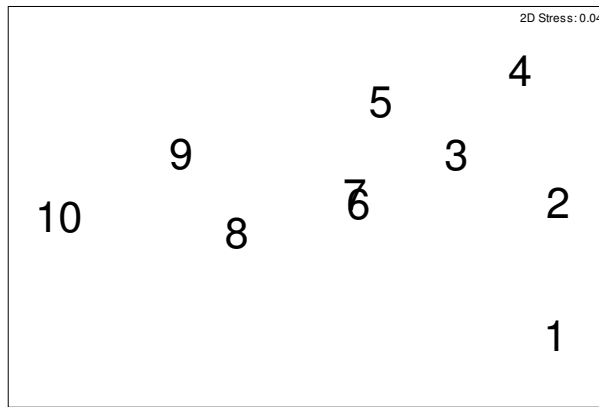


Figure 35: Ling fish diet. NMS based on percentage by volume (%V) of the 10 fish weight classes: 1, 80–520 g; 2, 521–920 g; 3, 921–1450 g; 4, 1451–2100 g; 5, 2101–2700 g; 6, 2701–3330 g; 7, 3331–4200 g; 8, 4201–5500 g; 9, 5501–9500 g; 10, 9501–28 600 g.

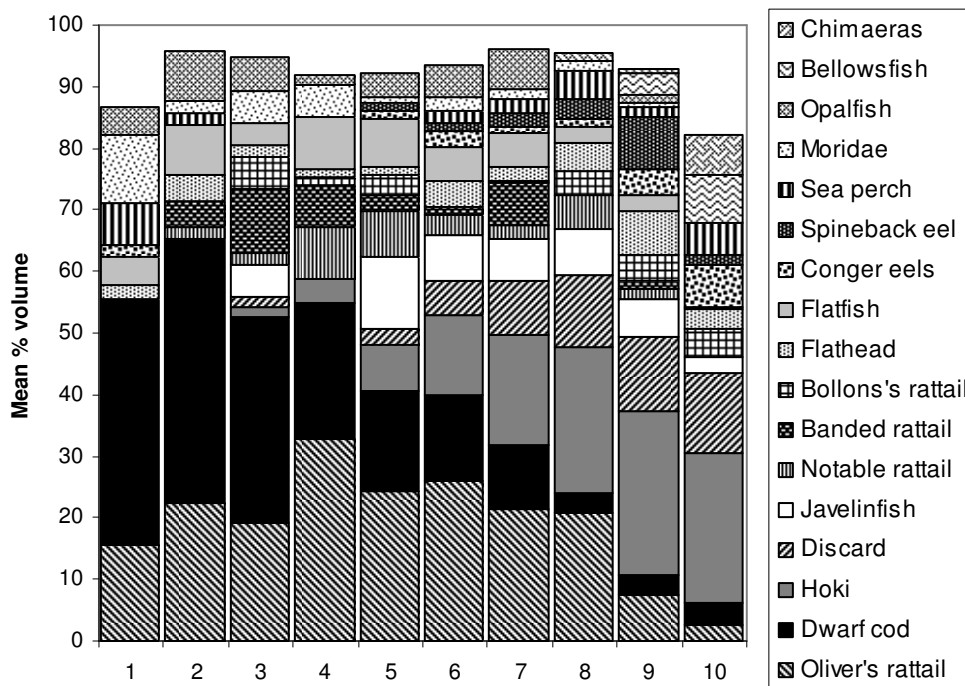


Figure 36: Ling fish diet. Mean percentage prey volume for the main prey types contributing to at least 90% of the SIMPER similarity within each group for each of the 10 fish weight classes: 1, 80–520 g; 2, 521–920 g; 3, 921–1450 g; 4, 1451–2100 g; 5, 2101–2700 g; 6, 2701–3330 g; 7, 3331–4200 g; 8, 4201–5500 g; 9, 5501–9500 g; 10, 9501–28 600 g.

Non-parametric MDS indicated no clear groupings of years, or any clear trends over time. The years 1990, 1995, and 1997 were possibly different from all other years (Figure 37). ANOSIM indicated a significant effect of year on diet (overall $R=0.071$, $P<0.01$), but low R -statistics from pair-wise tests ($R=0.001–0.234$) indicated a high degree of dietary overlap between year groups.

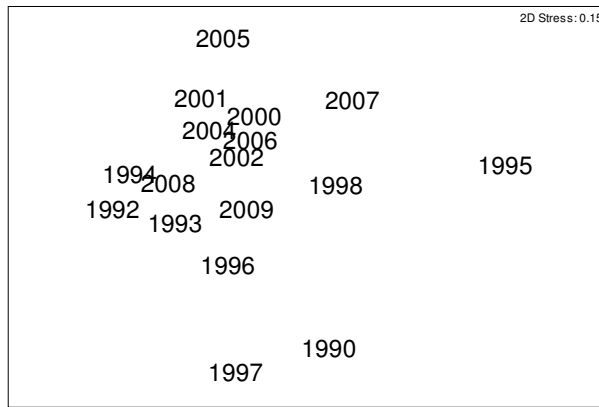


Figure 37: Ling fish diet. NMS based on percentage by volume (% V) of the 17 year groups.

The SIMPER analysis identified 18 prey groups that explained at least 90% of the similarities within each year group. Hoki contributed mostly in the earliest part of the time series (1990–97), whereas dwarf cod contributed most in mid-series (1998–2006) (Figure 38). Oliver’s rattail contributed throughout the series (except in 1995), possibly with a cyclical trend. Javelinfish contributed significantly to diet sporadically. Discarded fish was particularly important in 1995 and 2007, but in some years (particularly early in the survey series) prey identified as hoki were actually hoki heads discarded following processing (authors’ unpublished observations). No clear trends were apparent for any of the other fish prey species.

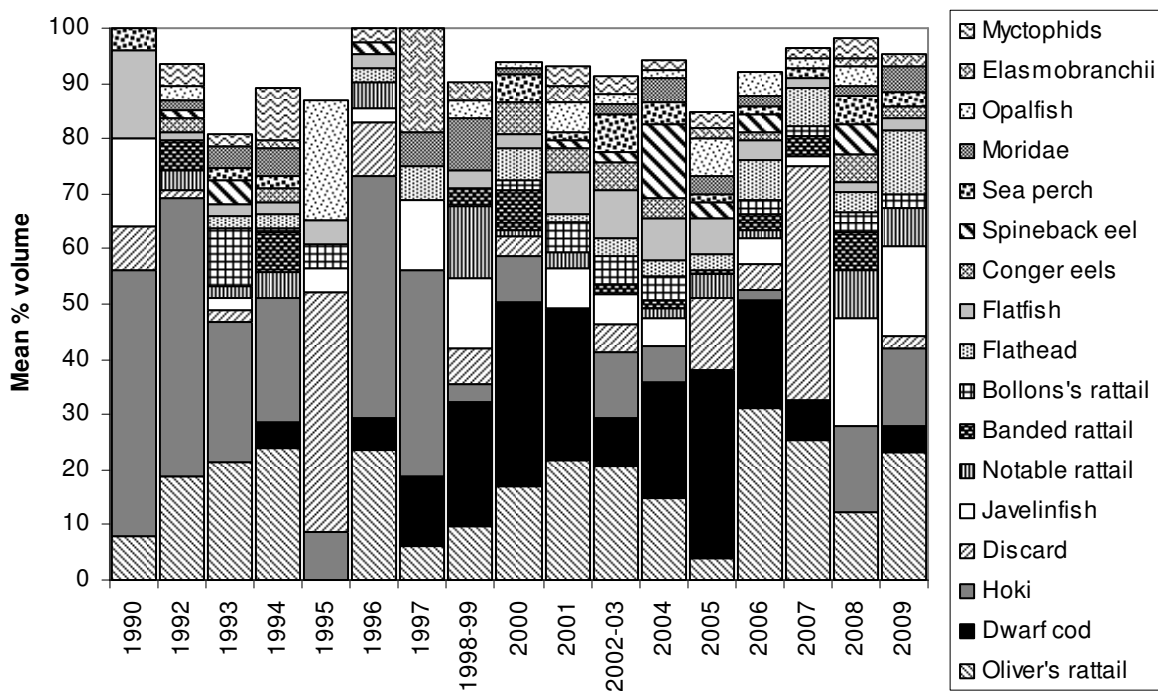


Figure 38: Ling fish diet. Mean percentage prey volume for the main prey types contributing to at least 90% of the SIMPER similarity within each group for each of the 17 year groups.

Non-parametric MDS indicated a gradual change in diet with longitude (Figure 39). ANOSIM confirmed a significant effect of longitude on diet (overall $R=0.044$, $P<0.01$), but low R -statistics from pair-wise tests ($R=0.003$ – 0.163) indicated a high degree of dietary overlap between longitude groups.

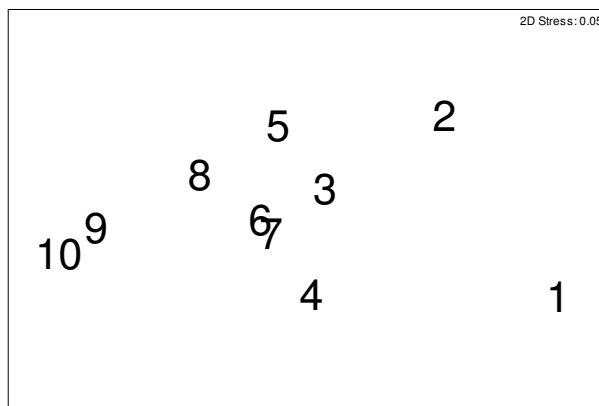


Figure 39: Ling fish diet. NMS based on percentage by volume (%V) of the 10 longitude groups (all in °E): 1, 172.76–174.70; 2, 174.71–175.70; 3, 175.71–176.55; 4, 176.56–177.80; 5, 177.81–178.69; 6, 178.70–179.90; 7, 179.91–180.95; 8, 180.96–181.65; 9, 181.66–182.40; 10, 182.41–185.16.

A SIMPER analysis identified prey that explained 90% of the similarity between longitude groups (Figure 40). Oliver’s rattail clearly contributed most to diet on the east Rise, and three other rattail species (Bollons’s, notable, and banded) were also commoner in the east. Dwarf cod appeared to be concentrated just east of the Mernoo Bank, but were preyed upon across the entire Rise. Hoki and commercial discards were least prevalent in the extreme eastern and western groups, while opalfish was the most common prey item in the westernmost group. Flatfish were common in the diet only on the west Rise.

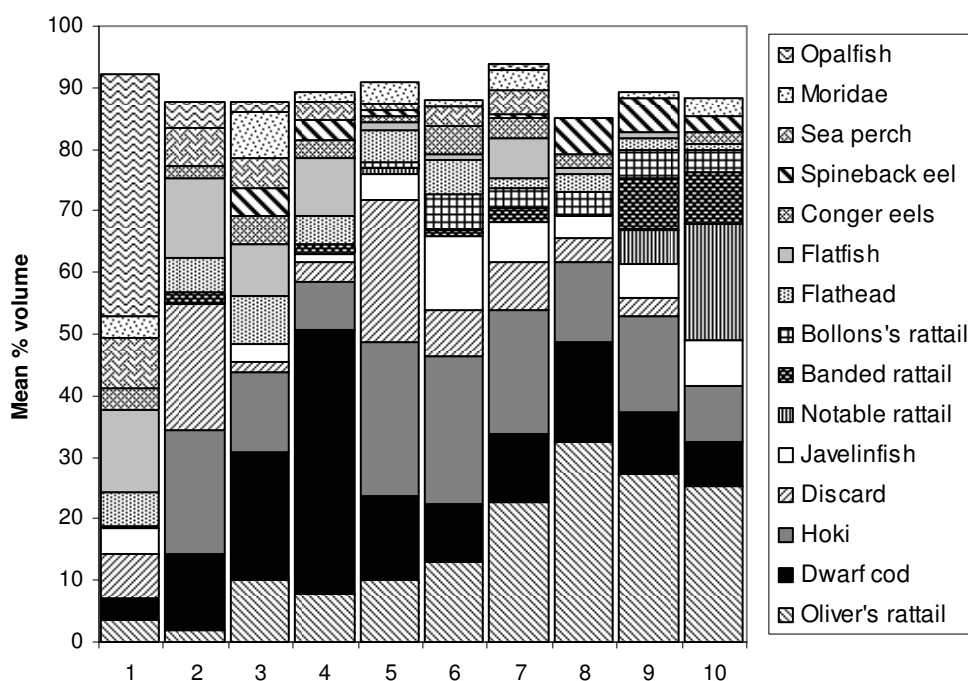


Figure 40: Ling fish diet. Mean percentage prey volume for the main prey types contributing to at least 90% of the SIMPER similarity within each group for each of the 10 longitude groups (all in °E): 1, 172.76–174.70; 2, 174.71–175.70; 3, 175.71–176.55; 4, 176.56–177.80; 5, 177.81–178.69; 6, 178.70–179.90; 7, 179.91–180.95; 8, 180.96–181.65; 9, 181.66–182.40; 10, 182.41–185.16.

4. DISCUSSION

One of the effects of fishing on the ecosystem that has been identified as potentially deleterious is the effects on feeding interrelationships, particularly when large proportions of key species are removed from the system. To detect any such effect, however, data need to have been collected over an extended period of time. Significant amounts of semi-quantitative stomach content data for hoki, hake, and ling have been collected routinely during summer trawl surveys of the Chatham Rise from 1990 to 2009. The work reported here used these data to investigate whether there were substantial changes in the diet of these three predators over a period of 20 years, during which the biomass of these species changed as a result of exploitation.

The available data fell into two categories. Data from 2005, 2006, and 2007 had been derived from laboratory examinations of stomachs as part of a detailed study of trophic relationships on the Chatham Rise (Dunn et al. 2009). These stomach contents were identified to as high a taxonomic level as possible, with prey items being weighed and counted. Data from all other years (i.e., 1990, 1992–2004, 2008, and 2009) were derived from at-sea examination of stomach contents. These prey items were also identified to as high a taxonomic level as possible, but most only to broad categories because of the difficulties of completing detailed prey identification at sea, with each prey group in a single stomach being allocated a percentage volume, such that the sum of all percentages added to 100 (regardless of the amount of material in the stomach). Comparisons of these two data sources were, therefore, problematic for two reasons.

First, it was necessary to convert the prey weight data from the detailed study into percentage volume. This was done by assuming prey weight was directly proportional to prey volume for all prey items. This assumption was untested, and so could lead to biases, but it seems reasonable to assume that there would be reasonable similarity in volume of a unit weight of fish, squid, or crustacean. Also, prey volume percentages from at-sea examinations were estimated by eye. It seems likely that errors in estimating volume could be relatively large, and any error or bias resulting from conversion of measured prey weight to percentage volume therefore relatively small.

Second, the at-sea identification of prey items were done much less comprehensively than laboratory examination, owing to time constraints, different abilities of seagoing staff to identify prey items, and the need to identify prey without the benefit of microscopes or other laboratory aids. Consequently, many at-sea identifications used broad codes like ‘rattail’, ‘squid’, or ‘prawn’, whereas in the laboratory the same items may well have been identified to family, genus, or species. This problem of different identification levels can be overcome in two ways, both with significant disadvantages. Either the detailed data can be collapsed down to the same low level of identification as the at-sea data (thereby losing much of the dietary detail), or the prey identified only broadly can be excluded from the analysis (thereby losing large volumes of the data). The latter thereby assumes that the broadly identified prey had the same composition as the prey identified in detail.

Because of the different assumptions and resolution, both the broad and detailed analysis of prey were completed. The analyses, and the results produced, will have been influenced by a series of biases that would be difficult to quantify.

- The assumptions that a unit of weight is equivalent to a unit of volume, and prey volumes were accurately estimated by eye (as mentioned above).
- Some stomachs examined at sea were probably classified as empty even though they might have contained traces of prey, and small prey items or prey fragments would be missed in at-sea examinations, particularly if they were part of a large, semi-digested food bolus. Such fragments were more likely to be identified in the laboratory, producing a fuller description of diet. Consequently the at-sea data may have under-represented small prey items, and over-represented empty stomachs.
- Commercial fishing discards have not been accurately identified and classified throughout the data series. It is known that some discards (e.g., hoki or jack mackerel heads) were classified by their respective species code (e.g., HOK or JMA) rather than a code for discards, particularly in the earlier part of the survey series. While some of these entries were reclassified later with confidence (using entries in the “comments” field of the biological table) or with reasonable

certainty (because it is highly unlikely that a demersal ling would chase and capture a pelagic jack mackerel), most must just be accepted as they were recorded. It is also likely that some prey items that were discards could not have been recognised as such. For example, ‘prey’ like rattails, marine eels, flatheads, or small sharks are likely to be discarded whole from fishing vessels, and if subsequently eaten would be indistinguishable from live predated individuals of the same species.

- Seagoing staff recording stomach content data would have had varied skill levels. A more skilled individual would have produced more comprehensive descriptions, with fewer identification errors.
- Resources available to enable the comprehensive identification of prey items have developed over time. Identification guides for ‘prawns’ were not used regularly for stomach content identification before the late 1990s, and comprehensive guides for most invertebrate groups have been only recently developed (e.g., Tracey et al. 2007). Changes over time in the number of detailed invertebrate identifications should not have biased the ‘initial’ analyses for all species, or the ‘detailed fish diet’ analyses for hake and ling, but may have affected the hoki ‘detailed’ analysis. This probably explains the apparent appearance of *Pasiphaea* spp. in the hoki diet in 2000.
- The 1990 *Amaltal Explorer* survey was conducted in November–December, whereas all the subsequent *Tangaroa* surveys were primarily in January. If the distributions of prey species vary seasonally, then it is possible that this time difference may have influenced which prey species were available.

4.1 Hoki

Hoki (*Macruronus novaezelandiae*) ate a high number of different prey types, but the diet was dominated by mesopelagic fishes (largely myctophids), euphausiids, and ‘prawns’ (i.e., natant decapods); this is a similar conclusion to that of Kuo & Tanaka (1984) and Dunn et al. (2009). However, on the Campbell Plateau, Clark (1985) found amphipods were the most important prey in smaller hoki (under 50 cm TL), and natant decapods, in particular *Pasiphaea* spp., increased in importance with increasing hoki size, with no shift to fish prey in the largest hoki. In the current study the most important prey for smaller hoki (100–350 g) was euphausiids followed by myctophids. The importance of euphausiids decreased for middle-sized hoki, being replaced by myctophid fishes. For the largest hoki (heavier than 1600 g), myctophids and euphausiids were still important, but squids and *Pasiphaea* spp. prawns also made a substantial contribution to the diet.

When using all data, but in broad prey categories, the diet of hoki was found to be influenced mainly by bottom depth, fish length, and year. However, SIMPER analyses showed only very weak patterns or trends associated with the depth or length variables. The inclusion of the year variable was probably a consequence of the markedly different crustacean diet recorded in 1990. The percentage of stomachs containing fish in 1990 (52%) was within the range recorded for all other years (50–85%). However, the percentage containing prawns in 1990 (2%) was much lower than the range for other years (11–44%), while the percentage containing euphausiids (58%) was much higher than for other years (4–33%). A misidentification of prawns as euphausiids is unlikely, so we conclude that in the summer of 1989–90, euphausiids were much more available to, or selected by, hoki than prawns. However, the ‘1990’ survey occurred from 26 November to 17 December 1989, while all the later surveys sampled primarily in January, and this timing difference cannot be ruled out as a cause of the different diet observed for 1990.

It is possible that the relative increase in frequency of fish prey in hoki stomachs over time could be related to an overall decrease in the mean size of hoki over the same time period, as a result of exploitation. However, no significant relationships were found between year and either mean length ($r^2 = 0.07$) or weight ($r^2 = 0.02$) of hoki in the sample, and there were no significant relationships between percentage of stomachs containing fish and either mean length ($r^2 = 0.01$) or weight ($r^2 = 0.01$) of hoki sampled in any year. Therefore, the increase in the frequency of fish (primarily myctophids) taken by hoki since the early 1990s appears likely to be unbiased, and genuine.

When using only data on prey items identified to a relatively high level, the diet of hoki was found to be influenced mainly by year, fish weight, and bottom depth. Euphausiids were the most important

component of diet from 1990 to 1995, while myctophids contributed the most from 1996 to 2009 (see Figure 9). Other prey contributed to diet sporadically with no clear trends. *Pasiphaea* spp. contributed substantially in several years, but three of these years were when the stomach contents were analysed in the laboratory rather than at sea. It is therefore possible that the importance of this prey item was related to more comprehensive identification rather than any greater abundance of, or predator preference for, *Pasiphaea* spp. prawns. *Sergestes* spp. prawns were seldom identified before 2002, but have been relatively common in stomachs since then. This is probably because of the more frequent use of prawn identification guides developed in the late 1990s.

In conclusion, it appears likely that the importance of fish (primarily myctophids) as a prey item for hoki has increased slightly but steadily between 1990 and 2009, while the importance of euphausiids has declined.

4.2 Hake

Hake (*Merluccius australis*) fed primarily on fish, of which javelinfish and hoki were the most important prey species. For small hake (less than 2.1 kg), Oliver's rattail and myctophids also occurred frequently in the diet, along with prawns (see Figure 22). These conclusions are similar to those of Dunn et al. (2009).

When using all available data, the diet of hake was found to be influenced mainly by predator weight, latitude, and bottom depth. In general, hake consumed mostly fish, but smaller, shallower, or more northern hake consumed a greater volume of prawns. There were no apparent differences between years.

When using only data on fish prey identified to a relatively high level, the diet of hake was found to be influenced mainly by predator weight, bottom depth, and year. Hoki was the most important prey in all years except 2004–05, 2006, and 2007 (the three year groups when the stomach contents were analysed in the laboratory rather than at sea) (see Figure 26). In the three years when more comprehensive identifications were completed, javelinfish contributed more to diet than hoki, and myctophids were particularly important in 2006. Javelinfish and/or Oliver's rattail contributed substantially in most years. It is possible that the greater importance of javelinfish (and myctophids) between 2004 and 2007 was related to more comprehensive identification, rather than any reduced abundance of, or predator preference for, the hoki prey, but confusion of these prey seems unlikely, so a true difference in diet cannot be ruled out. It is possible that the greater importance of small fish (javelinfish and myctophids) and the reduced importance of hoki between 2004 and 2007 was related to predator size. The mean size of analysed hake in 2006 and 2007 was markedly lower than in any other years. Alternatively, the apparent difference may simply be a bias caused by relatively small sample sizes; the number of samples per year was 24–81, but Dunn et al. (2009) estimated about 125 were required to provide a full measure of diet.

In conclusion, there are no obvious between-year differences or trends in hake diet from 1990 to 2009, other than those possibly caused by the more comprehensive laboratory analyses of 2005–2007 samples, and the systematic change in the mean size of hake over the period analysed.

4.3 Ling

Ling (*Genypterus blacodes*) consumed a particularly wide variety of prey, primarily fish and crustaceans. The fish component of the diet was characterised by dwarf cod in small ling, changing to Oliver's rattail for medium-sized ling, and as ling size continued to increase, hoki and commercial fishing discards increased in importance. Some, and perhaps much, of the prey identified as hoki was actually discarded hoki, for which there was no specific prey code available in the early part of the survey series. These conclusions on the Chatham Rise ling diet are similar to those of Mitchell (1984) and Dunn et al. (2009). i.e., crustacean prey (mainly galatheids) is most important overall, and fish prey (predominantly macrourids and hoki) becomes more important in the diet of larger ling. The

overall ling diet, and ontogenetic shift in diet, is similar to that reported in previous studies around New Zealand (Mitchell 1984, Clark 1985). Scavenging by ling has, however, only previously been suspected around the Falkland Islands (Nyegaard et al. 2004).

When using all available data, the diet of ling was found to be influenced mainly by fish weight, bottom depth, and latitude. Small ling fed primarily on galatheids (i.e., *Munida* spp), followed by fish; medium-sized ling preferred the same prey, but with the order reversed. Large ling preferred fish and scampi. Year explained little of the variability in diet (see Figure 34). However, there was a possible inverse relationship between fish and galatheids.

When using only data on fish prey identified to a relatively high level, the diet of ling was found to be influenced mainly by fish weight, year, and longitude. The analysis of the year effect identified no strong patterns in prey composition (see Figure 38). Hoki was most significant as a prey in the early part of the time series, but some unknown component of this was probably commercial fishing discards. Dwarf cod contributed significantly in the middle of the time series (1998–2006).

Fluctuations in prey are probably related to changes in prey abundance or availability. There is no information readily available on the relative abundance of dwarf cod. Oliver's rattail contributed substantially, but variably, to ling diet throughout the time series, and javelinfish contributed substantially in the last two years (see Figure 38); the abundance of both these species has been monitored by the trawl survey series (Livingston et al. 2002). The relationship between estimated total biomass of Oliver's rattail and javelinfish on the Chatham Rise with their frequency of occurrence in ling stomachs is shown in Figure 41. While visual examination of the plots suggests positive relationships between estimated biomass and occurrence as prey, the linear correlations are not significant.

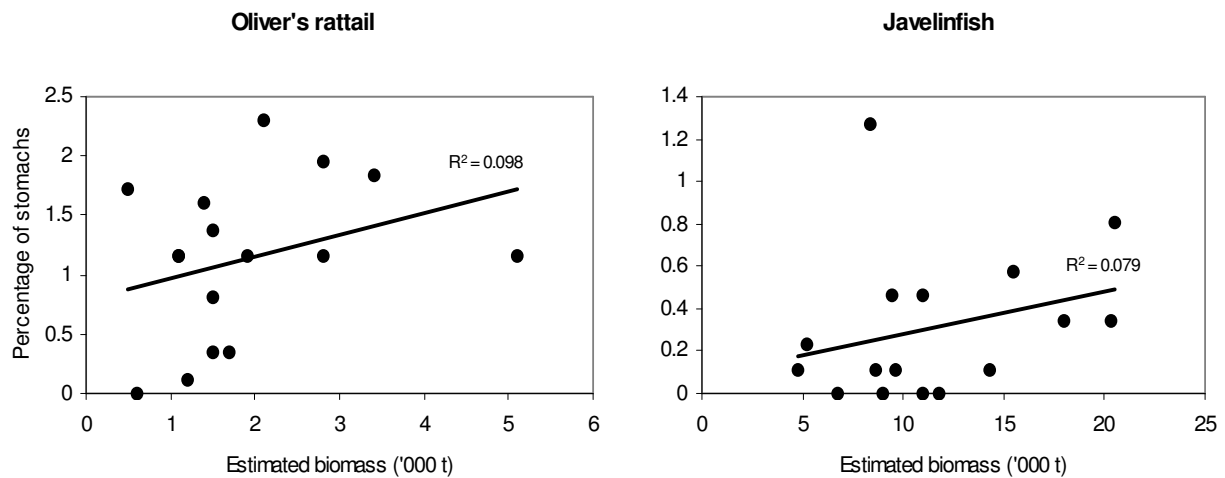


Figure 41: Relationships, for Oliver's rattail and javelinfish, between estimated trawl survey biomass and the percentage of stomachs used in the 'detailed fish prey' analyses that contained the species. Linear regression lines with r^2 values are presented on each plot.

While much of the variation in ling diet can be explained by the variables fish size, bottom depth, and location on the Chatham Rise, dietary differences between years are still apparently marked. Fish discarded from commercial fishing vessels were a component of the diet of larger ling, but this will clearly vary between years dependent on the proximity of fishing vessels to the survey stations. However, if discard fish are available to ling then this food source may be preferred over live prey (which would be more energy consuming to catch), and consequently could obscure relationships between the natural abundance of a prey species and its occurrence in the diet of medium to large ling. The problem of determining which prey items were actually fishing discards is particularly pertinent for ling. While there was little doubt about the provenance of items like hoki heads or jack mackerel heads and tails in stomachs, without any trace of other parts of the body, some other of the other discard 'prey' would have been ejected from fishing vessels whole and undamaged, and so be indistinguishable from live captured individuals (e.g., rattails, eels, flathead). It is therefore possible

that a higher, and possibly much higher, proportion of the ling diet could be commercial fishing discards.

In 2005, 2006, and 2007, the stomach contents were comprehensively identified in the laboratory and the species that contributed most to dietary similarity appeared to change, as in hake, with greater importance of dwarf cod, Oliver's rattail, and commercial discards, for 2005, 2006, and 2007, respectively (see Figure 38). This suggests the method of examination of stomach contents may vary depending on the method of analysis. This would seem to be an important bias, and worthy of further experimental evaluation.

In conclusion, there were some marked between-year differences in ling diet from 1990 to 2009. Examination of two common prey found no strong link between changing abundances of prey and the ling diet. The likely predilection of ling for scavenging on commercial discards will bias diet composition depending on commercial fishing practices, and may also obscure relationships between species abundance and their occurrence as ling prey.

4.4 Overall conclusions

In general, it was not possible to distinguish any strong dietary changes over time for hoki, hake, or ling, based on the data available. Most prey were examined at sea and identified to relatively low taxonomic levels, so the prey categories used in the analyses had poor resolution. The laboratory studies almost certainly identified more small prey and prey fragments than at-sea examinations, leading to a fuller description of diet. At-sea samples are likely to identify only gross changes in diet (e.g., changes from prawns to squid), rather than more subtle, but still quite important, changes (e.g., changing from hoki to javelinfish). Clearly, data collected at sea on gut contents would have greater value if the prey were identified to higher taxonomic levels than has generally occurred in the past.

Analyses using only information from prey that had been identified to a relatively high taxonomic level were generally data-poor, particularly for ling (n=869) and hake (n=625). Some differences between years were indicated, but concerns were raised about possible biases from data collection methodology (for hoki and hake), or patterns could not obviously be linked to any changes in estimated abundance of prey species (for ling). Intermittent, large scale, consistent and more detailed studies are likely to provide a better sample for analyses of trophic change than frequent, smaller scale studies of low prey resolution.

The only tentative conclusions that can be drawn from these analyses are that hoki have increased the proportion of fish (primarily myctophids), relative to prawns and euphausiids, in their diet over the time period examined, and that there may be some inverse relationship between fish and galatheids in the diet of ling. It is also possible that hake diet has varied as a result of the systematic change in the mean size of hake over the period analysed

5. ACKNOWLEDGMENTS

We thank all the NIWA staff who have identified stomach contents, both at sea and in the laboratory. Members of the Aquatic Environment Working Group provided useful discussion and suggestions, and Mary Livingston reviewed the manuscript. This work was funded by the Ministry of Fisheries under Project ENV2007-06.

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Appendix A: Hoki — distribution of survey tows and sampled stomachs

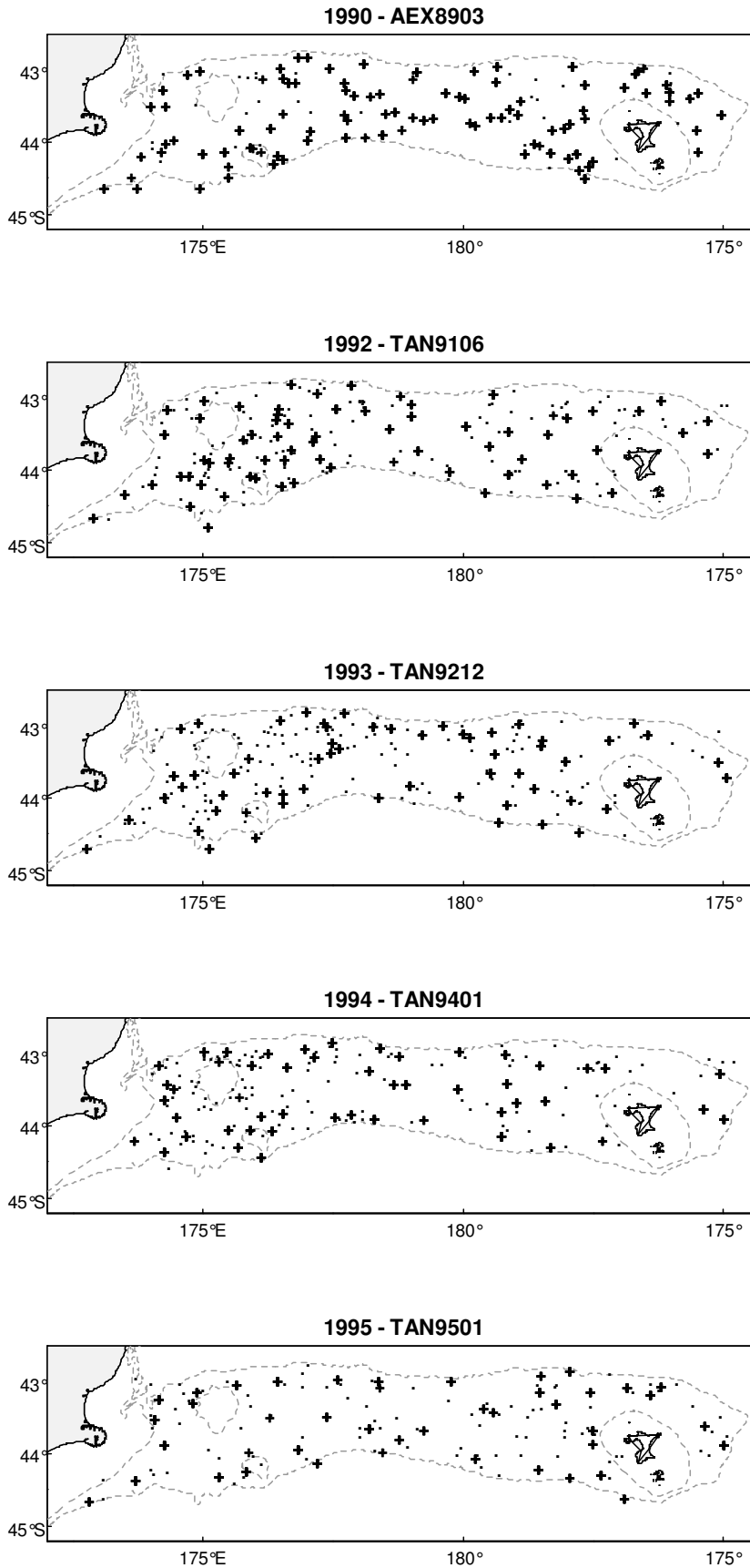


Figure A1: Hoki — locations of sampled stomachs (+) and all other tows catching hoki (.), by survey, 1990–1995.

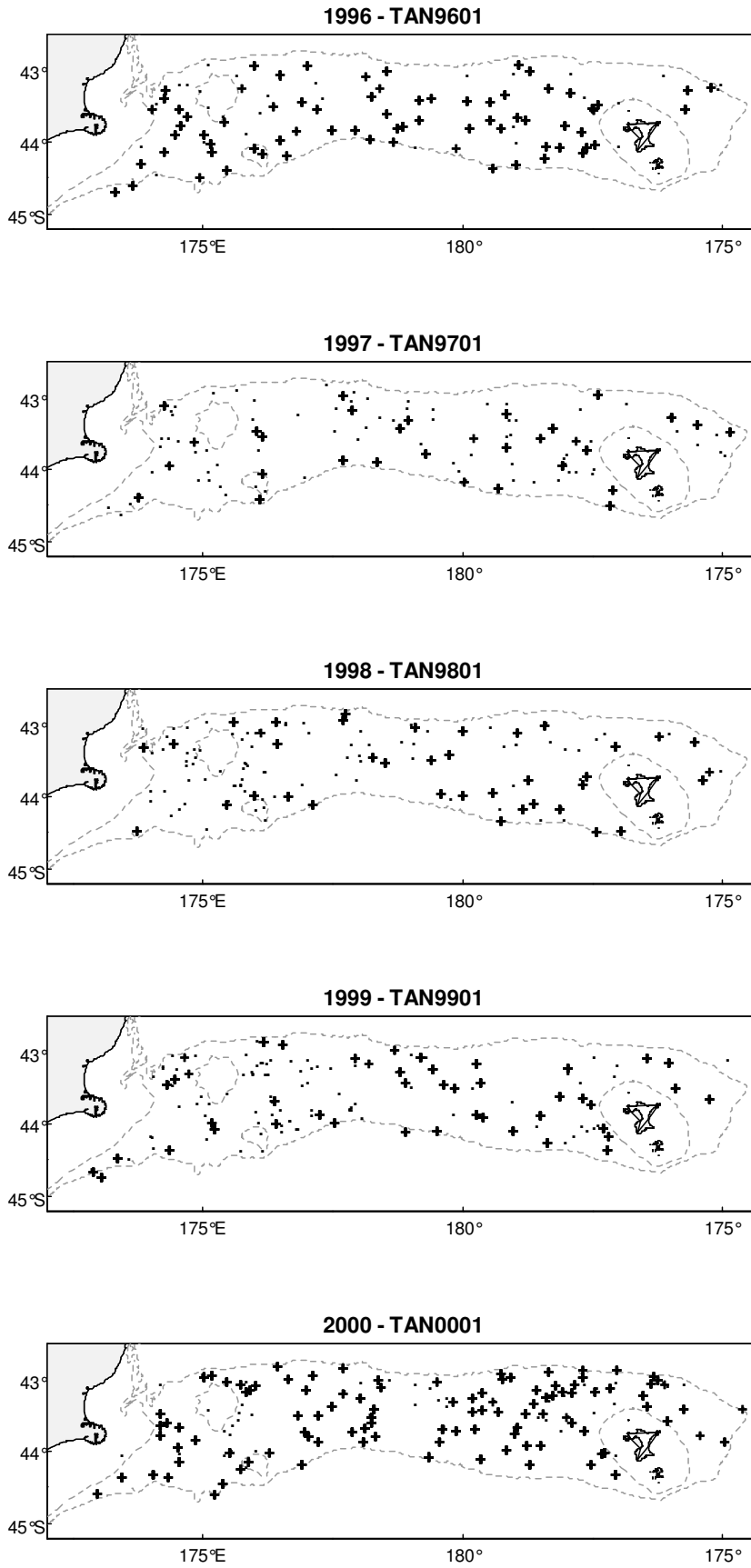


Figure A2: Hoki — locations of sampled stomachs (+) and all other tows catching hoki (.), by survey, 1996–2000.

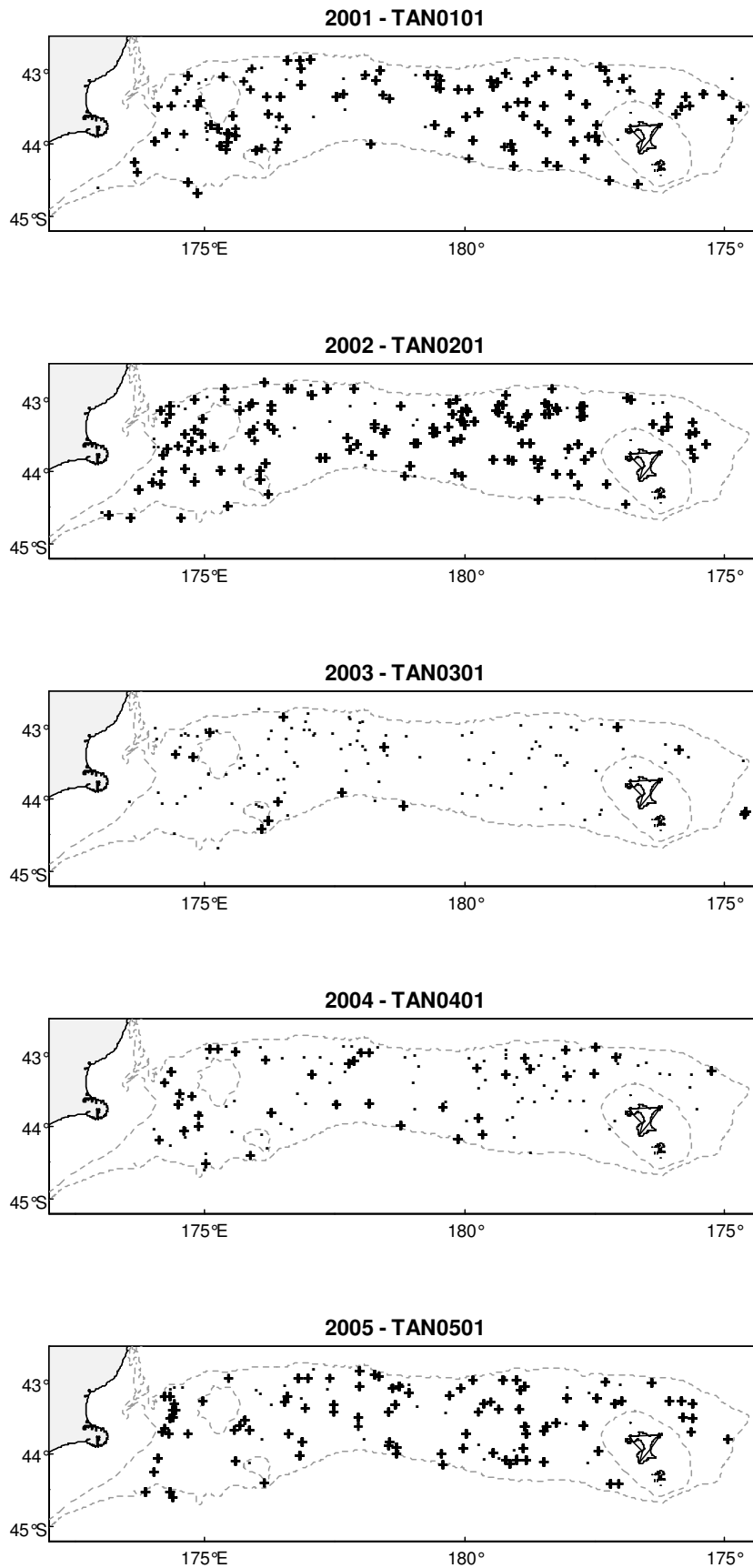


Figure A3: Hoki — locations of sampled stomachs (+) and all other tows catching hoki (.), by survey, 2001–2005.

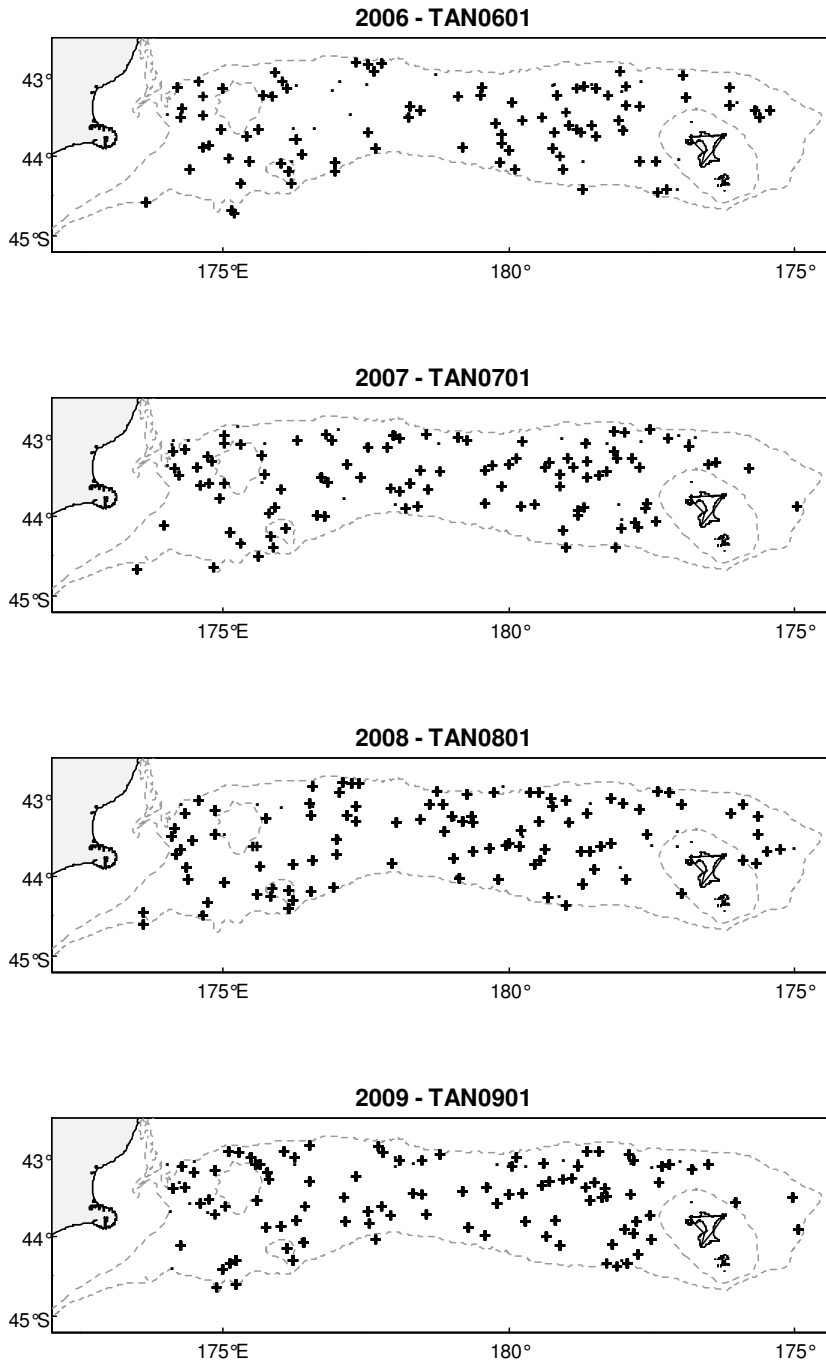


Figure A4: Hoki — locations of sampled stomachs (+) and all other tows catching hoki (·), by survey, 2006–2009.

Appendix B: Hake — distribution of survey tows and sampled stomachs

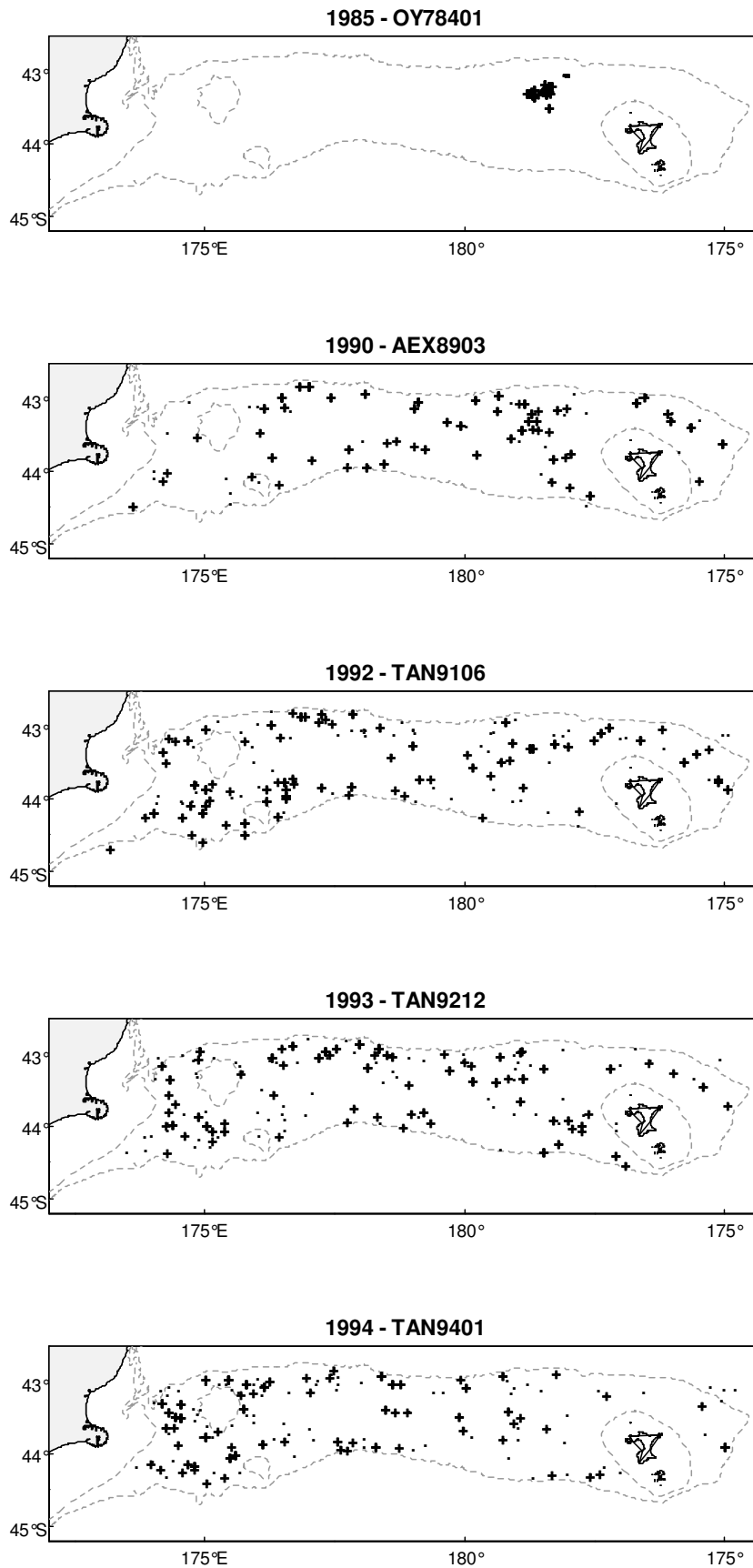


Figure B1: Hake — locations of sampled stomachs (+) and all other tows catching hake (.), by survey, 1985–1994.

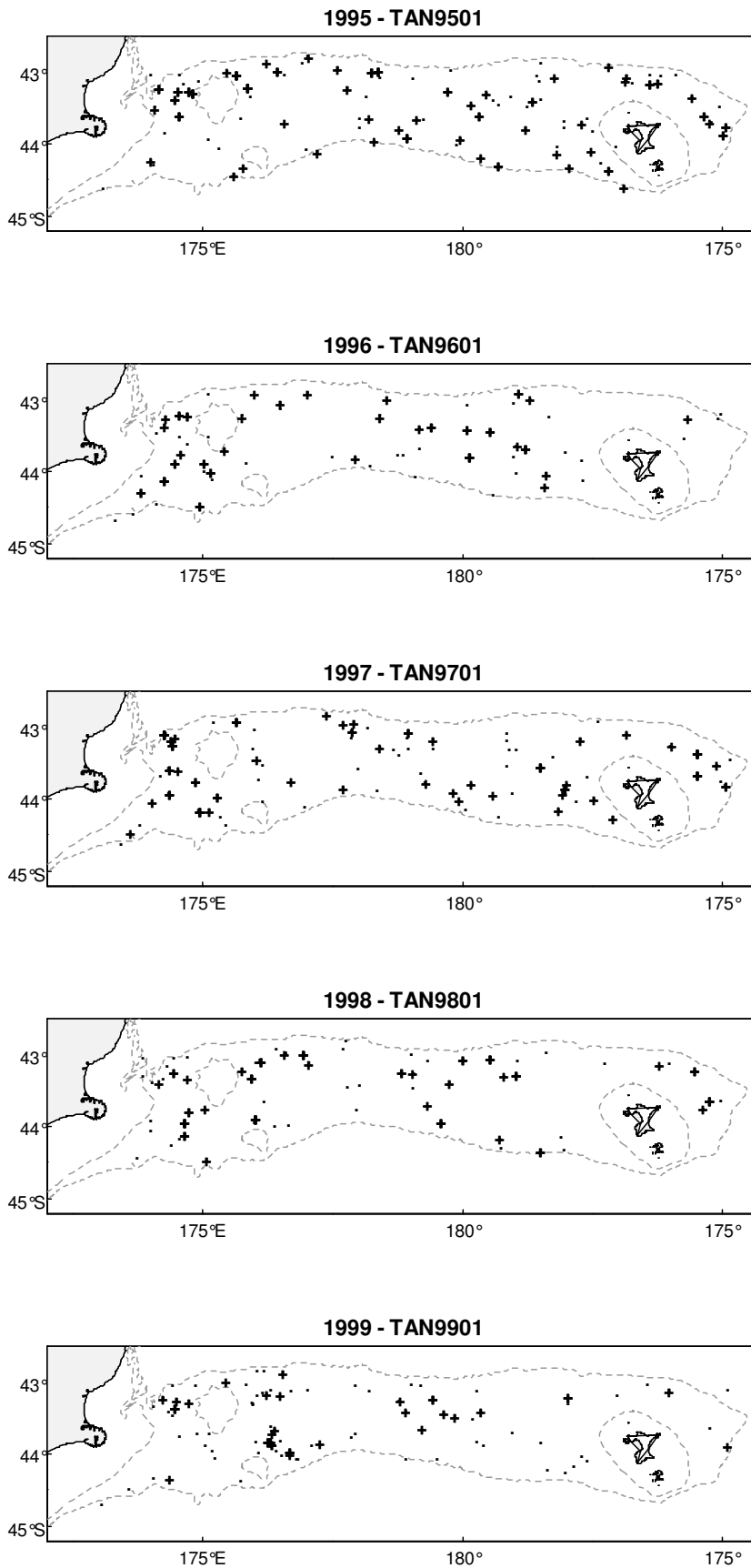


Figure B2: Hake — locations of sampled stomachs (+) and all other tows catching hake (.), by survey, 1995–1999.

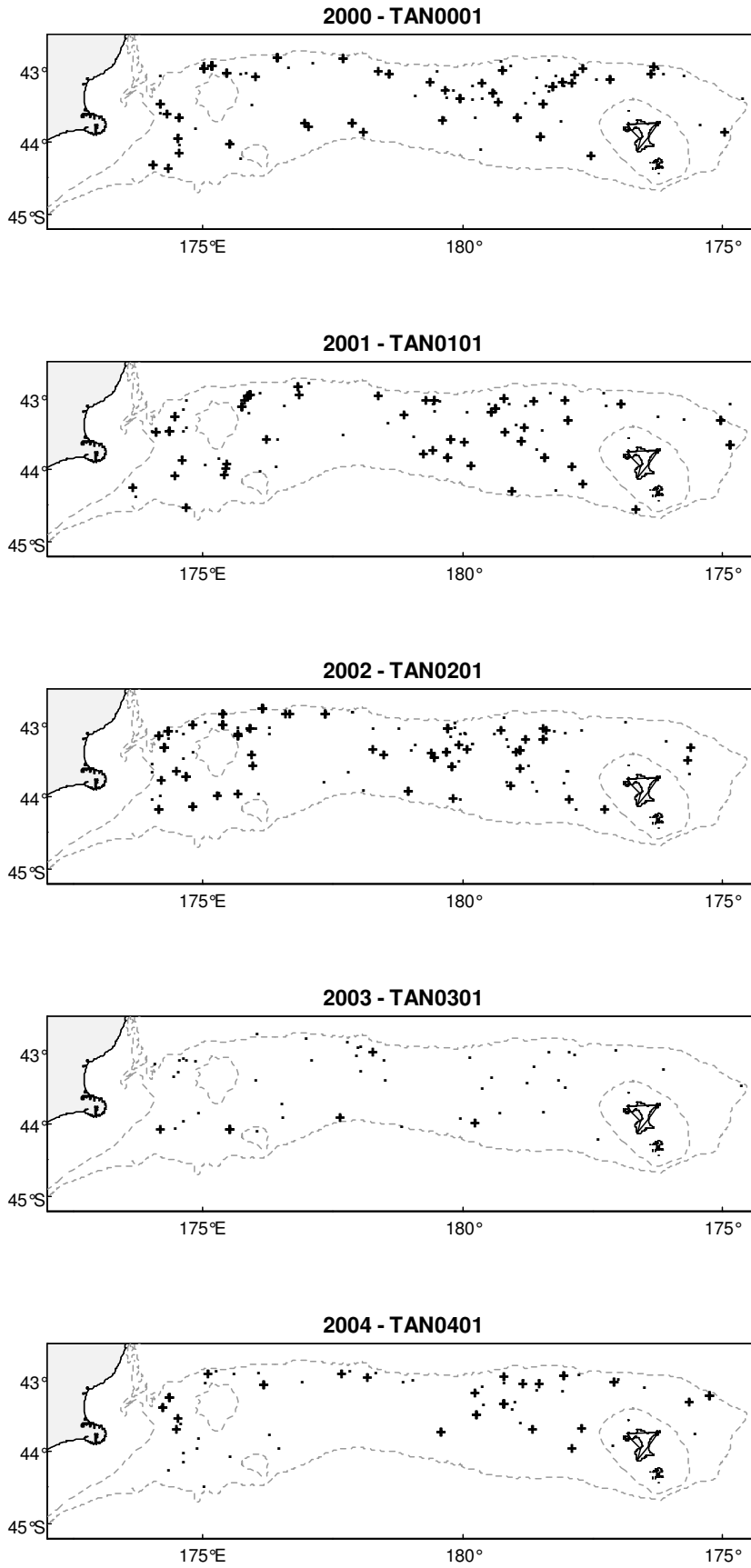


Figure B3: Hake — locations of sampled stomachs (+) and all other tows catching hake (.), by survey, 2000–2004.

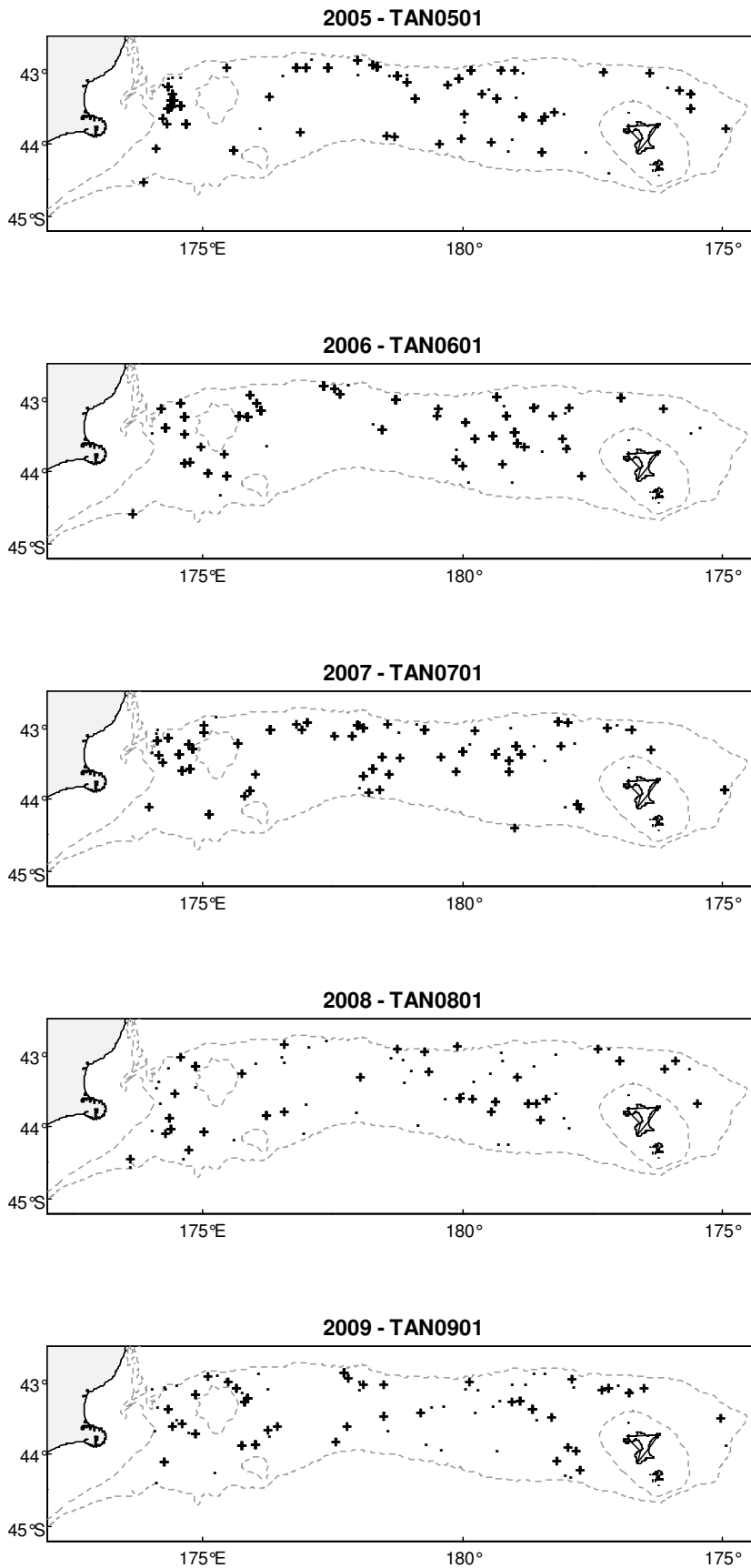


Figure B4: Hake — locations of sampled stomachs (+) and all other tows catching hake (.), by survey, 2005–2009.

Appendix C: Ling — distribution of survey tows and sampled stomachs

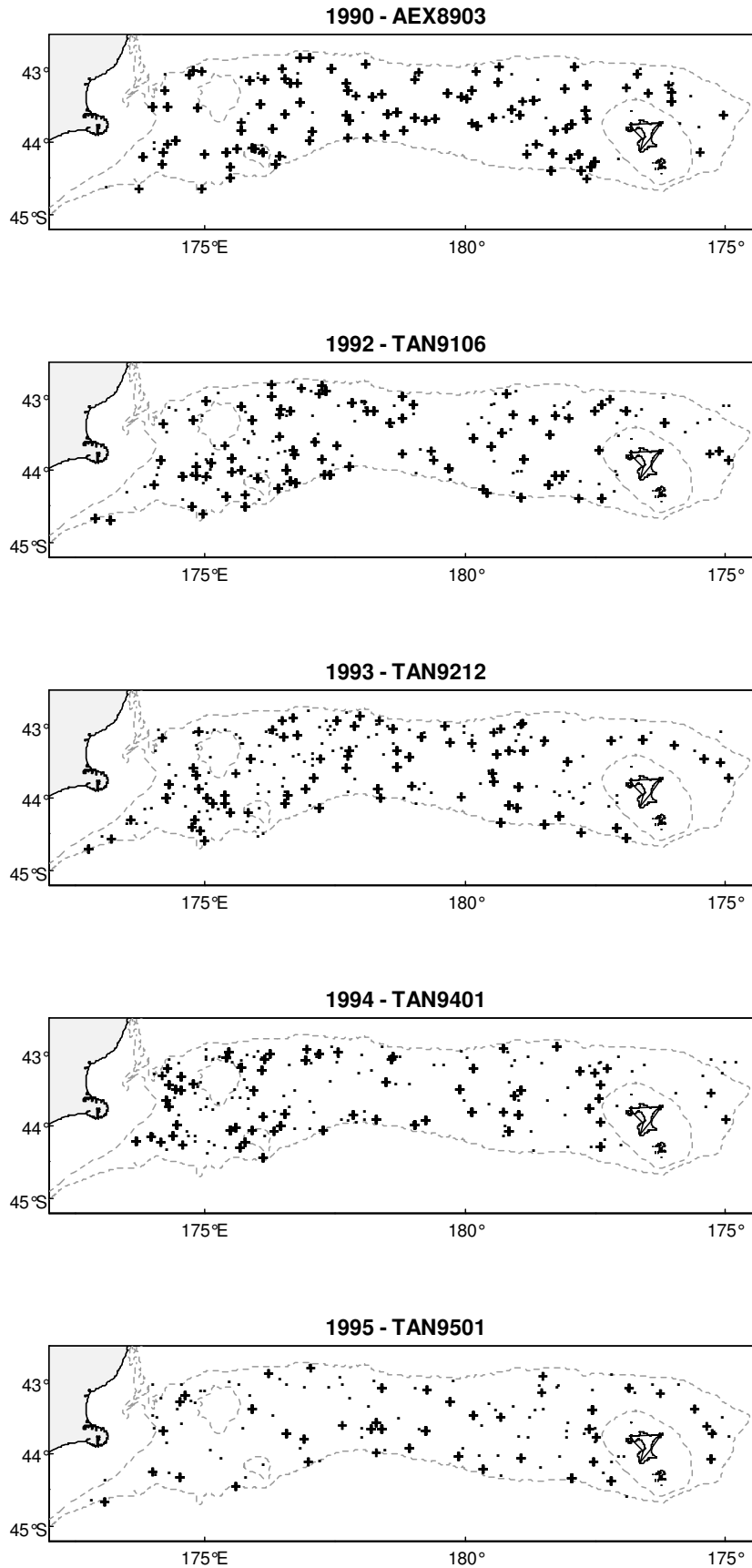


Figure C1: Ling — locations of sampled stomachs (+) and all other tows catching ling (.), by survey, 1990–1995.

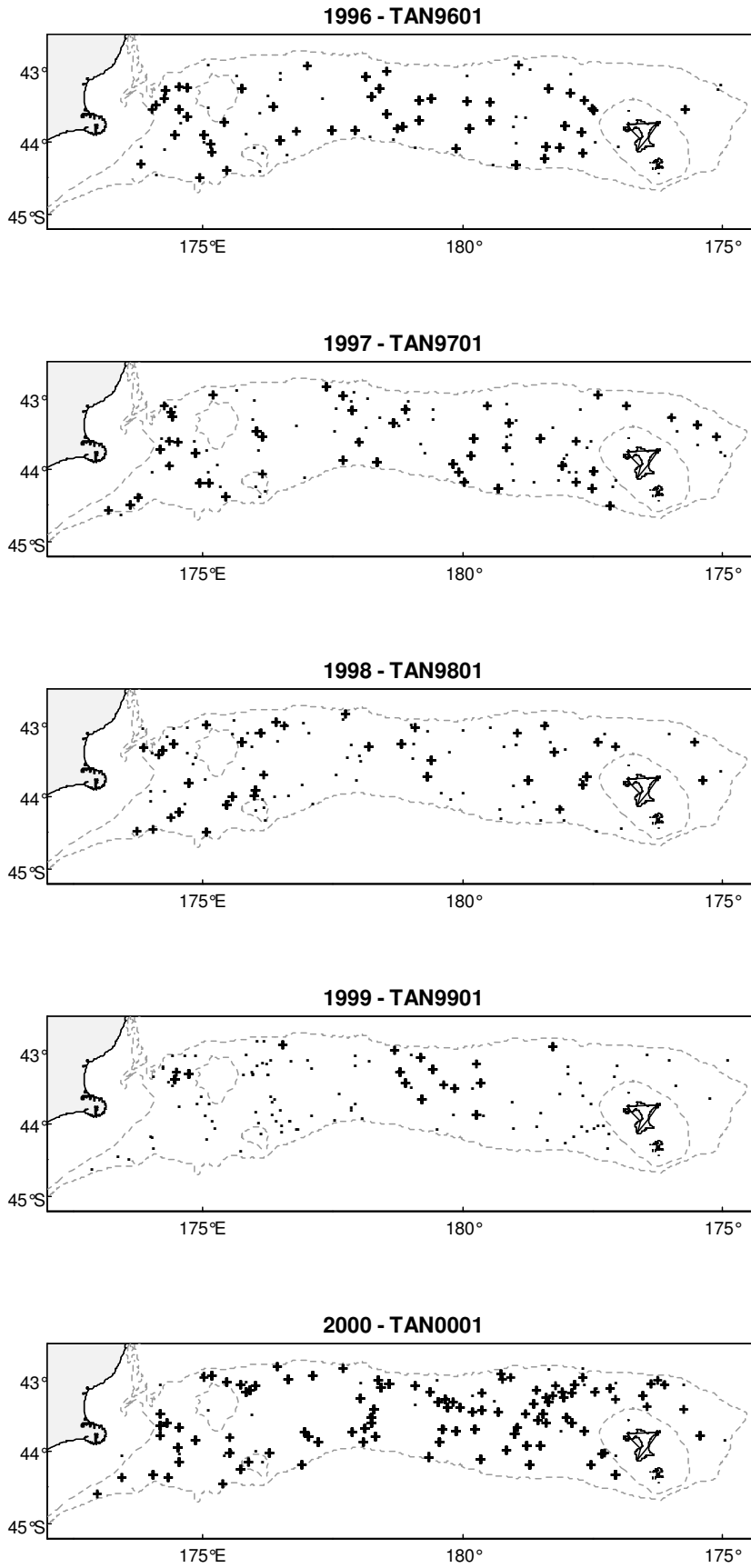


Figure C2: Ling — locations of sampled stomachs (+) and all other tows catching ling (.), by survey, 1996–2000.

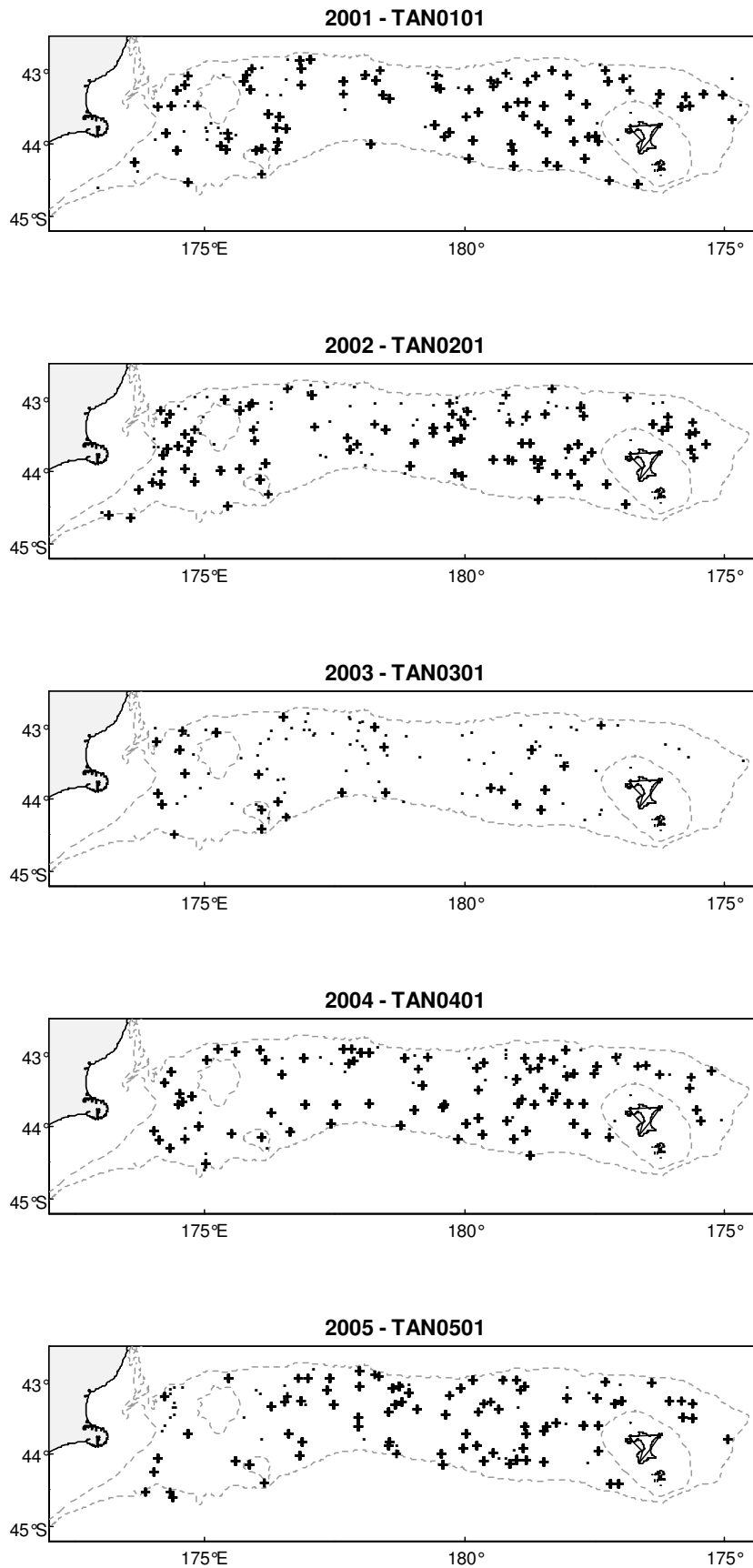


Figure C3: Ling — locations of sampled stomachs (+) and all other tows catching ling (.), by survey, 2001–2005.

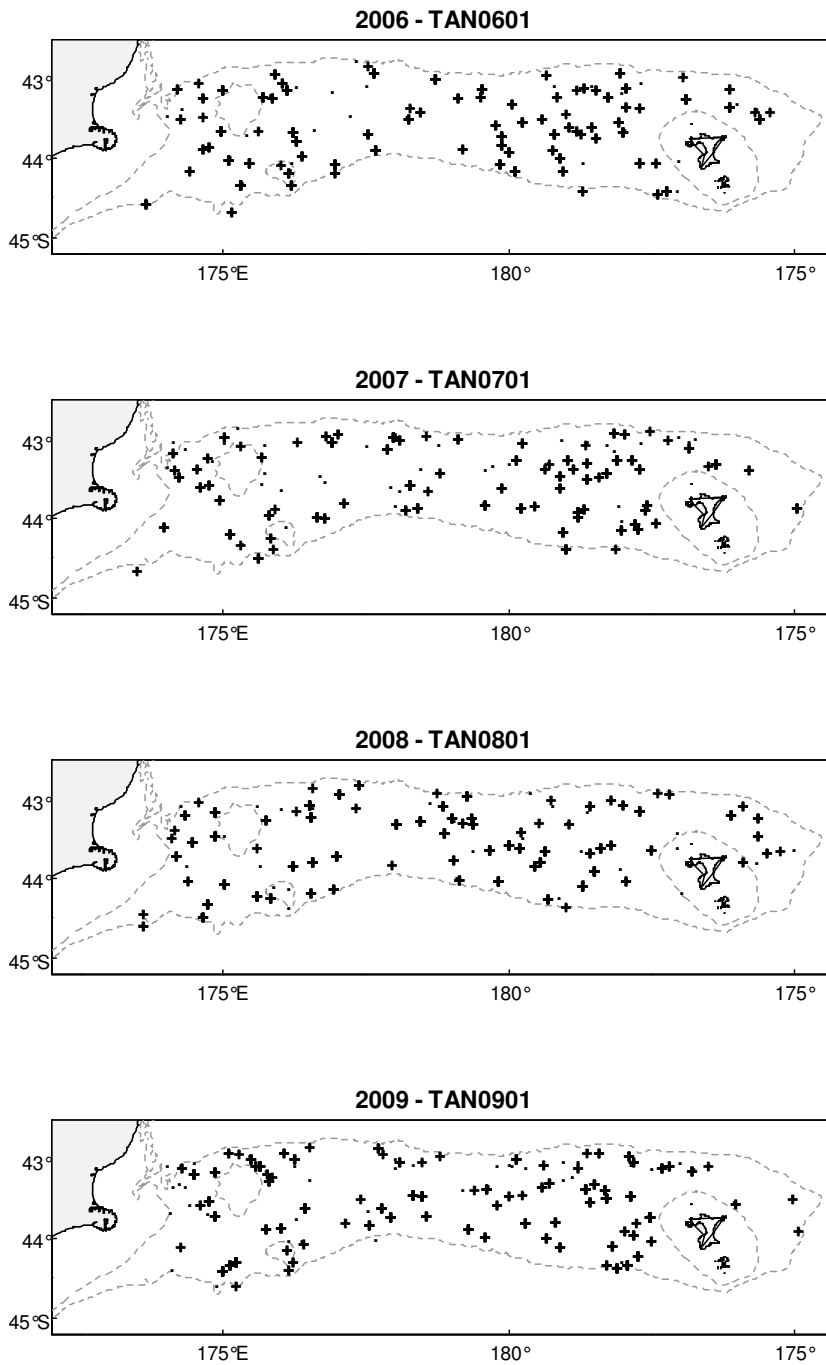


Figure C4: Ling — locations of sampled stomachs (+) and all other tows catching ling (.), by survey, 2006–2009.