Scampi stock assessment for 1998 and an analysis of the fish and invertebrate bycatch of scampi trawlers

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Contents

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1. Executive Summary

Catch, effort, and landing information for scampi trawl fisheries in QMAs 1, 2, 3, 4 (eastern and western portions), and 6A are updated to include data from the 1996–97 fishing year. Unstandardised CPUE indices are calculated and standardised indices estimated using a multiple regression approach. The two indices continue to be highly correlated. Standardised indices for 1996–97 in QMAs 1, 3, and 4 were all considerably higher than the index year and show generally increasing trends. There is no discernible trend in QMA 2 and the 1996–97 index is slightly below that for the base year. The standardised index for SCI 6A appears to have increased from about 0.3 to about 0.4. Detailed examination of interaction effects in CPUE models (usually vessel-year interactions) suggests that interaction effects can provide a useful means of detecting anomalous data. The exclusion of such anomalous data seems to lead to better CPUE models which sometimes show different trends to the base models. Similarly, the exclusion of shots from which no estimated catch of scampi was recorded increases the proportion of explained variance to a greater extent than might be expected from the frequency of such shots. It is thought that such zero shots are largely reporting errors.

An experimental photographic survey to estimate the density of scampi burrows in the western Bay of Plenty is described in other documents and summarised here. Burrows and emergent scampi could both be discerned from the photographs in densities similar to those encountered overseas. Tentative estimates of scampi abundance, size distribution, and biomass for a small part of QMA 1 are made using photographic survey data.

Growth rates for scampi in QMAs 1 and 2 are estimated by simultaneous length frequency analysis using data from trawl surveys, other research trawling activity, and from scientific observers in these areas. No further tagged animals have been recaptured from QMA 1, so no revision of this estimate is possible. Estimates of the von Bertalanffy K (0.05–0.08) and L_∞ (65–97 mm) from length frequency analyses were different (low and high respectively) compared with the tagging estimates (K = 0.11–0.14 and L_∞ = 49 mm).

The distribution of scampi is examined, confirming previous heuristic analyses which suggested that males are apparently more abundant in trawl catches than females in shallower water, and that the average size of animals in trawl catches generally increases with depth. This latter relationship is much stronger for males than it is for females. These relationships with depth cannot be separated from any putative relationship with bottom water temperature as depth and temperature are so highly correlated.

The relative abundance and length frequency of major finfish bycatch species, hoki, ling, giant stargazer, and gemfish were examined using both research trawl data (QMAs 1 and 2

only) and data from scientific observers and commercial returns (all QMAs). For the first time, the composition of the invertebrate bycatch of research trawling was examined in detail for the area between the Mercury Islands and White Island. Bycatch composition was found to be relatively predictable given information on depth and historical fishing pressure at each site. Historical fishing pressure was estimated by uniting trawl survey data and commercial returns in a GIS environment. In addition, there were significant negative relationships between the indices of fishing pressure and invertebrate richness and diversity, the abundance of a variety of invertebrate taxa, and the average size of some invertebrate taxa.

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2. Introduction

2.1 Overview

This document summarises catch, effort, observer, and research information for scampi fisheries in QMAs 1, 2, 3, 4 (east and western portions), and 6A. All major scampi fisheries were characterised in detail in 1997, and only updates are given here. Unstandardised and standardised indices of CPUE are generated for QMAs 1, 2, 3, 4 (east and western portions), and 6A, based on catch and effort information which has been rigorously screened for errors. Length frequency distributions from scientific observers are given for scampi and the four major finfish bycatch species, hoki, ling, giant stargazer, and gemfish, and the invertebrate bycatch of research trawling for scampi is characterised in detail for the first time.

2.2 Description of the fishery

The fishery for scampi is conducted almost entirely using light, bottom trawl gear, restricted by permit condition to a minimum mesh size of 55 mm in the codend. Most of the vessels are 20–40 m in length, and all use multiple rigs of two or three nets of very low headline height. Most scampi fishing is conducted in QMA 1 (Bay of Plenty), QMA 2 (Hawke Bay, Wairarapa), QMA 3 (western Mernoo Bank), QMA 4 (eastern Mernoo Bank, Chatham Rise, Chatham Islands), and QMA 6A (Auckland Islands) (Figure 1).

Some small or damaged scampi may be tailed, but the proportion of such processed product is usually small as it commands a lower price than whole scampi graded and frozen at sea.

2.3 Literature review

Cryer et al. (1995) and Cryer (1996) reviewed the international literature and little new work has been published since of relevance to *Metanephrops challengeri*. Cryer et al. (1997) described new standardised indices of CPUE for the commercial fisheries in QMAs 2, 3, 4, and 6A. The release and recapture phases of a tagging study to estimate growth rates, carried out in 1995–96 in the Bay of Plenty, were described by Cryer & Stotter (1997 and *in press*). Cryer & Hartill (1998) described the results of an experimental photographic survey of scampi in the Bay of Plenty in 1998.

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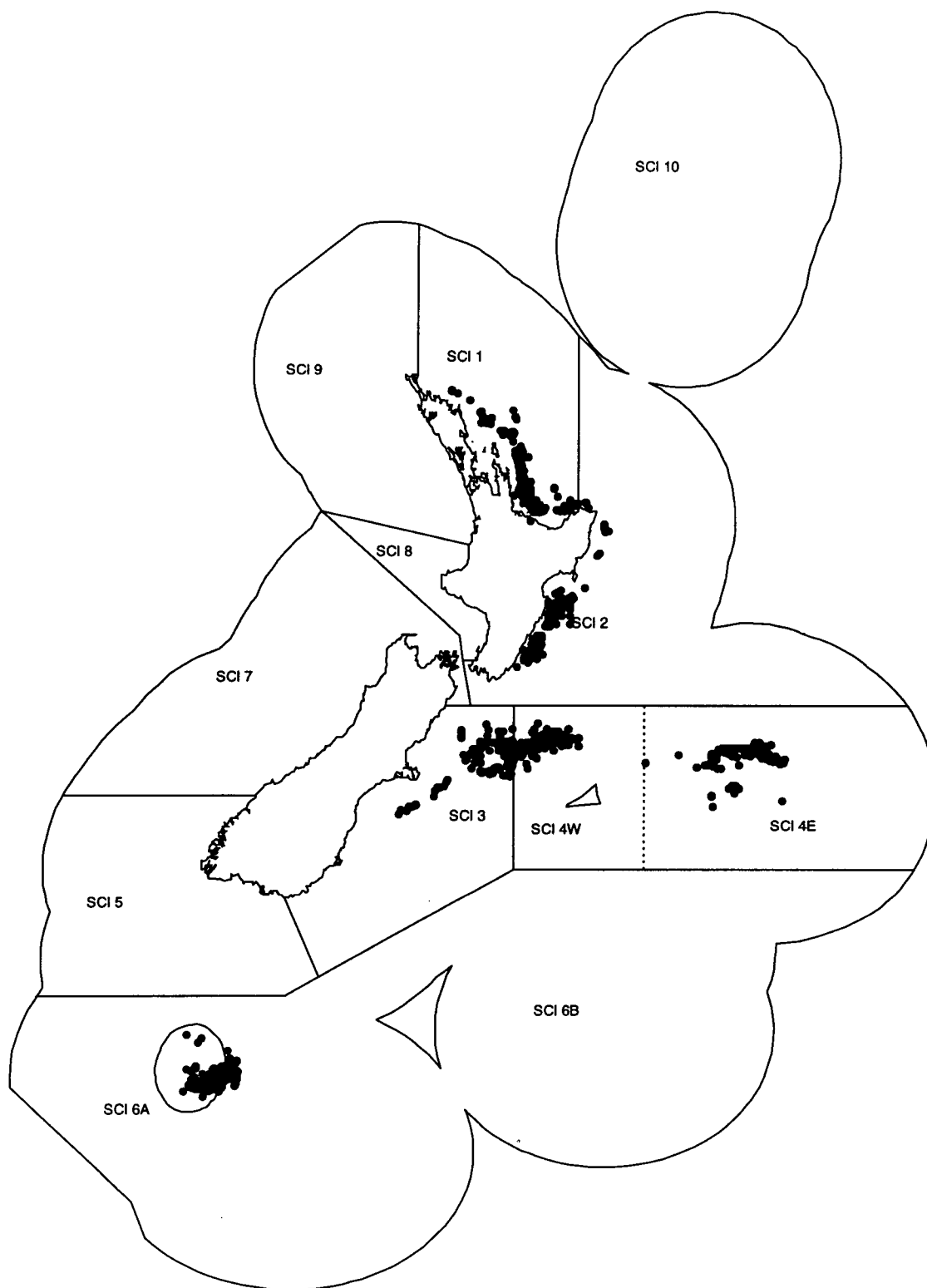
Figure 1: Fishery management areas and the location of the main fishing areas for scampi, *Metanephrops challengeri*, in New Zealand waters. Dots indicate the start positions of trawl shots targetting scampi. SCI 6A is a separate regulated management area containing all waters within 50 nautical miles of the Auckland Islands, whereas SCI 4 is informally separated into eastern and western portions at latitude 180 ° E.

3. Review of the Fishery

3.1 TACCs, catch, landings and effort data

3.1.1 Estimated landings

Until 1992, access to the scampi fishery was restricted by non-QMS permitting policies, but there were no limits on catches. For the 1991–92 and subsequent fishing years, catch limits were applied to all QMAs (Table 1). Fisheries in QMAs 1, 2, 4, and 6A were considered to be "developed" and catch limits were allocated individually to permits in proportion to their "catch history". Conversely, fisheries in QMAs 3, 5, 6B, 7, 8, and 9 were not considered to be "developed" and catch limits in these areas remained competitive. The QMA 3 fishery was wrongly ascribed to the former category by Cryer (1996).

Table 1: **Estimated commercial landings (t) from the 1986–87 to 1996–97 fishing years and current catch limits (t) by QMA (from Ministry of Fisheries catch effort database, Trawl Catch Effort and Processing Returns, TCEPR; early years' data may be incomplete; data for 1996–97 provisional and may be incomplete). – no data probably zero catch; * no separate catch limits for QMAs 6A and 6B before 1992–93, total catch limit 300 t**

	QMA 1 Landings	QMA 1 Limit	QMA 2 Landings	QMA 2 Limit	QMA 3 Landings	QMA 3 Limit	QMA 4 Landings	QMA 4 Limit	QMA 5 Landings	QMA 5 Limit
1986–87	5		–		–		–		–	
1987–88	15		5		–		–		–	
1988–89	60		17		–		–		–	
1989–90	103		135		–		–		–	
1990–91	179		295		–		23		–	
1991–92	132	120	221	245	0	60	246	250	0	60
1992–93	125	120	210	245	84	60	211	250	2	60
1993–94	115	120	244	245	64	60	261	250	1	60
1994–95	108	120	226	245	62	60	216	250	0	60
1995–96	114	120	228	245	76	60	226	250	0	60
1996–97	115	120	213	245	66	60	225	250	2	60

	QMA 6A Landings	QMA 6A Limit	QMA 6B Landings	QMA 6B Limit	QMA 7 Landings	QMA 7 Limit	QMA 8 Landings	QMA 8 Limit	QMA 9 Landings	QMA 9 Limit
1986–87	–		–		–		–		–	
1987–88	–		–		–		–		–	
1988–89	–		–		–		–		–	
1989–90	–		–		–		–		–	
1990–91	2		–		–		–		–	
1991–92	322	*300	4		0	75	0	60	0	60
1992–93	198	250	81	50	2	75	0	60	2	60
1993–94	241	250	61	50	0	75	0	60	1	60
1994–95	209	250	7	50	2	75	0	60	0	60
1995–96	220	250	5	50	0	75	0	60	0	60
1996–97	230	250	45	50	0	75	0	60	0	60

3.1.2 CPUE analyses

3.1.2.1 General methodology

Data were taken from MFish databases (Trawl Catch, Effort, and Processing Returns, TCEPR). All records for which scampi was the target species were extracted. All were by

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the method of bottom trawl. The following fields were extracted: vessel id, start and end dates, start and end times, start and end location (latitude and longitude), wing spread, net depth during fishing, bottom depth during fishing, headline height, nominal speed of tow, and catch of scampi.

The 35 297 records extracted were rigorously screened for obvious errors using the following procedure. All records for each vessel were sorted in order of their reported date and start time. For each record in the series, the reported data were used to estimate the catch rate of scampi (kg h^{-1}), the duration of the trawl shot, the distance between the start and finish locations, the average speed at which the trawl shot was conducted, the "down-time" between the start of the shot and the end of the previous shot, and the average "steaming" speed necessary to get to the start position of the shot from the end position of the previous shot. A further check was run to assess whether adjacent records in the series were essentially "duplicates" in that they weie reported at the same time and in the same place. Range checks were applied to these "diagnostics" as follows.

Diagnostic	Criterion
Catch rate	>100 kg h^{-1}
Trawling speed for a given shot	>5 kn
Steaming speed between shots	>10 kn
Trawl duration	>8 h
Down-time between shots	<0.5 h
Trawl distance	> 35 n.m

Records which violated any one of the diagnostic criteria were examined for errors. In most instances, the field causing the "error" was evident, and the cause of the violation clear. Most errors were mis-reported, mis-punched, or missing positions (e.g., a latitude of 37 within a series of shots at latitude 39), dates (wrong months or years being most common), or times (a.m. as opposed to p.m. and vice versa). Some records had mis-punched vessel identifiers. Data editing was undertaken to correct these errors and, where the correction removed the diagnostic violations, the record was flagged as "corrected". Where the cause of the violation was not easily reconcilable, or diagnostic violations remained after the correction of obvious errors, then the record was flagged as "irreconcilable". Many records with diagnostic violations were examined and considered not to be errors (e.g., some unusually long shots, especially in QMA 6A). Sixty-five records from 13 vessels having less than 50 records in the database were considered to be errors and excluded.

Tows with zero catches were accorded a nominal 1 kg catch to allow the use of a logarithmic transformation. Vignaux & Gilbert (1993) showed that, for the scampi fishery in QMA 1, the choice of nominal catch for zero tows did not greatly affect the performance of their model, which was essentially the same as those used here.

Standardised indices of CPUE were calculated using a multiple regression approach described by Vignaux & Gilbert (1993, 1994) developed for all scampi fisheries by Cryer et al. (1997). The model was used to estimate multiplicative effects on scampi CPUE (kg greenweight per nautical mile trawled) of environmental, vessel, and year variables:

$$C_t = M + Y_{i,t} + P_{j,t} + Q_{k,t} + R_{l,t} + ...$$

where C_t is the logarithm of catch per nautical mile trawled on tow t, M is an overall mean for C_t, $Y_{i,t}$ is the effect on C_t of tow t being in year i, $P_{j,t}$ is the effect of variable P having value j_t, $Q_{k,t}$ is the effect of variable Q having value k_t, and so on.

Likely variables (from previous analyses) include seasonality, time of day, depth, areal location within each QMA, and vessel. Location was usually modelled as position along the main axis of the fishery "ribbon", i.e. in a single dimension. Vessel and fishing year are categorical by nature, and the other variables were converted to categories by splitting the data into eight evenly sized bins. Eight bins were used because this was small enough to allow simultaneous analysis of all data for a QMA, yet adequate to model any relationships. An initial screening for likely influential variables (in a given QMA) was conducted by including all variables in a stepwise regression procedure. Only those shots without any missing data can be used in this process, and this was sometimes only about two-thirds of all the data (missing data are common, especially for gear descriptors such as headline height and wingspread in the early years of these fisheries).

After initial screening, all shots without missing data for the likely influential variables were included in a final stepwise procedure, using, for ease of interpretation, 12 categorical bins for seasonality and time of day (giving bins equivalent to months and 2 hour time slots respectively). Most records were included in the final model because the variables used tended to be those for which missing data are rare. Variables were included until no significant improvement in explanatory power was achieved (improvement in R^2 less than 2 percentage points).

The year effects in the multiple regression model are taken as putative indices of stock abundance as

$$A_i = exp(Y_i - Y_0)$$

where Y_i is the regression coefficient for year i, Y_0 is the regression coefficient for the base year (usually the year when fishing started), and A_i is the year effect in year i relative to the year effect in the base year. If the year effect explains variance (viz. changes in CPUE) in a way that is not explained by any of the other variables, then it may be measuring changes in stock size. The variance of this estimate, A_i, can be estimated from

$$s^2_{A_i} = A_i^2 \, exp(\sigma^2) \, (exp(\sigma^2) - 1)$$

where
$$\sigma^2 = Var(Y_i) + Var(Y_0) - 2 \, Cov \, (Y_i, Y_0)$$

These models are called the base case models for a given QMA.

Following estimation of base models, the data for each area were examined for interaction effects between variables influential in the base case model. Substantive interactions were examined to determine if they were "real" (indicative of genuine interactions between variables). For example, a real interaction between year and area variables might indicate that catch rates had been improving in one area and declining in another and would tend to

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invalidate the estimation of overall year or area effects for the QMA in question (and suggest separate analyses for the separate areas).

The interaction effects commonly provided some guidance as to how the base model CPUE could be improved. For example, a large interaction term between year and vessel largely invalidates the estimated year effect, but examination of the interaction can often demonstrate that most of the interaction stems from one, or a few, vessels. Removal of these vessels from the analysis can be justified in terms of better meeting the assumptions of the modelling approach (which assumes little interaction among the variables) and possibly in operational terms (vessels may change skipper, refit, re-power, etc).

Further sensitivity analyses were conducted by deleting all zero tows from the base models. Apart from shots with gear failures or shots made during exploratory fishing, zero catch shots are highly unusual in scampi fisheries because the best fishing locations are relatively consistent and easy to re-locate.

Tables of fleet characteristics, catch, and average (unstandardised) catch rates may differ slightly from those pres ʌted ɪn previous documents. This is because of the more rigorous error checking used this year, one result of which was the "transfer" of catch and effort information from one year to another or from one QMA to another.

3.1.2.2 QMA 1 (Bay of Plenty)

Cryer *et al.* (1997) described a standardised index of CPUE for scampi in QMA 1. This model has been updated using data up to the end of the 1996–97 fishing year (Table 2). Data from two vessels with very small numbers of tows were dropped from the database (nine tows altogether). The model was standardised to the 1988–89 fishing year. Similar variables were found to be significant in the model in the two assessments, although the order has changed slightly, with the year effect now being the most important (Table 3).

Table 2: **Data available for CPUE model for QMA 1. "N tows" is the number of tows included in the model, "N vessels" is the number of vessels fishing in a given year, and "% zeros" is the percentage of all tows with a reported zero catch of scampi. The index year was chosen as 1988–89**

Year	N tows	N vessels	Catch (t)	Mean kg h^{-1}	% zeros
1988–89	443	2	39	32.9	7.2
1989–90	872	5	104	31.8	2.8
1990–91	1 545	9	163	22.7	2.3
1991–92	1 086	8	129	21.7	1.4
1992–93	744	7	115	28.3	7.4
1993–94	570	5	111	36.3	3.5
1994–95	427	6	114	49.0	1.4
1995–96	371	6	117	60.4	3.0
1996–97	382	6	117	59.0	7.3

Table 3: Choice of significant variables for 1995, 1997, and 1998 QMA 1 scampi assessments (in the order chosen) and the percent of variation in log(cpue) (R^2) explained following the inclusion of each variable in 1998

1995 assessment	1997 assessment	1998 assessment	R^2(%)
area	year	year	7.2
month	time	time	13.6
time	area	depth	18.9
year	month	area	21.6
depth	depth	month	24.2
vessel			

Table 4: Standardised (from a multiple regression model) and unstandardised indices of relative abundance for scampi (with standard errors, S.E., for the standardised indices) in QMA 1 1988–89 to 1996–97. The standardised model explains 28.1% of the variation in log(cpue)

| Year	Unstandardised index	Standardised index	S.E.
1988–89	1.00	1.00	0.00
1989–90	0.97	0.95	0.06
1990–91	0.69	0.87	0.05
1991–92	0.66	0.99	0.06
1992–93	0.86	1.21	0.08
1993–94	1.10	1.58	0.11
1994–95	1.49	2.07	0.15
1995–96	1.84	2.32	0.17
1996–97	1.79	1.99	0.15

The standardised index for QMA 1 shows a steady increase between the 1990–91 and 1995–96 fishing years (Table 4), followed by a slight decline for the 1996–97 fishing year. This index has, for 3 years, been about double its level at the start of the fishery in 1988–89. The pattern in the standardised index is similar to that in the unstandardised index, although the standardised index peaks at 2.32 compared with 1.84 for the unstandardised index.

Three sensitivity analyses were run. First (sensitivity 1.1), all tows with a zero reported catch of scampi were excluded. This resulted in a large increase in R^2 (from 24.2% to 36.4%) and a change to the shape of the year effect, especially in the last year (Figure 2). For the 1996–97 year, this sensitivity gives an index higher than for 1995–96, whereas the base model index for 1996–97 is lower than that for 1995–96. Further, this sensitivity gives an overall pattern in the index much more similar to previous standardised indices than does the base case (in other words, there is something about the data for 1996–97 which seems to be distorting the index). Two further sensitivity analyses were suggested by an inspection of the data for 1996–97. An unusually large number of shallow shots were made in this year, and so all tows in the shallowest of the eight categorical bins were excluded (sensitivity 1.2), leaving data only from 350 m and deeper. This resulted in a negligible increase in R^2 (from 24.2% to 24.5%), but a change in the shape of the year index similar to the first sensitivity (with the index for 1996–

97 being higher than that for 1995–96, Figure 2). Similarly (sensitivity 1.3), omitting all tows for the vessel making most of the shallow shots in 1996–97 resulted in a similar R^2 (24.2% to 21.4%) and a 1996–97 index higher than that for 1995–96.

The most influential second order interaction term in the model was between the year and depth effects, implying that the pattern of fishing success with depth has varied among years. The increase in R^2 over the base model after the inclusion of this term was about 5.4%. Inspection of a series of plots of CPUE in each of the eight depth bins (one plot for each year) revealed that 1996–97 was an unusual year, and most of the interaction term was generated by this year (by poor catch rates in the shallowest depths). This observation prompted the two sensitivity analyses excluding all shallow shots (1.2) and the vessel responsible for most of the shallow shots (1.3, see above). The next most influential second order interaction term in the model was between year and vessel effects and was also caused mostly by one vessel in the 1996–97 year. The increase in R^2 over the base model after the inclusion of this term was only about 3%.

The presence of these interaction terms (caused largely by relatively unsuccessful shallow fishing, and mainly by a single vessel in 1996–97) suggests that sensitivity analyses excluding shallow shots, or the unusual vessel, may be preferred to the base model.
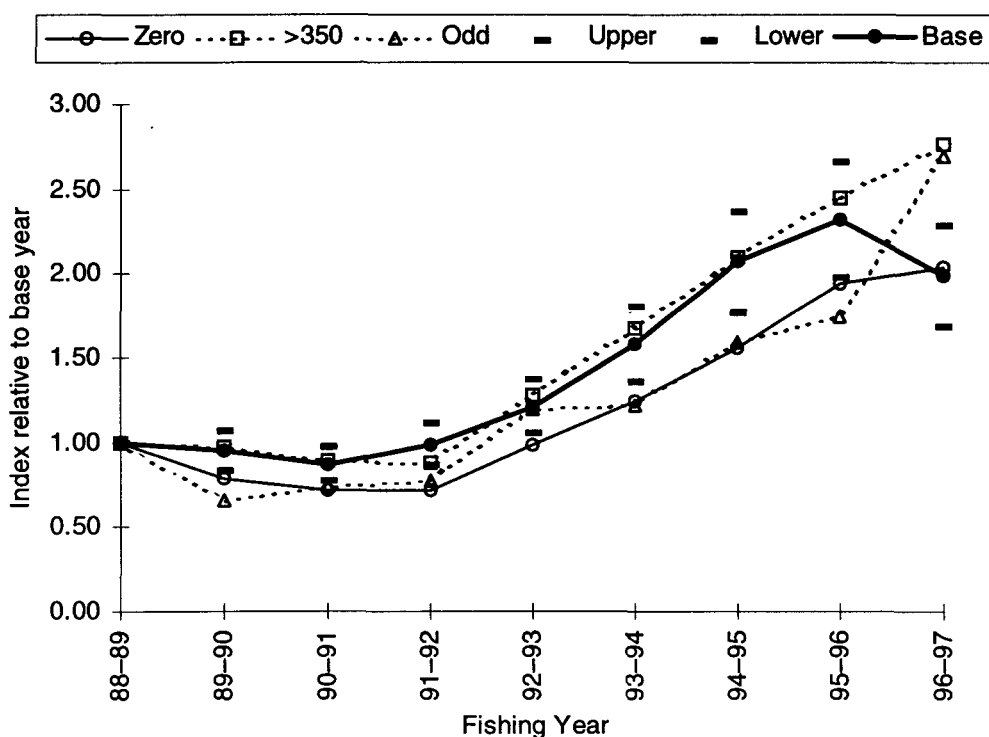
Figure 2: **Indices of relative abundance from a multiple regression CPUE model for QMA 1. The base model is represented by the bold line and solid circles (with upper and lower 95% confidence limits), a sensitivity test excluding all shots for which no catch of scampi was reported is represented by a solid line and open circles, a sensitivity test excluding all shots shallower than 350 m is represented by a dashed line and closed squares, and a sensitivity test excluding all shots from a vessel showing trends different from the rest of the fleet is represented by a dashed line and open triangles.**

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3.1.2.3 QMA 2 (Hawke Bay, Wairarapa coast)

The available data are summarised in Table 5. Data from five vessels with very few tows, or tows only in a single year were dropped from the database (89 tows altogether). The model was standardised to the 1989–90 fishing year as there was relatively little fishing in the 1988–89 year. The month effect in the model (Table 6) suggests that the best catch rates are experienced in summer and are about double the worst catch rates in the winter. Effort tends to occur evenly throughout the year. The time of day effect suggests that the best catch rates are experienced early in the morning and are about 1.5 times that of the worst catch rates in the evening.

Table 5: Data available for CPUE model for QMA 2. "N tows" is the number of tows included in the model, "N vessels" is the number of vessels fishing in a given year, and "% zeros" is the percentage of all tows with a reported zero catch of scampi. The index year was chosen as 1988–89

Year	N tows	N vessels	Catch (t)	Mean kg h^{-1}	% zeros
1988–89	187	3	16.7	34	5.4
1989–90	1 246	6	138.4	29.6	3.8
1990–91	2 267	8	259.9	25.4	2.7
1991–92	1 594	10	212.0	26.0	0.9
1992–93	1 343	9	208.5	30.6	1.6
1993–94	1 416	8	229.9	29.7	1.6
1994–95	912	6	231.1	47.9	1.8
1995–96	924	8	229.6	41.9	3.5
1996–97	1 144	9	212.4	32.5	9.9

Table 6: **Choice of significant variables for the 1997 and 1998 QMA 2 scampi assessments (in the order chosen) and the percent of variation in log(cpue) (R^2) explained following the inclusion of each varaible in 1998**

1997 Variable	1998 Variable	R^2 (%)
Year	Year	4.32
Time of day	Time of day	7.44
Month	Month	10.22

After an initial decline, the standardised index for QMA 2 showed a steady increase between 1990–91 and 1994–95, followed by a decline over the past 2 years to a little below its starting level by 1996–97 (Table 7). The pattern in the standardised index is similar to that in the unstandardised index.

Two sensitivity analyses were run. First (sensitivity 2.1), all tows with a zero reported catch of scampi were excluded. This resulted in a large increase in R^2 (from 10.2% to 22.0%) and a change to the shape of the year effect (Figure 3). For the 1996–97 year, this sensitivity gives an index higher than that in the base year, whereas the base model index for 1996–97 is lower than for the base year. Second (sensitivity 2.2), all tows by the two vessels having the highest proportion of questionable tows (zero catches, positions outside the normal fishing areas, very

high calculated tow speeds etc.) were excluded. This resulted in a modest increase in R^2 (from 10.2% to 12.8%) and a change in the year index similar to the first sensitivity (*see* Figure 3).

Table 7: Standardised (from a multiple regression model) and unstandardised indices (total weight divided by total hours) of relative abundance for scampi (with standard errors, S.E., for the standardised indices) in QMA 2 19898–90 to 1996–97. The model explains 10.2% of the variation in log(cpue)

Year	Unstandardised index	Standardised index	S.E.
1989–90	1.00	1.00	0.00
199C -91	0.86	0.86	0.03
1991–92	0.88	0.94	0.04
1992–93	1.03	1.06	0.04
1993–94	1.00	1.10	0.04
1994–95	1.62	1.85	0.08
1995–96	1.42	1.47	0.06
1996–97	1.10	0.84	0.03
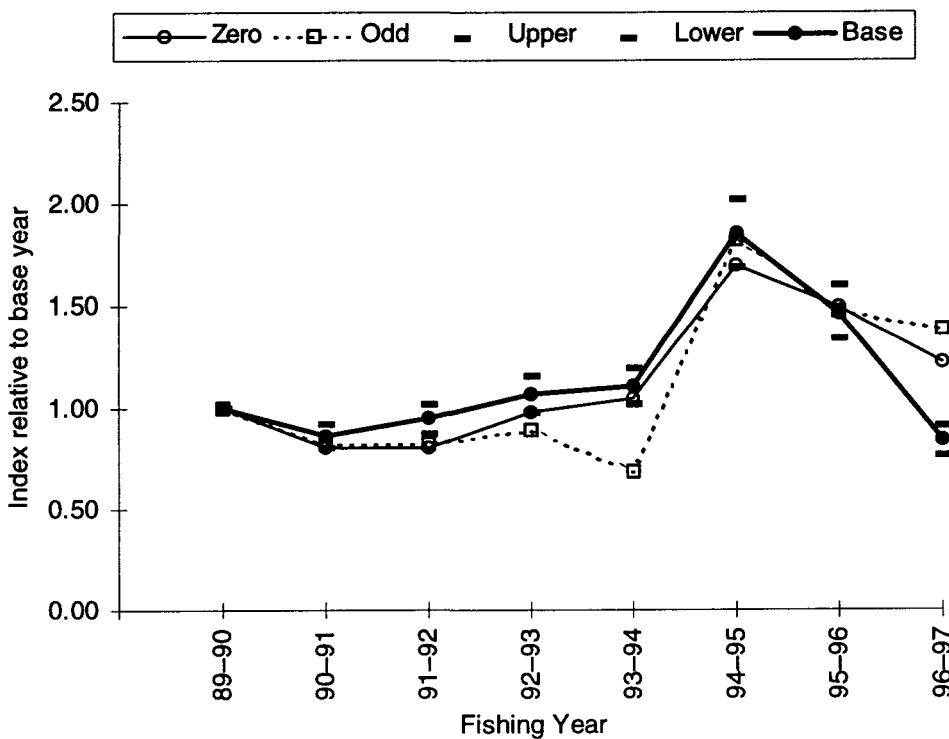
Figure 3: Indices of relative abundance from a multiple regression CPUE model for QMA 2. The base model is represented by the bold line and solid circles (with upper and lower 95% confidence limits), a sensitivity test excluding all shots for which no catch of scampi was reported is represented by a solid line and open circles, and a sensitivity test excluding all shots from two vessels with apparently poor reporting precision is represented by a dashed line and closed squares.

The most influential second order interaction term in the model was between the year and month effects, implying that the seasonal pattern of fishing success has varied among years. The increase in R^2 over the base model after the inclusion of this term was about 6.5%. Inspection of a series of plots of CPUE in each of the eight seasonal bins (one plot for each year) revealed that 1996–97 was an unusual year, and most of the interaction term was generated by this year (by poor catch rates towards the end of the fishing year). This is unfortunate as the most appropriate response to an interaction caused by just one year would be to exclude data from that year. This would not be very useful in assessing the current status of the stock. However, this interaction term is less influential (improvement in R^2 of 4% as opposed to 6.5%) when vessels with the poorest reporting are excluded (sensitivity 2.2), suggesting that this sensitivity may be preferred to the base model.

3.1.2.4 QMA 3 (Mernoo Bank)

The scampi fishery in QMA 3 before 1992–93 was very small and scattered along the east coast of the South Island. In 1992–93, a "new" and much larger fishery started on the Mernoo Bank and, because almost all subsequent fising for scampi in this QMA has been in this area, the standardised analysis has been restricted to the years 1992–93 to 1996–97 (Table 8).

Data from five vessels with very few tows, or tows only in a single year, and from 1988–89 to 1991–92 were dropped from the database (338 tows altogether). The model was standardised to the 1992–93 fishing year as there was relatively little fishing before then.

Vessel, year, month, time of day, and longitude were identified as potentially useful in explaining variability in log(cpue). Of these, vessel, month, and a year effect were included in the final model (Table 9). Because fishing in this area is highly seasonal (driven by the competitive catch limit of 60 t), there is almost no fishing other than in October to December. Records for months other than this period were therefore included in a "catch-all" category giving a total of 4 month bins compared with 12 for most other areas. The year effect for this fishery was very strong, showing an almost three-fold increase over 4 years (Table 10).

Table 8: Data available for CPUE model for QMA 3. "N tows" is the number of tows included in the model, "N vessels" is the number of vessels fishing in a given year, and "% zeros" is the percentage of all tows with a reported zero catch of scampi. The 1992–93 year was chosen as the index year because the pattern if fishing changed dramatically at this time

Year	N tows	N vessels	Catch (t)	Mean kg h^{-1}	% zeros
1988–89	5	1	0	0	100
1989–90	7	1	<0.1	2.1	14.3
1990–91	13	4	0.2	6.2	30.8
1991–92	26	7	0.4	5.6	46.2
1992–93	763	8	82.8	29.2	2.6
1993–94	677	8	59.6	20.5	0.7
1994–95	537	9	65.7	24.8	1.1
1995–96	405	9	75.7	36.6	2
1996–97	248	9	72.3	51.5	2.8

Six vessels were in the fishery throughout the period analysed (1993–96) and they account for most of the effort. Most of the remaining vessels were present for more than 1 year. The strongest feature of the data is the "gold rush" effect with catch being taken competitively in the weeks after the start of each fishing year on 1 October. Since 1992–93, the fishery has been progressively compressed in time. In the last 2 years the fishery has lasted less than 2 months. That the fishing within QMAs 3 and 4 spans the boundary at 176° E suggests that this analysis (nominally for QMA 3) does not relate to a discrete stock. It is treated separately here because the competitive catch limit enforces a pattern of fishing effort which is very different from that observed in the neighbouring QMA 4.

Table 9: **Choice of significant variables for the 1997 and 1998 QMA 3 scampi assessments (in the order chosen) and the percent of variation in log(cpue) (R^2) explained following the inclusion of each variable in 1998**

1997 Variable	1998 Variable	R^2(%)
Vessel	Year	13.35
Year	Vessel	18.50
Month	Month	21.18

Table 10: **Standardised (from a multiple regression model) and unstandardised indices of relative abundance for scampi (with standard errors, S.E., for the standardised indices) in QMA 3 1992–93 to 1996–97. The model explains 16.9% of the variation in log(cpue)**

| Year	Unstandardised index	Standardised index	S.E.
1992–93	1.00	1.00	0.00
1993–94	0.70	1.06	0.07
1994–95	0.82	1.42	0.11
1995–96	1.25	2.18	0.18
1996–97	1.76	2.96	0.26

The selection of a vessel effect contrasts with the models for most other QMAs where vessel was not often important.

Because there is so little data outside the October to January period it is not clear if there is a seasonal effect similar to that found in other QMAs. However, the trend of increasing CPUE within the October to January period is consistent with the pattern in other QMAs where the highest catch rates are experienced in summer. The "time of day" effect is not selected as an important explanatory variable in QMA 3, and is suggested in only 1 of the 4 years of data.

The reasons for this difference from other areas are not clear, but could be a result of the competitive fishing process.

The standardised and unstandardised indices for QMA 3 have both increased markedly since the index year (the former more than the latter). Standardised catch rates are now almost three times greater than in 1992–93 when substantive fishing started on the Mernoo Bank.

Two sensitivity analyses were run. First (sensitivity 3.1), all tows with a zero reported catch of scampi were excluded. This resulted in a large increase in R^2 (from 21.2% to 40.1%) but very little change to the shape of the year effect (Figure 4). Second (sensitivity 3.2), all tows by the vessel apparently causing interactive effects were excluded. This resulted in little change to R^2 (21.2% to 18.8%) and almost no change in the year index. The large increase in R^2 following the deletion of shots with no reported catch of scampi (sensitivity 3.1) strongly suggests that this approach may be preferred to the base model.
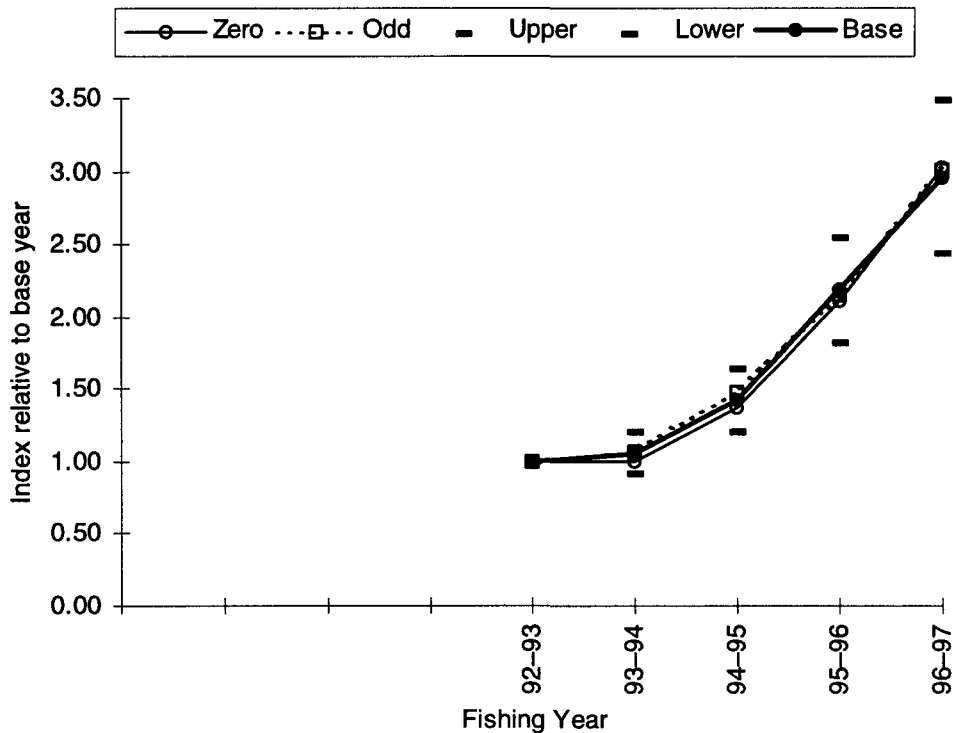
Figure 4: Indices of relative abundance from a multiple regression CPUE model for QMA 3. The base model is represented by the bold line and solid circles (with upper and lower 95% confidence limits), a sensitivity test excluding all shots for which no catch of scampi was reported is represented by a solid line and open circles, and a sensitivity test excluding all shots from a vessel showing trends different from the rest of the fleet is represented by a dashed line and closed squares.

The most influential second order interaction term in the model was between the year and vessel effects, implying that the relative fishing success of at least some vessels has varied among years. The increase in R^2 over the base model after the inclusion of this term was about 7.4%. Inspection of a series of plots of CPUE for each of the vessels revealed that one

vessel had a particularly poor year when it first entered the fishery in 1994–95, and most of the interaction term seemed to be generated by this vessel (based on very few trawl shots). Exclusion of this vessel did not affect the standardised index, suggesting that the interaction term is not very important, even though it potentially explains 7% of the variation in log(cpue).

3.1.2.5 QMA 4W (western Chatham Rise)

Data from four vessels with very few tows, or tows only in a single year, were dropped from the database (179 tows altogether). The model was standardised to the 1991–92 fishing year as this was the first year of fishing (Table 11).

Table 11: **Data available for CPUE model for QMA 4W. "N tows" is the number of tows included in the model, "N vessels" is the n.. ·ber of vessels fishing in a given year, and "% zeros" is the percentage of all tows with a reported zero catch of scampi.. The 1991–92 year was chosen as the index year because very little fishing was conducted in this area before then**

Year	N tows	N vessels	Catch (t)	Mean kg h^{-1}	% zeros
1991–92	1376	13	155.7	25.3	1.2
1992–93	1350	11	213.3	30.1	1.6
1993–94	1123	10	253.2	42.0	1.6
1994–95	602	8	225.6	69.4	7.6
1995–96	501	8	228.1	94.9	6.6
1996–97	547	9	232.1	101.3	5.3

Table 12: **Choice of significant variables for the 1997 and 1998 QMA 4W scampi assessments (in the order chosen) and the percent of variation in log(cpue) (R^2) explained following the inclusion of each variable in 1998**

| 1997 Variable	1998 Variable	R^2(%)
Year	Year	12.98
Time of day	Vessel	20.80
Vessel	Time of day	25.37
Month	Month	27.89

The model accounts for almost 30% of the variation in log(cpue), including a strong year effect (Table 12). The standardised and unstandardised indices for QMA 4W have both increased markedly since the index year. Standardised catch rates are now three times greater than in 1991–92 when substantive fishing started on the western Chatham Rise (Table 13).

Table 13: **Standardised (from a multiple regression model) and unstandardised indices of relative abundance for scampi (with standard errors, S.E., for the standardised indices) in QMA 4W 1991–92 to 1996–97. The model explains 27.9% of the variation in log(cpue)**

Year	Unstandardised index	Standardised index	S.E.
1991–92	1.00	1.00	0.00
1992–93	1.19	1.03	0.05
1993–94	1.66	1.67	0.08
1994–95	2.74	1.66	0.10
1995–96	3.75	2.33	0.16
1996–97	4.00	2.91	0.20

There is a daily cycle of catch rates with the best (late morning) being about double the worst (late evening). Effort is spread throughout the day with slightly more fishing during daylight hours. There appears to be a seasonal cycle of catch rates with the best catch rates (spring) being about double the worst (autumn). This is a slightly different seasonal pattern to that in most other QMAs.
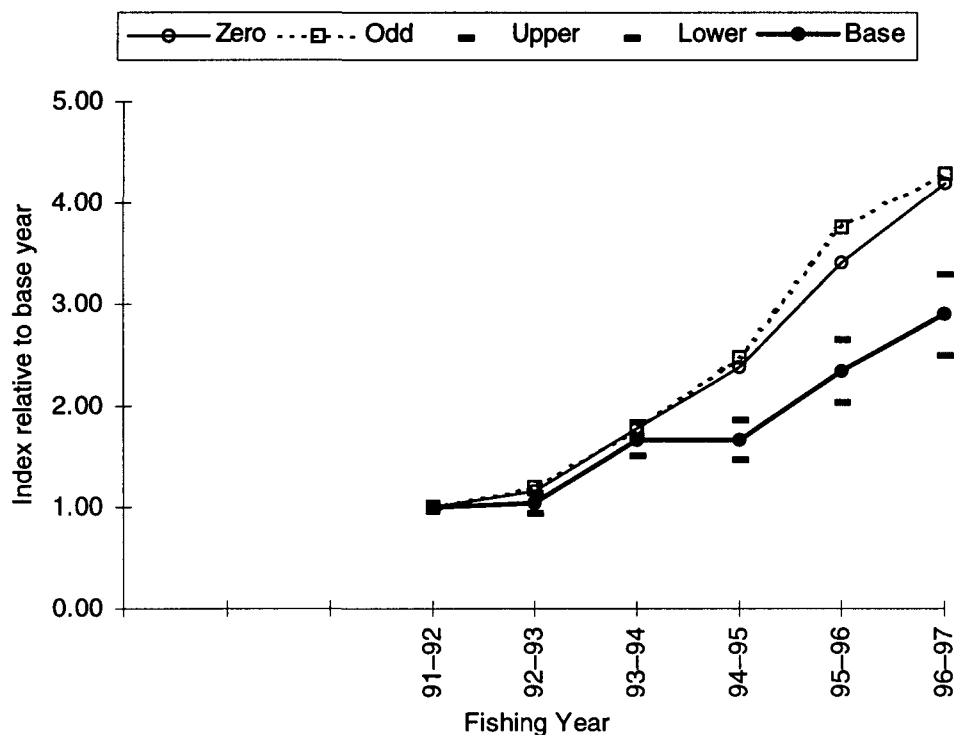
Figure 5: **Indices of relative abundance from a multiple regression CPUE model for QMA 4W. The base model is represented by the bold line and solid circles (with upper and lower 95% confidence limits), a sensitivity test excluding all shots for which no catch of scampi was reported is represented by a solid line and open circles, and a sensitivity test excluding all shots from a vessel showing trends different from the rest of the fleet is represented by a dashed line and closed squares.**

Two sensitivity analyses were run. First (sensitivity 4.1), all tows with a zero reported catch of scampi were excluded. This resulted in a very large increase in R^2 (from 27.9% to 60.6%) and a marked increase in the steepness of the year effect, with the index for 1996–97 being 4.20 in the sensitivity test as opposed to 2.91 in the base model (Figure 5). Second (sensitivity 4.2), all tows by the two vessels having the highest proportion of questionable tows (zero catches, positions outside the normal fishing areas, very high calculated tow speeds, etc.) were excluded. This resulted in a moderate change to R^2 (27.9% to 41.4%) and a similar steepening of the year index to that cause by the dropping of shots with zero catches (sensitivity 4.1). The large increase in R^2 following the deletion of shots with no reported catch of scampi (sensitivity 4.1) strongly suggests that this approach may be preferred to the base model.

As implied above, the most influential second order interaction term in the model was between the year and vessel effects, implying that the relative fishing success of at least some vessels has varied among years. The increase in R^2 over the base model after the inclusion of this term was about 17%. Inspection of a series of plots of CPUE for each of the vessels revealed that two vessels had patterns of the year effect which were markedly different from the rest of the vessels in the fleet, and most of the interaction term seemed to be generated by these two vessels. Exclusion of these vessels (sensitivity 4.2) almost entirely removed the interaction effects affecting the standardised index, suggesting that the interaction term is probably spurious (although, *a priori*, important as it explains 17% of the variation in log(cpue)). The spurious interaction term may be caused by poor reporting, especially of the estimated catch of scampi in each shot. This further supports the utility of a "non zero" model in preference to the base model.

3.1.2.6 QMA 4E (eastern Chatham Rise)

Fishing on the eastern Chatham Rise and close to the Chatham Islands was conducted in three fishing years, 1990–91 to 1992–93. Since then, fishing has been concentrated close to the Mernoo Bank where catch rates have continued to increase. Available data are summarised in Table 14. No changes to the standardised analysis presented in the 1997 assessment have been made because there was no fishing in 1996–97. There are some minor changes to the data in Table 14 occasioned by the more intensive error checking in 1998.

Table 14: Data available for CPUE model for QMA 4E. "N tows" is the number of tows included in the model, "N vessels" is the number of vessels fishing in a given year, and "% zeros" is the percentage of all tows with a reported zero catch of scampi.. The 1990–91 year was chosen as the index year because it was the first year of fishing in this area

Year	N tows	N vessels	Catch (t)	Mean kg h^{-1}	% zeros
1990–91	224	2	32.5	36	3.1
1991–92	687	11	72.5	20.6	3.4
1992–93	77	1	11.1	30.1	0

The model was severely unbalanced as most effort occurred in a single year (1991–92) and very few vessels fished in the first or last year. This means any year effect will be poorly determined. The model is unusual in accounting for almost 47% of the variation in log(cpue) (Table 15). Most of this (about 40%) is accounted for by vessel, time of day, and month variables. Position has modest explanatory power (longitude and latitude variables adding a further 5% in R^2).

Table 15: **Choice of significant variables for the 1997 QMA 4E scampi assessments (in the order chosen) and the percent of variation in log(cpue) (R^2) explained following the inclusion of each variable. Note that the year effect was not automatically selected 'its inclusion led to an improvement in R^2 of <2%) but was included as it is the putative index of stock size and is therefore the variable of interest in this analysis. This analysis has not been updated for the 1998 assessment as there was no fishing in the 1996–97 year**

Variable	R^2(%)
Vessel	24.56
Time of day	35.10
Month	40.84
Longitude	44.32
Latitude	45.96
Year (forced)	46.61

Table 16: **Standardised (from a multiple regression model) and unstandardised indices of relative abundance for scampi (with standard errors, S.E., for the standardised indices) in QMA 4E 1990–91 to 1992–93. The model explains 46.6% of the variation in log(cpue). Note that this year effect was not influential in the model and will be poorly determined. This analysis has not been updated for the 1998 assessment as there was no fishing in the 1996–97 year**

Year	Unstandardised index	Standardised index	S.E.
1990–91	1.00	1.00	0.00
1991–92	0.56	0.95	0.22
1992–93	0.84	2.17	0.68

There is a daily cycle of catch rates with the best (late morning) being over double the worst (late evening). Effort is spread throughout the day (somewhat more heavily during daylight). There is a seasonal cycle of catch rates with the best (spring) being about double the worst (autumn), although this may not be well defined because of the lack of any fishing in October and November in any year. The pattern of catch rates is, however, similar to that on the western side of the Chatham Rise.

The year effect is poorly determined by this analysis, and there is no significant change in the index over the 3 years for which data are available (Table 16).

3.1.2.7 QMA 6A (Auckland Islands)

The few records for 1990–91 (11 tows) were not included in the analysis, and the records for one vessel fishing in only 1 year (68 tows) were excluded. Available data are summarised in Table 17. A year effect, seasonality, time of day and, perhaps, location and vessel were identified as potentially useful in explaining log(cpue). Year, month, and time of day were included in the final model (Table 18).

The data design is good (for this type of analysis) as there has been a fairly stable fleet with similar effort over time. There is a seasonal cycle of catch rates with the best (summer) being about four times better than the worst (winter). Most effort occurred from January to April, probably to coincide with fishable weather in this location. There was a daily cycle of catch rates with the best (late morning) being about double the worst (late evening). Effort is spread evenly over the day.

Table 17: Data available for CPUE model for QMA 6A. "N tows" is the number of tows included in the model, "N vessels" is the number of vessels fishing in a given year, and "% zeros" is the percentage of all tows with a reported zero catch of scampi.. The 1991–92 year was chosen as the index year because there was very little fishing in this area before that year

Year	N tows	N vessels	Catch (t)	Mean kg h-1	% zeros
1990–91	11	1	0.9	38.1	18.2
1991–92	959	10	320.5	67.4	2.4
1992–93	660	8	193.4	51.6	2.1
1993–94	1 267	10	241.6	34.5	1.7
1994–95	1 347	8	214.6	25.7	12.0
1995–96	1 284	7	219.2	26.4	6.7
1996–97	1 133	8	228.1	30.4	5.4

Table 18: Choice of significant variables for the 1997 and 1998 QMA 6A scampi assessments (in the order chosen) and the percent of variation in log(cpue) (R^2) explained following the inclusion of each variable in 1998

1997 Variable	1998 Variable	$R^2(\%)$
Year	Year	10.19
Month	Month	15.45
Time of day	Vessel	19.86
	Time of day	23.84

Table 19: Standardised (from a multiple regression model) and unstandardised indices of relative abundance for scampi (with standard errors, S.E., for the standardised indices) in QMA 6A 1991–92 to 1996–97. The model explains 21.2% of the variation in log(cpue)

Year	Unstandardised index	Standardised index	S.E.
1991–92	1.00	1.00	0.00
1992–93	0.77	0.71	0.05
1993–94	0.51	0.43	0.02
1994–95	0.38	0.28	0.02
1995–96	0.39	0.32	0.02
1996–97	0.45	0.39	0.02
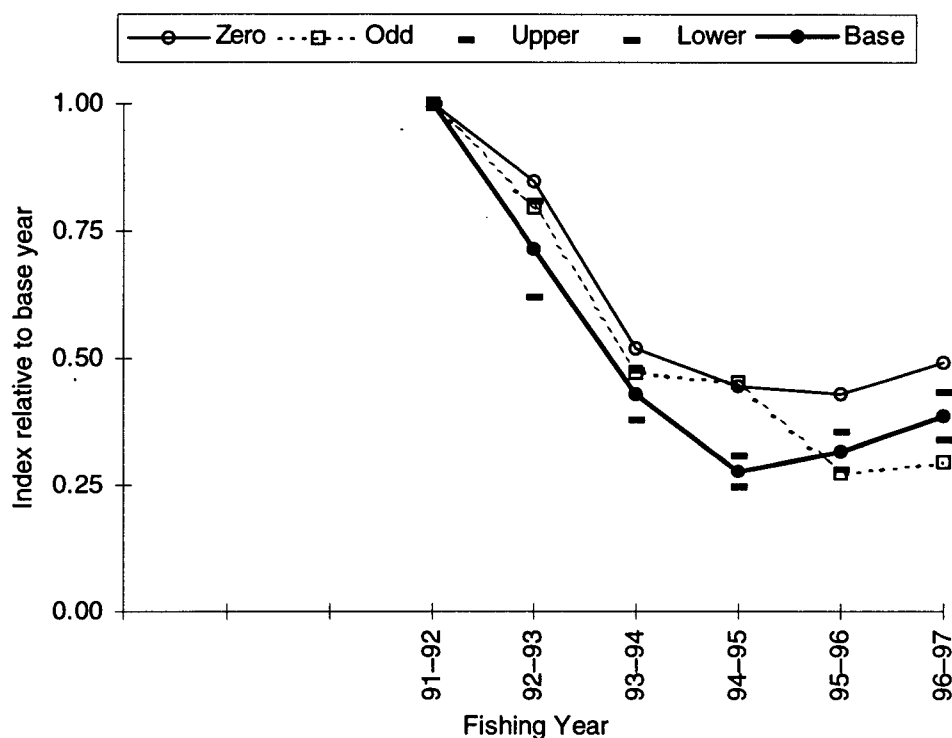
Figure 6: Indices of relative abundance from a multiple regression CPUE model for QMA 6A. The base model is represented by the bold line and solid circles (with upper and lower 95% confidence limits), a sensitivity test excluding all shots for which no catch of scampi was reported is represented by a solid line and open circles, and a sensitivity test excluding all shots from a vessel showing trends different from the rest of the fleet is represented by a dashed line and closed squares.

There are two preferred depth ranges in QMA 6A (around 400 m and 500 m) with a trend towards the 500 m band with time. However, depth is not an important variable in the model. It is noteworthy that standardised catch rates declined to less than one-third of 1991–92 catch rates in 1994–95 and 1995–96 (Table 19).

Two sensitivity analyses were run. First (sensitivity 6.1), all tows with a zero reported catch of scampi were excluded. This resulted in a large increase in R^2 (from 23.8% to 41.5%) and a flattening of the shape of the year effect (standardised catch rates did not fall to such a low level, Figure 6). This might be expected because the proportion of tows where no catch of scampi was reported was very high (almost 12%) in the years when the standardised catch rates were estimated to have been low. Second (sensitivity 6.2), all tows by the vessel apparently causing interactive effects were excluded. This resulted in little change to R^2 (23.8% to 22.4%) and a modest change in the year index (resulting in the apparent "recovery" of catch rates in the base model being much less clear). The large increase in R^2 following the deletion of shots with no reported catch of scampi (sensitivity 6.1) strongly suggests that this approach may be preferred to the base model.

The most influential second order interaction term in the model was between the year and vessel effects, implying that the relative fishing success of at least some vessels has varied among years. The increase in R^2 over the base model after the inclusion of this term was about 16%. Inspection of a series of plots of CPUE for each of the vessels revealed that one vessel had a very different pattern of fishing success by year than the other vessels involved, with a particularly poor year in 1994–95. Most of the interaction term seemed to be generated by this vessel. Exclusion of this vessel removed almost all of the interaction as well as changing the shape of the standardised index (sensitivity 6.2), suggesting that this vessel is unusual in some way, supporting its exclusion.

3.1.3.8 Summary of standardised CPUE analyses

The variables represented in scampi CPUE models most consistently were the temporal ones (Table 20): month (six out of six models), time of day (five out of six), and year (five out of six, also the putative index of stock size). Vessel effects were included in four models, area effects in two, and a depth effect in one. The most important variable was usually the year effect (five out of six), and where this was not the case, the vessel effect was most important and the year effect was not significant (in QMA 4E where the model was not very reliable).

Table 20: **Summary of influential variables for scampi CPUE models by QMA. For QMA 4E, the "area" effect is a composite of longitude and latitude effects, whereas that for QMA 1 is a single categorical variable. Note that there was no significant year effect in QMA 4E and one had to be "forced" in the analysis. Current "status" is the standardised index of CPUE for 1996–97 relative to the index year (usually the start of substantive fishing in each QMA). R^2 and current status values in this table are slightly different from those given in tables 4–19 because these results are for final models with 12 bins for Month and Time of Day variables whereas previous tables use developmental models with 8 bins**

Variable	QMA 1	QMA 2	QMA 3	QMA 4W	QMA 4E	QMA 6A
1	Year	Year	Year	Year	Vessel	Year
2	Time of day	Time of day	Vessel	Vessel	Time of day	Month
3	Depth	Month	Month	Time of day	Month	Vessel
4	Area	–	–	Month	Area	Time of day
5	Month	–	–	–	–	–
Total R²(%)	25.9	9.1	18.2	28.7	46.6	23.9
Current "status"	1.92	0.85	2.77	4.31	–	0.38

The shape and magnitude of temporal variables has not changed much since the 1997 assessment (Cryer *et al.* 1997). The month variable usually showed a maximum in spring (fisheries on the Chatham Rise) or summer (fisheries off the east North Island coast and Auckland Islands). The worst catch rates were in autumn or early winter. The magnitude of the effect was about constant at a factor of 2 between best and worst, other than at the Auckland Islands fishery (which is the most hostile environment for fishing) where there was a factor of about 5 between best and worst.

The time of day effect always showed a maximum in the early morning, tows being started between 04:00 and 08:00 being the best. Similarly, the worst catch rates were experienced in all areas for shots started in late evening (17:00 to 22:00) which tended to run overnight. The magnitude of the effect was about constant at a factor of 2 between best and worst. This is consistent with the results of short research trawls in the Bay of Plenty (Cryer & Stotter 1997) which showed a dramatic increase in scampi catch rates at dawn followed by a steady decline throughout the day.

The consistency of temporal effects among QMAs strongly suggests that the pattern observed in CPUE analyses is real, that there is indeed temporal variation in catch rates by trawl. This variation probably stems from the activity cycle of this species as it emerges and re-enters burrows from which they cannot be taken by trawl.

Analysis of second order (interaction) terms in models of CPUE has been useful. The most common interaction term was between year and vessel effects (Table 21) and inclusion of this interaction improved R^2 in the base models by 7–17%. Frequently, inspection revealed that interaction terms stem from one or a few vessels having trends different from those of other vessels fishing in the same area. This approach was used to identify additional analyses to test the sensitivity of the base model to violations of the assumptions inherent in this type of modelling (one of which is, essentially, that there are no significant interactions among the variables included in the model). Thus, where an interaction term seemed to be caused by one vessel with an unusual pattern in the year effect, the exclusion of this vessel was considered as a sensitivity test. In most cases, large year-vessel interaction effects were found to disappear after the exclusion of data from the apparently unusual vessel.

Table 21: Interaction effects identified within base CPUE models for each QMA, the increase in explanatory power (ΔR^2) for each, and the sensitivity tests suggested. Only interactions between variables influential in the base model are included

QMA	Interaction	ΔR^2(%)	Comments
1	year - depth	5	exclude very shallow shots?
2	year - month	7	reduced interaction when unusual vessels excluded
3	year - vessel	7	exclude unusual vessel? (interaction removed)
4W	year - vessel	17	exclude 2 unusual vessels? (interaction removed)
6A	year - vessel	16	exclude unusual vessel? (interaction removed)

Sensitivity analyses were conducted for all QMAs (Table 22). Exclusion of shots with a zero estimated catch of scampi markedly increased the explanatory power (R^2 increasing from about 20% to about 40%) for most of the models, and increased the 1996–97 level of the standardised index of CPUE in all QMAs. In QMA 1, the exclusion of shots with zero catch altered the direction of the recent trend in the index. These changes are large considering the relatively small proportion of shots involved (usually less than about 10%).

Table 22: **Results of sensitivity tests excluding all shots for which no catch of scampi was recorded on CPUE models for each QMA. In each case, "base" refers to the base model using all data and "no zero" refers to models from which all shots reporting no catch of scampi have been excluded. "Status" is the standardised index of CPUE for 1996–97 relative to the base year, and "Trend" indicates whether this index is larger or smaller than the index for 1995–96**

QMA	R^2 base	no zero	Status base	no zero	Trend base	no zero
1	24.2	36.4	1.99	2.04	Down	Up
2	10.2	22.0	0.84	1.22	Down	Down
3	21.2	40.1	2.96	3.02	Up	Up
4W	27.9	60.6	2.91	4.20	Up	Up
6A	23.8	41.5	0.39	0.49	Up	Up

The exclusion of data from one or a few vessels (due to their apparent poor reporting or to their indication as "odd" by an analysis of interaction terms in the multiple regression) led to substantive changes in the explanatory power of the model, in the trend of the standardised index with time, and in the current status of the stock. The direction of changes to the index was not consistent among QMAs. Sensitivity tests (other than the exclusion of shots with no reported catch of scampi) produced more favourable models than the base model in QMAs 1, 2, and 4W, a very similar model in QMA 3, and a less favourable model in one QMA 6A. When compared with the exclusion of shots with no reported catch of scampi, other sensitivity tests produced more favourable models in QMAs 1 and 2, very similar models in QMAs 3 and 4W, and a less favourable model in QMA 6A.

Based on the analyses presented here and the nature of these fisheries, it is suggested that future modelling of commercial CPUE for "developed" scampi fishery areas should incorporate only those shots where a non-zero estimated catch of scampi is reported. Further, it is suggested that the standard error of the CPUE index for each year (as presented here) is a poor descriptor of the total uncertainty associated with that index, and should be complemented by a jackknife estimate of uncertainty generated by successive omission of each participating vessel. This should capture the uncertainty associated with vessel-year interaction effects which seem thus far to have been the most important non-linear feature of the data.

3.2 Other information

3.2.1 Length frequency distributions of scampi

Length frequency distributions and sex ratios of scampi from measurements taken by scientific observers on board scampi trawlers were presented by Cryer (1997) and are updated here (Figures 7–11). These length frequency distributions do not show any gross changes which would be consistent with large decreases in stock size (for example large reductions in the proportion of large, presumably old, individuals). To the contrary, unscaled length frequency distributions derived from measurements taken by scientific observers in QMAs 1 and 6A (Figures 7 and 11) both show increasing proportions of larger individuals between 1991–92 and 1995–96. This trend continued in 1996–97 for QMA 1, but not for QMA 6A where the modal length declined slightly and noticeable "shoulders" appeared on the left side of the distribution, especially for males.

The extent to which these differences among years are due to changes in fishing gear and its selectivity (mesh sizes are known to have increased since the early years of the fishery for instance) or to the opportunistic and unstandardised nature of observer sampling are not known. Examination of the spatial location and depth of shots in QMA 1 from which observers measured scampi suggest that data collected in 1991 and 1992 were taken mostly from the main fishery area close to the Aldermen Islands, whereas samples in 1995 and 1996 were spread throughout areas that might be considered peripheral, such as north of Great Barrier Island and east of Mayor Island. Even within the Aldermen Islands area, shots sampled in 1992 were significantly deeper than those sampled in 1991. Similarly, while the depth distribution of the fishery in QMA 6A changed consistently between 1992 and 1996, the depth of observed shots did not change very much, although there were some spatial changes which broadly mimicked the changes in the wider fishery (shots in later years have tended to be further offshore).

Both location and depth of trawl shots for scampi can be expected to have significant implications for the size range of scampi available to observers (*see* Section 3.2.2.) and, without a very large number of samples, it is very difficult to generate the standardised length frequency distributions which are routinely generated by trawl survey methods. In addition, it is not clear whether differences in the location and depth of observed and unobserved shots can lead to length frequency distributions generated by observers being biased, although there is clear potential for this to occur.
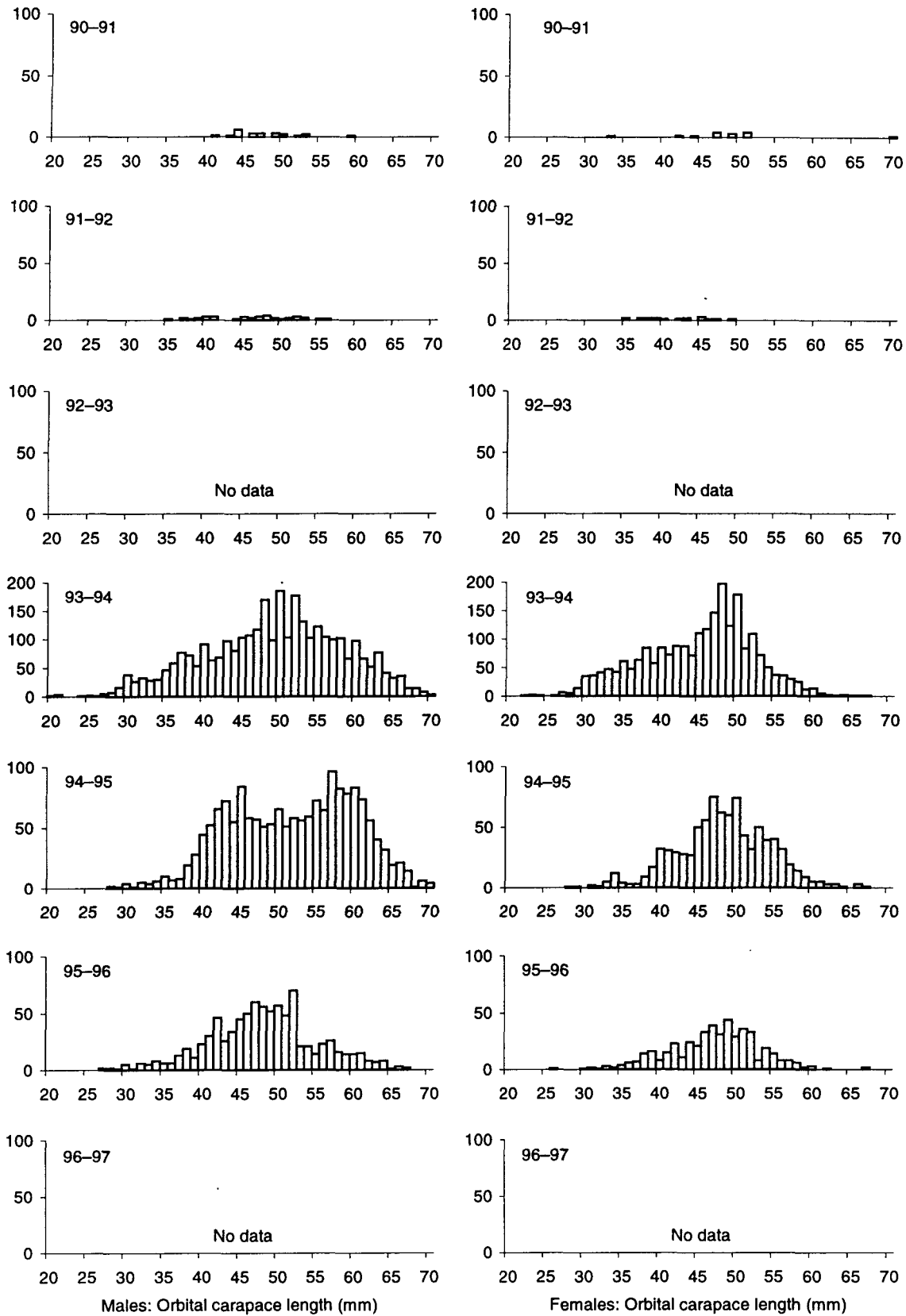
If observer length frequency distributions are accepted as unbiased samples of commercial catches within a given QMA, and if commercial catches are accepted as providing consistent samples of the available population, then the observer length frequency distributions for QMAs 1 and 6A are not easy to explain. An increase in the proportion of large individuals is not usually consistent with a stock responding to heavy exploitation, but could be consistent with a stock in which recruitment has recently been relatively poor.
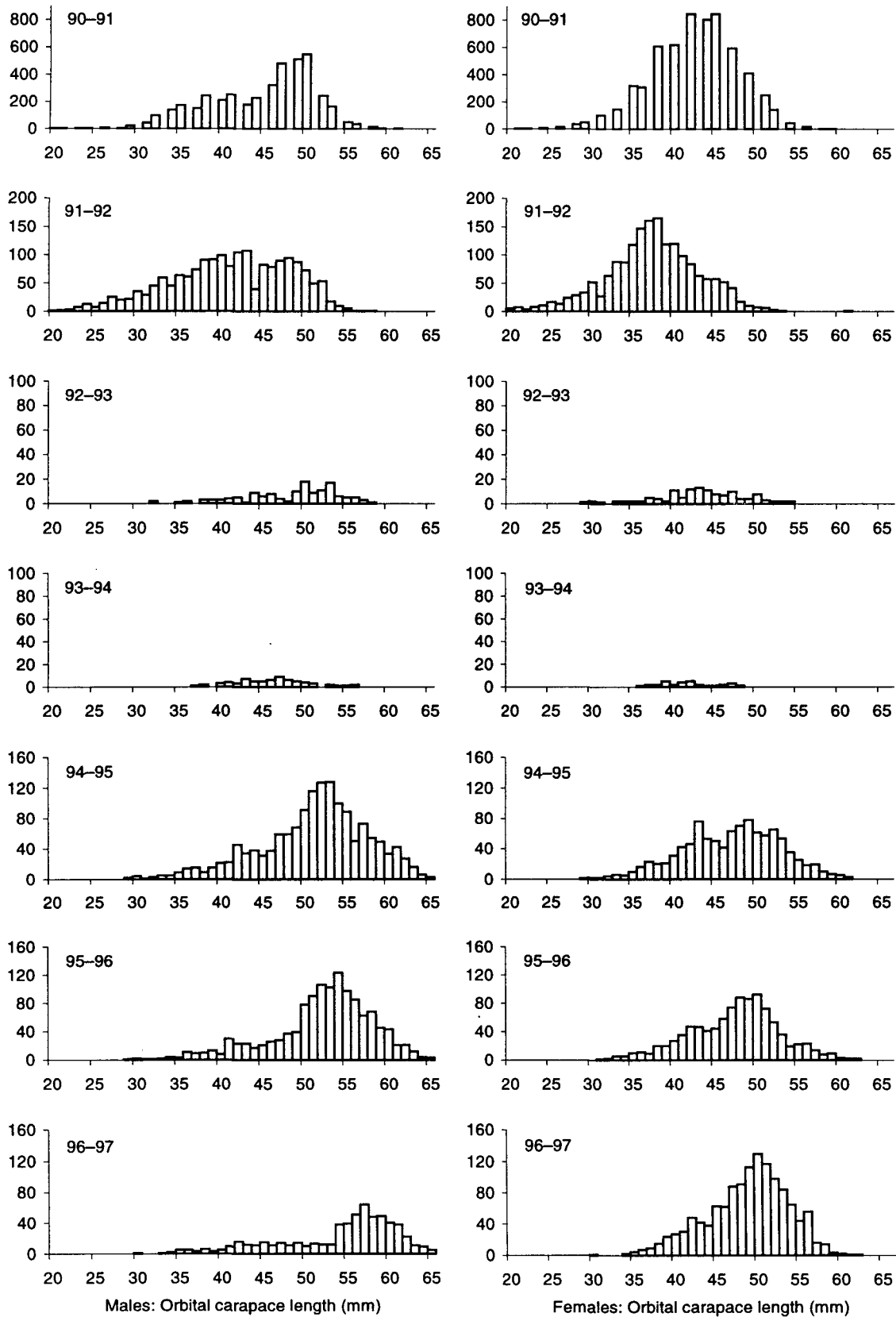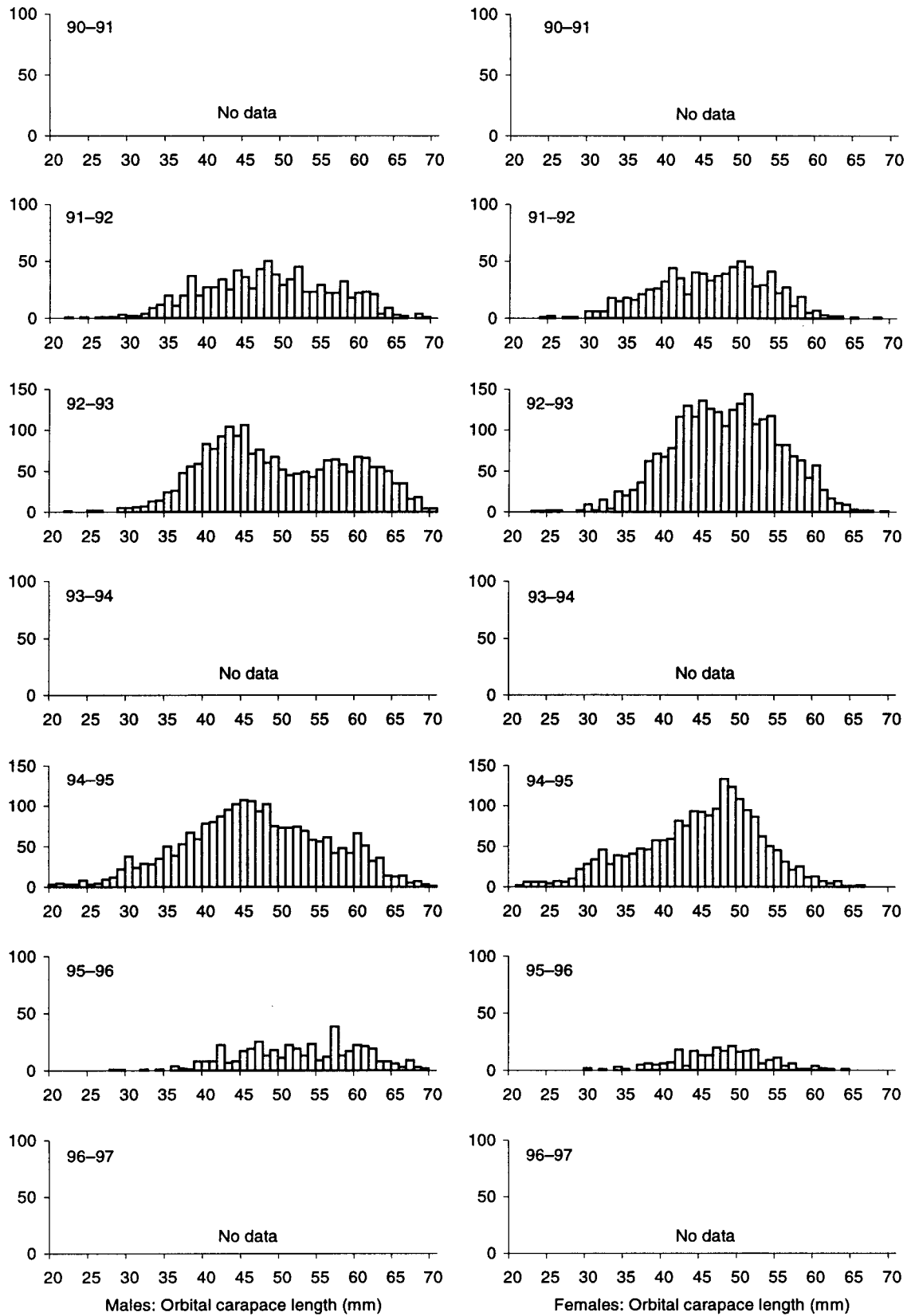
Figure 7: **Unscaled length frequency distributions from scientific observers for male (left) and female (right) scampi in QMA 1.**
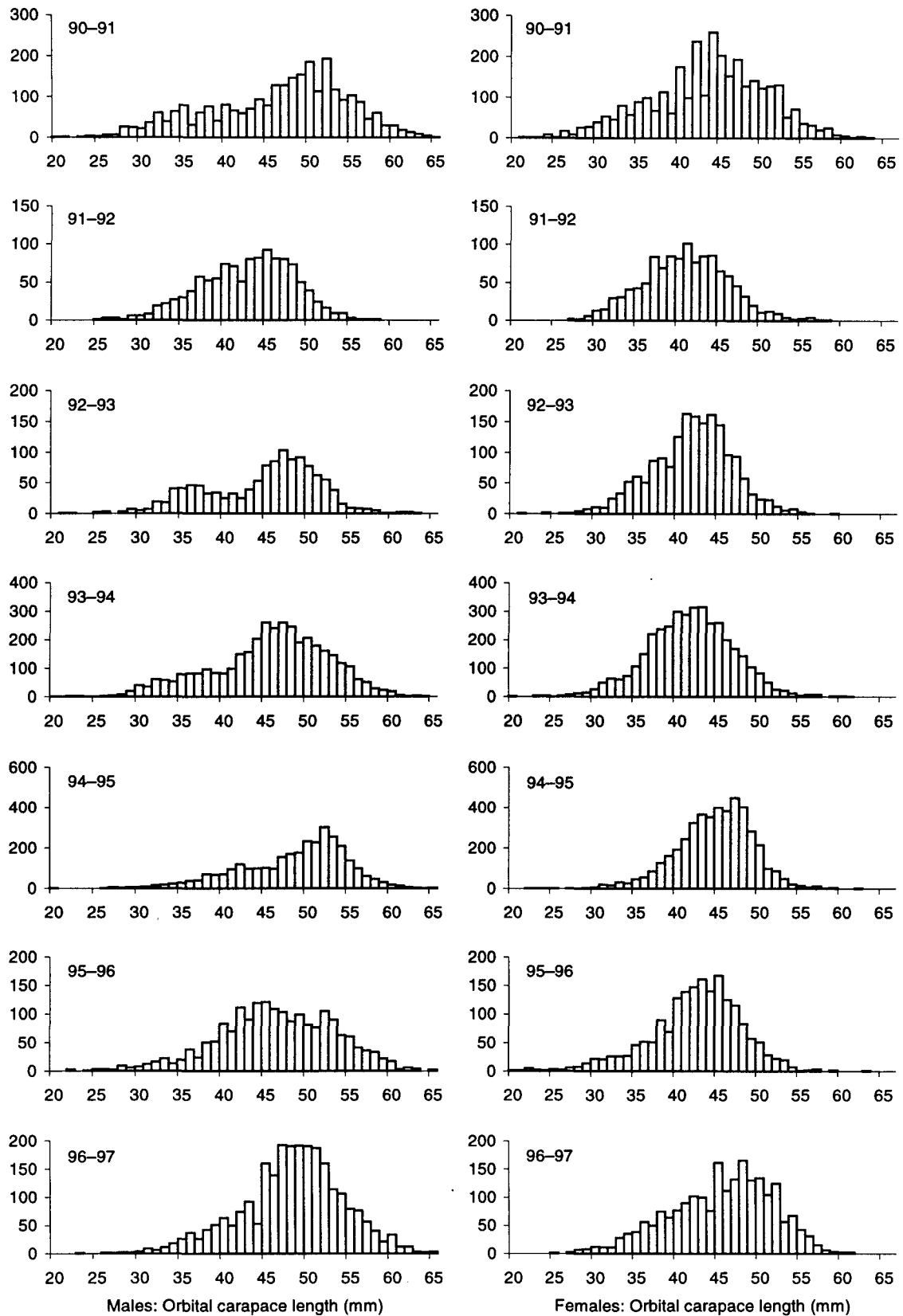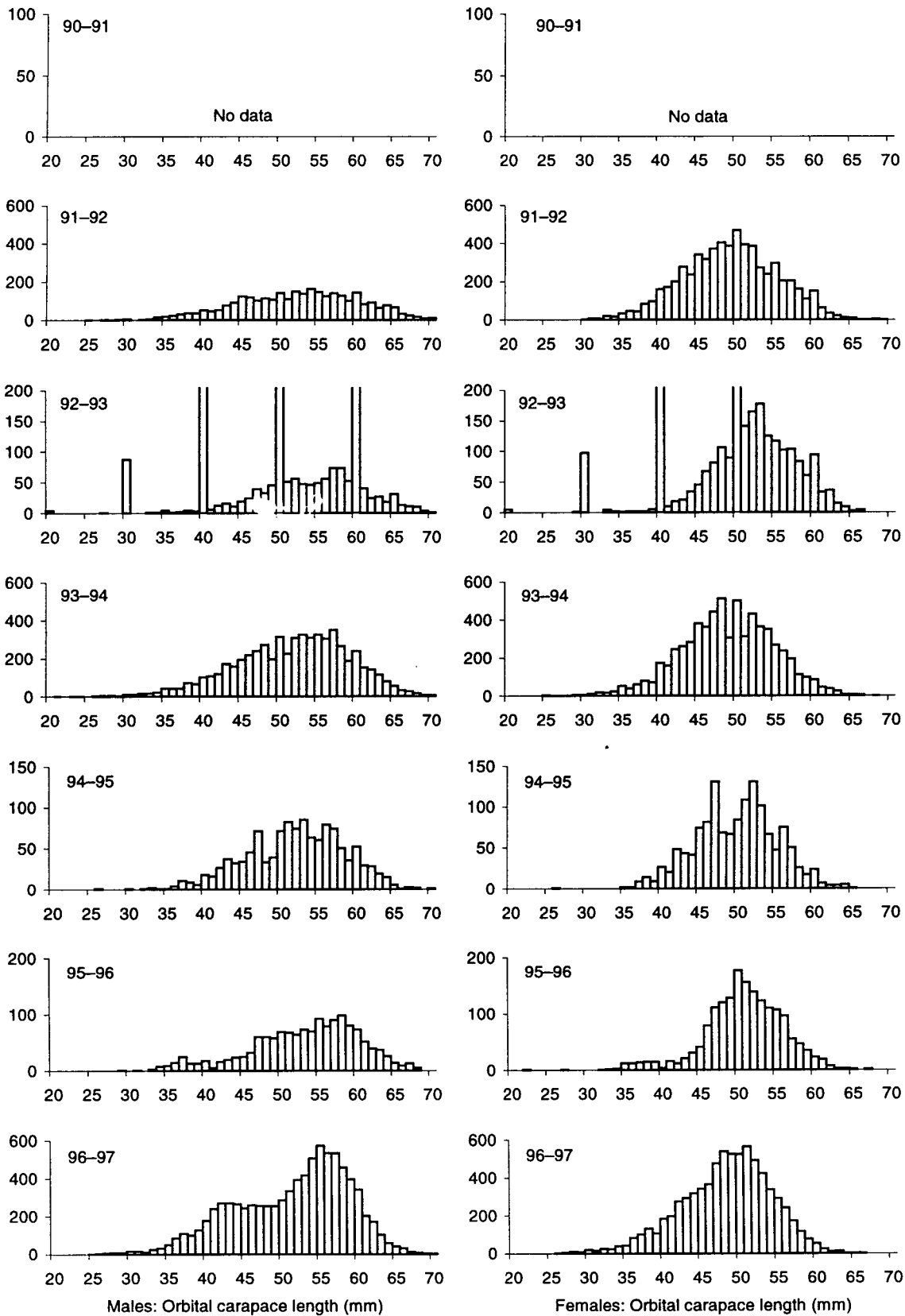
Figure 8: Unscaled length frequency distributions from scientific observers for male (left) and female (right) scampi in QMA 2.

Figure 9: Unscaled length frequency distributions from scientific observers for male (left) and female (right) scampi in QMA 3.

Figure 10: **Unscaled length frequency distributions from scientific observers for male (left) and female (right) scampi in QMA 4W.**

Figure 11: **Unscaled length frequency distributions from scientific observers for male (left) and female (right) scampi in QMA 6A.**

3.2.2 Spatial distribution of scampi

Variation in commercial CPUE is explained to some extent by area, season (month of the year), time of day, vessel, and sometimes depth (*see* CPUE analyses, Section 3.1.2). Models incorporating these "environmental" factors (as well as vessel effects) are able to explain between 9 and 47% of the variation in CPUE. The magnitude of changes in CPUE (i.e., the year effects from linear models) seem to be too large to be explained entirely in terms of changes in stock size, and we hypothesise that temporal variation in catchability (or vertical availability) accounts for the apparent trends in CPUE. This variation possibly stems from the activity cycle of the species as it emerges from and re-enters burrows from which they cannot be taken by trawl.

Changes in commercial CPUE may reflect changes in some or all of the following: animal density, mean size, average catchability, or differing behaviour of the sexes. If the sexes behave differently, then full interpretation of trends in commercial CPUE would require both information on the sex composition of the catch and an understanding of the factors (season, temperature and/or depth) controlling such behaviour.

General approach

Length frequency distributions and environmental data from trawl surveys and other research voyages carried out by *Kaharoa* from 1992 to 1996 were examined to determine the extent to which abundance, sex ratio, and size frequency are predictable. An initial (univariate) screening process was used to identify likely useful predictive variables, and these were then incorporated into linear models describing the apparent distribution (as inferred from research trawl catch rates) of given categories of scampi.

Two data series were found to be useful for the detailed examination of scampi distribution.

a)   Seven relatively distinct areas of commercial fishing off the east coast of the North Island (separated by areas with little or no fishing caused by islands, foul or unsuitable ground) (Table 23, Figure 12) were sampled during trawl surveys in the first quarter, of 1993, 1994, and 1995. These data have been analysed to describe abundance and size structure across a narrow range of temperatures and depths without any confounding seasonal effects. Not all tows could be used, however, as some were missing temperature or length of tow data.

b)   One area near the Aldermen Islands (Area B), has been more intensively sampled for various reasons, using essentially the same trawl gear, and therefore provides a longer time series (albeit with some seasonal confounding). The seasons within year are not replicated, so it is not easy to discern a seasonal effect.

Scientific observer data are also available, and over a greater area, but temperature and shot duration were not generally recorded, which makes their inclusion in this analysis problematic. Such data might be used in a more wide ranging analysis of length frequency and sex ratio to assess the extent to which there may be difference among large geographical areas such as QMAs.

Table 23: Number of research tows used in the study of spatial distribution. Tows without temperature or tow length data not included

Year	Quarter	A	B	C	D	E	F	G
							No. tows	
1993	1st	11	6	8	13	–	19	–
1994	1st	14	8	17	2	5	20	14
1995	1st	14	11	16	8	6	22	18
1995	3rd	–	38	–	–	–	–	–
1996	2nd	–	55	–	–	–	–	–
1996	3rd	–	12	–	–	–	–	–
1996	4th	–	14	–	–	–	–	–
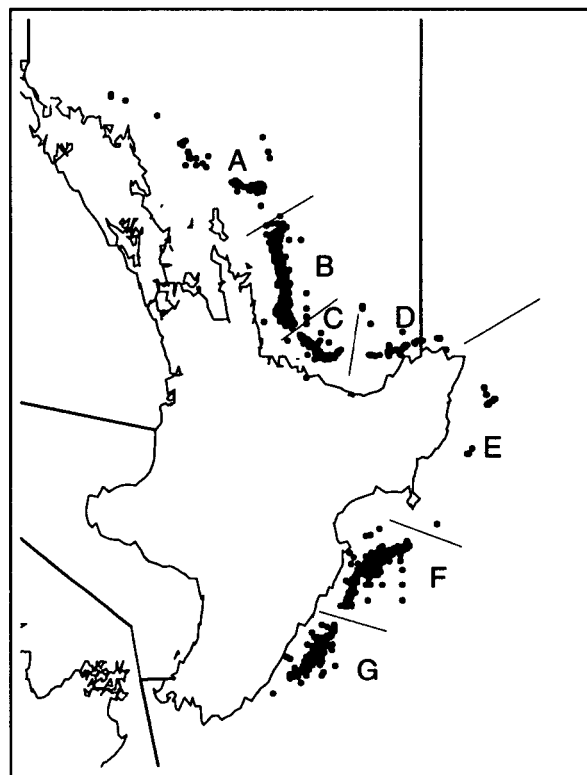
Figure 12: Approximate location of each of the 7 sub-areas (labelled A–G) used for analysis of scampi spatial distribution. Dots indicate the start locations of commercial shots from TCEPR for comparison.

The following "dependent" variables were extracted for each tow.

i) scampi density (number of animals caught per nautical mile trawled)
ii) mean size (as orbital carapace length, OCL, mm)
iii) juveniles density (number per nautical mile trawled)
iv) the percentage of males in the catch

Univariate screening

The first three variables were logarithmically transformed ($\log_e(x + 0.001)$), while the sex ratio was left untransformed. Juveniles were defined as females smaller than 35 mm OCL and males smaller than 30 mm OCL. All data were pooled and plotted in univariate relationships. Gross relationships were investigated by correlation, and possible explanatory variables were identified for inclusion in further analysis.

Overall, it appeared that females were smaller than males. There was no obvious pattern of mean size with latitude, but for both males and females mean size increased with increasing depth and with decreasing temperature. Correlation coefficients of mean size against temperature and against depth were significant for both sexes (Table 24), but the relationships with both were stronger for males than for females. Temperature and depth were also highly correlated, although the effects can be separated from one another by calculating partial correlation coefficients (a test of likelihood of a linear relationship between two variables, excluding the effects of a third).

Table 24: **Strength of apparent (univariate) relationships (as correlation coefficients) among temperature, depth, and the average size of scampi in research trawl catches, and strength of partial correlation coefficients, excluding the effects of the confounding relationship between depth and temperature**

Relationship	Coefficient	n	p
Mean female size x temperature	-0.1656	223	0.0133
Mean male size x temperature	-0.2935	238	0.0001
Mean female size x depth	0.2631	255	0.0001
Mean male size x depth	0.3894	269	0.0001
Temperature x depth	-0.6838	478	0.0001
Female size x temperature, excl. depth	0.0203	223	0.7633
Male size x temperature, excl. depth	-0.0405	238	0.5349
Female size x depth, excl. temperature	0.2083	255	0.0009
Male size x depth, excl. temperature	0.2705	269	0.0001

Female scampi were consistently less abundant than males in research trawl catches in all areas and years. The density of both sexes showed domed relations with temperature, peaking at about 10.5 °C, and with depth, peaking at about 400 m. Simple correlation coefficients for apparent relationships among density, temperature, and depth were, however, all significant for both sexes (Table 25). These correlation coefficients are not very informative as the relationships are known not to be linear. Partial correlation analysis was therefore not attempted.

The proportion of males in research trawl catches was high (often close to 100%) at low scampi density, at shallower depths, and at higher temperatures (Figure 13). A preponderance of females was rare. At higher densities of scampi, the sex ratio was about even. There was no obvious pattern in the proportion males by area.

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Table 25: Strength of apparent (univariate) relationships (as correlation coefficients) among temperature, depth, and the numerical abundance of scampi in research trawl catches

| Relationship	Coefficient	n	p
Female abundance x temperature	-0.3237	239	0.0001
Male abundance x temperature	-0.1549	239	0.0165
Female abundance x depth	0.3715	272	0.0001
Male abundance x depth	0.1654	272	0.0063
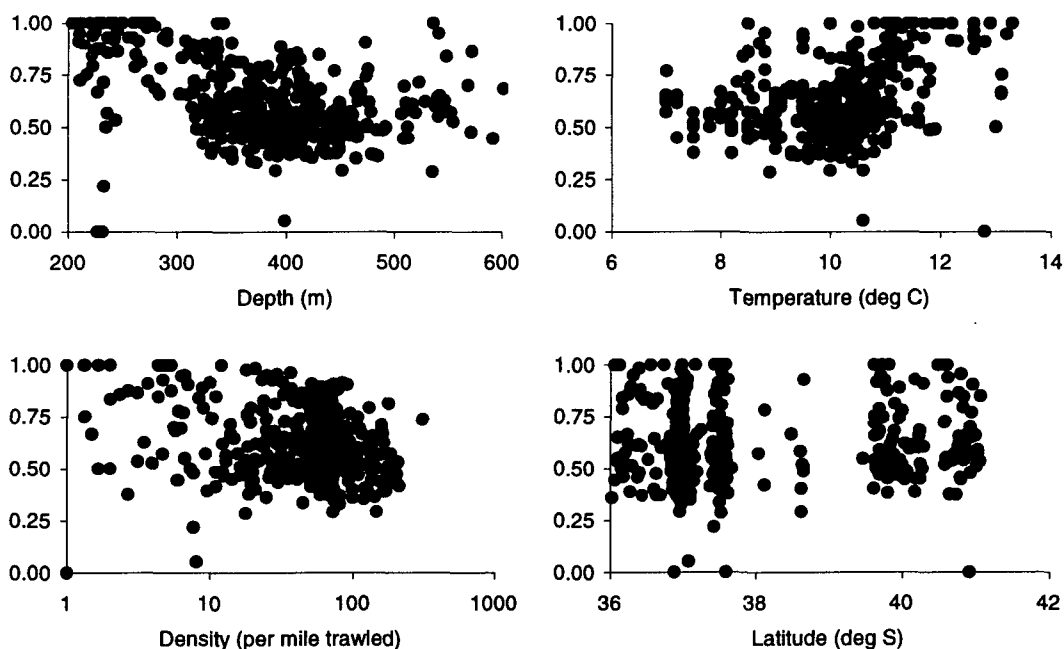
Figure 13: The proportion of males (by number) in relation to depth, bottom temperature, apparent density, and latitude for research tows made by *Kaharoa*. The groupings with latitude correspond closely with the areas selected for analysis, those less than 38° S being in QMA 1 and those greater than 38° S being in QMA 2.

Multivariate modelling

Analysis of variance and multiple regression techniques employing the SAS (version 6.01) GLM (general linear modelling) procedure were used to explain observed variation in scampi density, mean size, distribution of juveniles, and the percentage of males. An initial exploration with the categorical explanatory factors, AREA, SEX, and YEAR as main effects together with all first order interactions, highlighted the importance of SEX in explaining variation in both size and density. The patterns of difference between the sexes did not alter among areas or years, but in both cases the interaction of year with area was significant (i.e. the pattern with time differed among areas).

Final models were then developed by "overfitting" to all available variables, conducting separate analyses for male and females, and using separate models for mean size and density. Continuous variables, such as temperature and depth, were included as the best-fitting higher order (up to cubic) polynomials. No vessel effects were used because the same vessel and gear was used for all samples. Variables were then eliminated depending on the significance of the Student's t and F statistics. In this manner, time of the day was discarded, even though this variable has been shown to be important in explaining variation in commercial CPUE. Longitude and latitude were also found not to be useful explanatory variables, leaving the categorical factor AREA as the only geographical variable in the model. Year effects were nested within areas. The percentage of males was investigated independently. The linear models chosen included the explanatory variables: YEAR, TEMP, $TEMP^2$, DEPTH, $DEPTH^2$, all nested within AREA, and repeated by SEX.

These linear models were successful in explaining 66.2% of the variation in density of females, 58.9% of the variation in density of males, 41.8% of the variation in the mean size of females, and 49.6% of the variation in mean size for males.
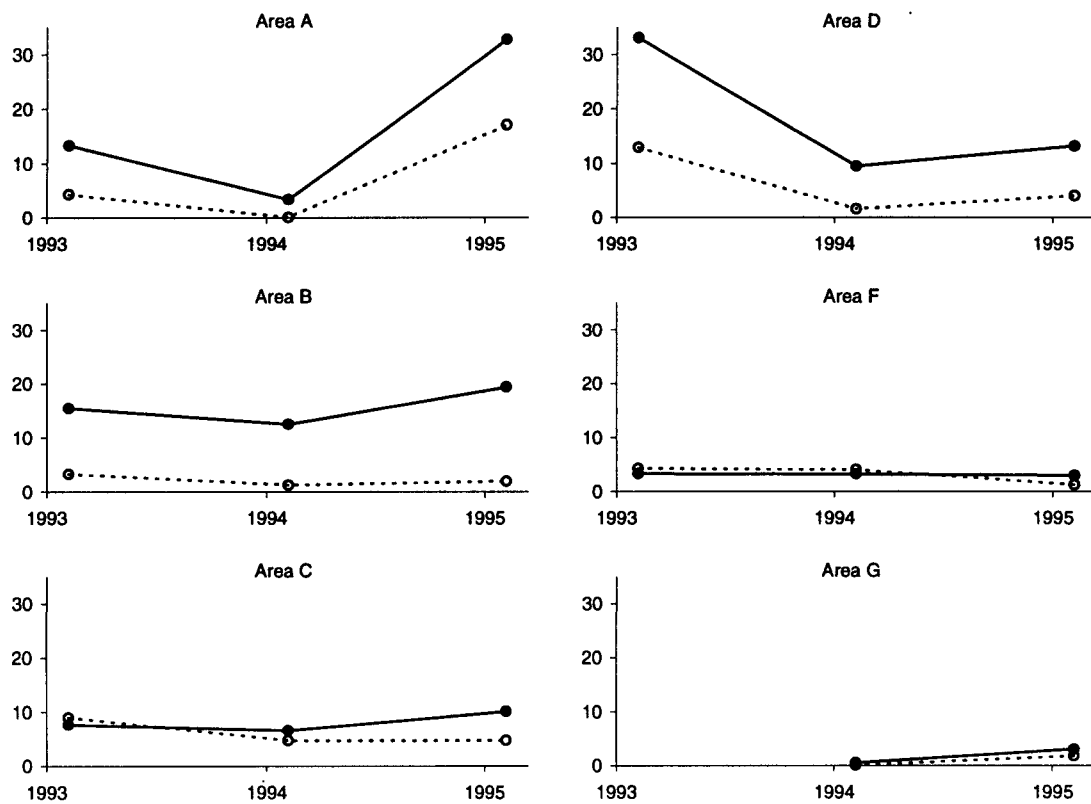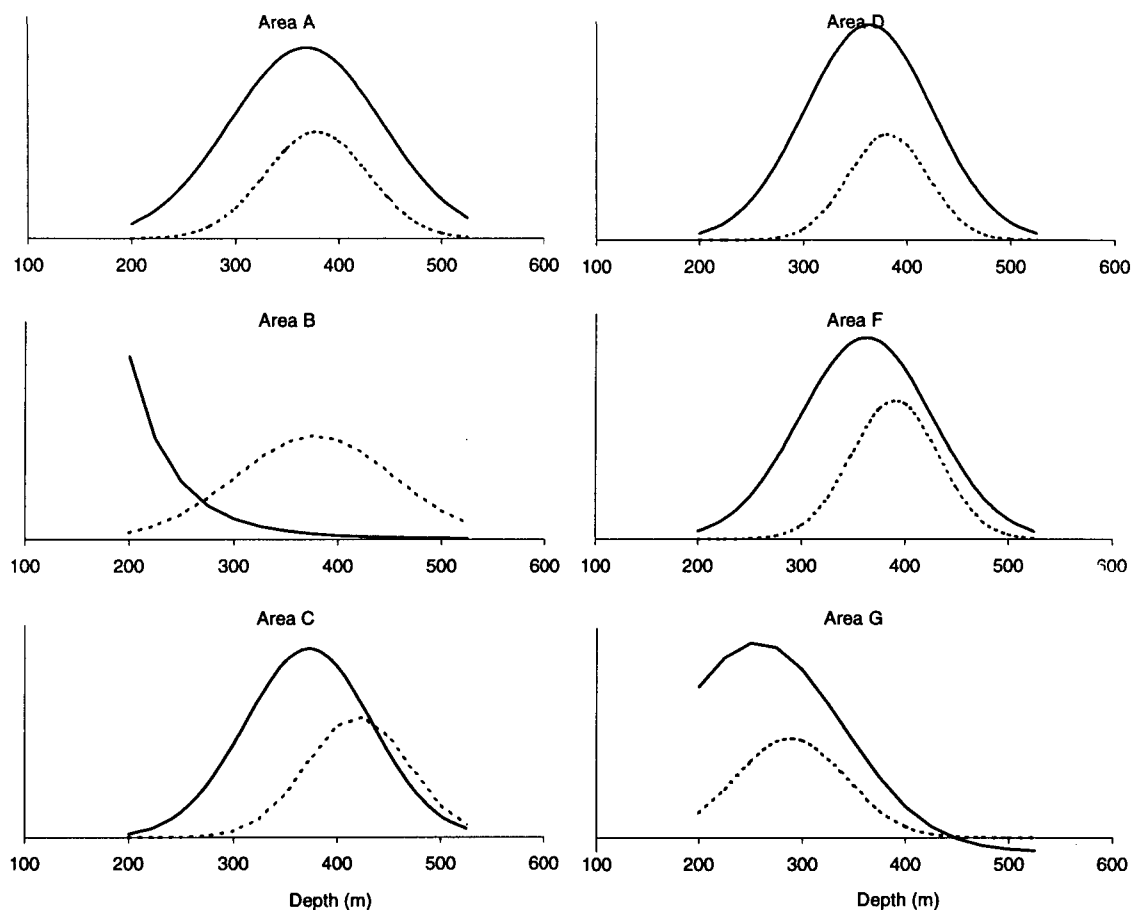

Figure 14: Relative year effects for the linear model of scampi density (number of animals caught per nautical mile towed) with time for the three *Kaharoa* trawl surveys, 1993–95. Area "E" has been excluded as very few shots were conducted in this area. Males are represented by filled circles and solid lines, females by open circles and dotted lines. The different heights of indices among areas are not in themselves informative.

Relative year effects for density and for mean size are plotted for each sex, for each area separately, with temperature and depth held constant (and equal to zero) (Figures 14 and 15). The values are relative to the 1995 observations in each case. There is no evidence of an increase in density between 1993 and 1995 to corroborate the trend seen in commercial CPUE, although this may be confounded by the restricted seasonal coverage of sampling. The mean size of scampi caught by *Kaharoa* varied among years, but without any consistent trend by area.
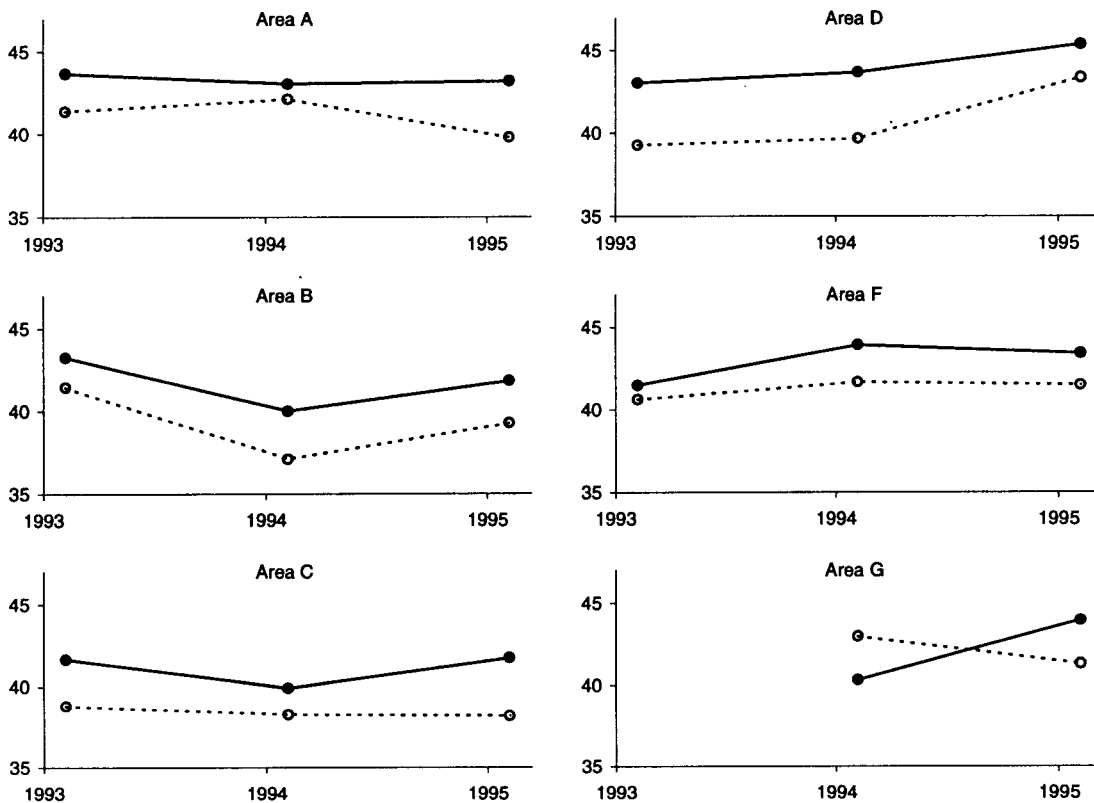
Figure 15: Relative year effects for the linear model of scampi mean size (OCL, mm) for the three *Kaharoa* trawl surveys, 1993–95. Area "E" has been excluded as very few shots were conducted in this area. Males are represented by filled circles and solid lines, females by open circles and dotted lines. The different heights of indices among areas are not in themselves informative.

Depth was more successful than temperature in explaining differences in the size and density of both male and female scampi. The model predictions for density against depth (with other factors held constant) show that, for all areas, the highest density was found at a shallower depth for males than for females (Figure 16). The model predictions for size with depth (with other factors held constant), are not very informative (Figure 17), but size tends to increase with depth for both males and females, without any clear optimum depth.

Figure 16: **Depth effects (on arbitrary scales) for the linear model of scampi density (number of animals caught per nautical mile towed) for the three *Kaharoa* trawl surveys, 1993–95. Area "E" has been excluded as very few shots were conducted in this area. Males are represented by solid lines, females by dotted lines. The different heights of indices among areas are not in themselves informative.**

The numbers of "juveniles" per nautical mile trawled did not vary significantly with area, year, sex, depth or temperature, and no results are reported here. The percentage of males, however, was found to be related significantly to all these factors (which prompted the separate analysis for male and females reported above).

The Aldermen Islands (Area B) data were analysed separately using a model with the same structure as it was thought that the longer time series might be useful for exploring seasonal variability in scampi catch rates. The results of this analysis (Figures 18 & 19) were similar to those for the wider analysis, although the year effect becomes more variable after 1995. The behaviour of the year effect is probably an artefact caused by sampling in different seasons.
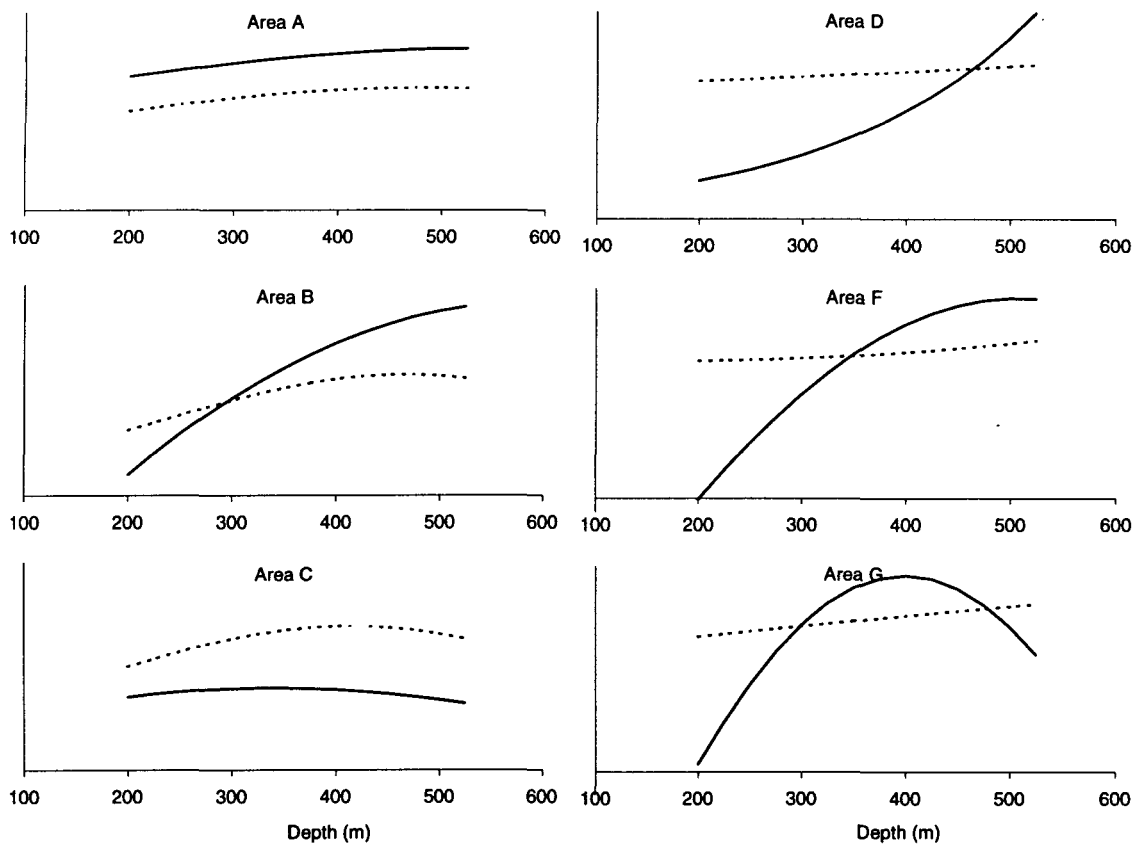
Figure 17: Depth effects (on arbitrary scales) for the linear model of scampi size (OCL, mm) for the three *Kaharoa* trawl surveys, 1993–95. Area "E" has been excluded as very few shots were conducted in this area. Males are represented by solid lines, females by dotted lines. The different heights of indices among areas are not in themselves informative.
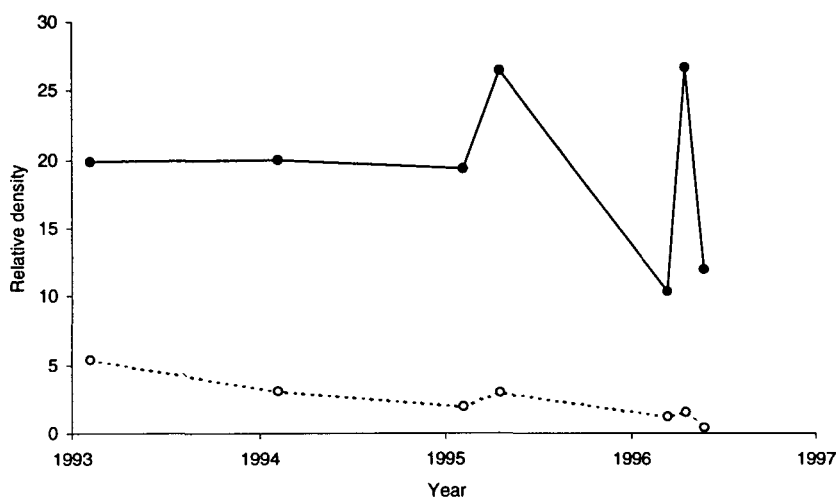
Figure 18: Relative year effects for the linear model of scampi density (number of animals caught per nautical mile towed) for all research trawl studies, 1993–96 in Area "B" (Aldermen Islands) only. Males are represented by filled circles and solid lines, females by open circles and dotted lines. The different heights of indices for the two sexes are not in themselves informative.

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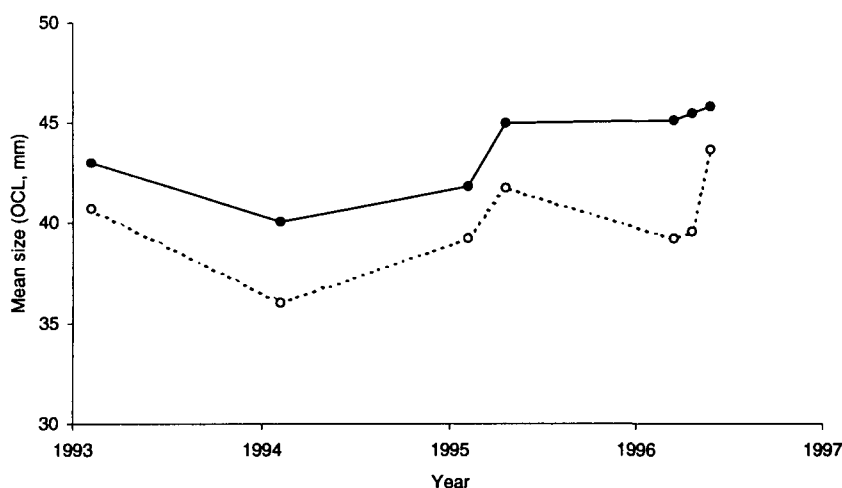
Figure 19: **Relative year effects for the linear model of scampi mean size (OCL, mm) for all research trawl studies 1993–96 in Area "B" (Aldermen Islands) only. Males are represented by filled circles and solid lines, females by open circles and dotted lines.**

In summary, linear and quadratic DEPTH variables were found to be very useful in explaining both density and average size for both sexes. Despite temperature and depth being linearly correlated, linear and quadratic TEMP variables also appear to be important in the multivariate model (but not in the simpler partial correlation analysis incorporating only assumed linear relationships among temperature, depth, and average size), suggesting that temperature may be an important structuring variable for scampi distribution (in interaction with depth). The "Area B" model suggests a greater variability in the density of scampi in later years, although this is probably due to sampling in different seasons. This would suggest that season may be an important determinant of apparent density (as inferred from catch rates by trawl), essentially corroborating the common MONTH effect in models of commercial CPUE.

3.2.3 Length frequency distributions of major finfish bycatch species

Hoki, ling, giant stargazer, and gemfish are the major QMS bycatch species of scampi trawlers in all QMAs. There is considerable other bycatch, but information on these other species is scant because observers have been instructed to concentrate on measuring scampi and the bycatch of QMS species. Figures 20–33 show raw (unscaled) length frequency distributions for these four species since observer coverage began in 1990–91. Those length frequency distributions for scampi fisheries in QMAs 3, 4W, and 4E have been amalgamated as they are essentially subsets of a Chatham Rise continuum. A full analysis and a test of the proposition that scampi fisheries take a large bycatch of juvenile QMS fish would require comparison with observer measurements in respective target fisheries. Such data are not available for all species or all methods.

For hoki (*see* Figures 20–23), the modal class in all QMAs was 60–65 cm in 1990–91, rising steadily to 85–90 cm in 1994–95 and 1995–96. Very few hoki were measured in1996–97. The modal progression is consistent with the progression of the 1987 year class identified by Ballara *et al.* (1997) from the west coast South Island target fishery for spawning hoki. Smaller (30–50 cm) hoki were caught by the scampi fleet mainly in QMA 2, and especially between 1991–92 and 1993–94 (in which year small hoki were also relatively common in scampi bycatch on the Chatham Rise). These fish may represent the 1991 and 1992 year classes of hoki. It does not appear that the length frequency distributions of hoki taken as a bycatch of scampi trawlers are markedly different from those of fish taken by target fisheries and documented by Ballara *et al.* (1997).

There is much less consistency in the length frequency distributions of ling measured by observers on board scampi trawlers (*see* Figures 24–27) and no ling were measured in any area other than QMA 6A in 1996–97. The sample of ling measured by observers in QMA 1 is very small, but shows a range of sizes from about 50 to 120 cm in several years. In QMA 2, a wide range of sizes was measured in 1990–91 (including many very large ling of over 140 cm), whereas in subsequent years the ling taken by scampi trawlers have been much smaller, typically 30–80 cm. The length frequency of ling taken as a bycatch of scampi trawlers is most consistent on the Chatham Rise, with the bulk of fish being between 80 and 140 cm total length in all years when samples were taken. In common with QMA 2, the average sizes of ling taken in QMA 6A tends to be small. A mode at about 50 cm has occurred in most years, and the largest fish rarely exceed 110 cm. An especially large sample of 1310 ling was measured in 1996–97, wherein the small fish (30–70 cm) were especially well represented. The presence of small fish may represent the recruitment of one or more good year classes of ling into QMAs 2 and 6A, but the consistency of the pattern suggests that the scampi fisheries in these areas may take place in areas containing relatively large proportions of small fish.

Few giant stargazers were taken in QMA 1, although the sample measured in 1996–97 was the largest ever. The reasons for this large sample is not known, but could include deliberate "targeting" of giant stargazers for measurement by observers or an increase in the level of bycatch. In other areas, the length frequency distributions were broadly similar among years (*see* Figures 28–31). In QMA 2, the fish were large, averaging 60–80 cm, whereas on the Chatham Rise and off the Auckland Islands, a smaller size class of 40–60 cm was usually also apparent and, in the latter area, dominant.

The numbers of gemfish measured by observers on scampi trawlers was small and confined to QMAs 1 and 2. There is little or no consistency between years, but some consistency between the two areas (*see* Figures 32 and 33). For the first time since 1991–92, a few very small gemfish (less than 40 cm) were measured in QMA 1 in 1996–97
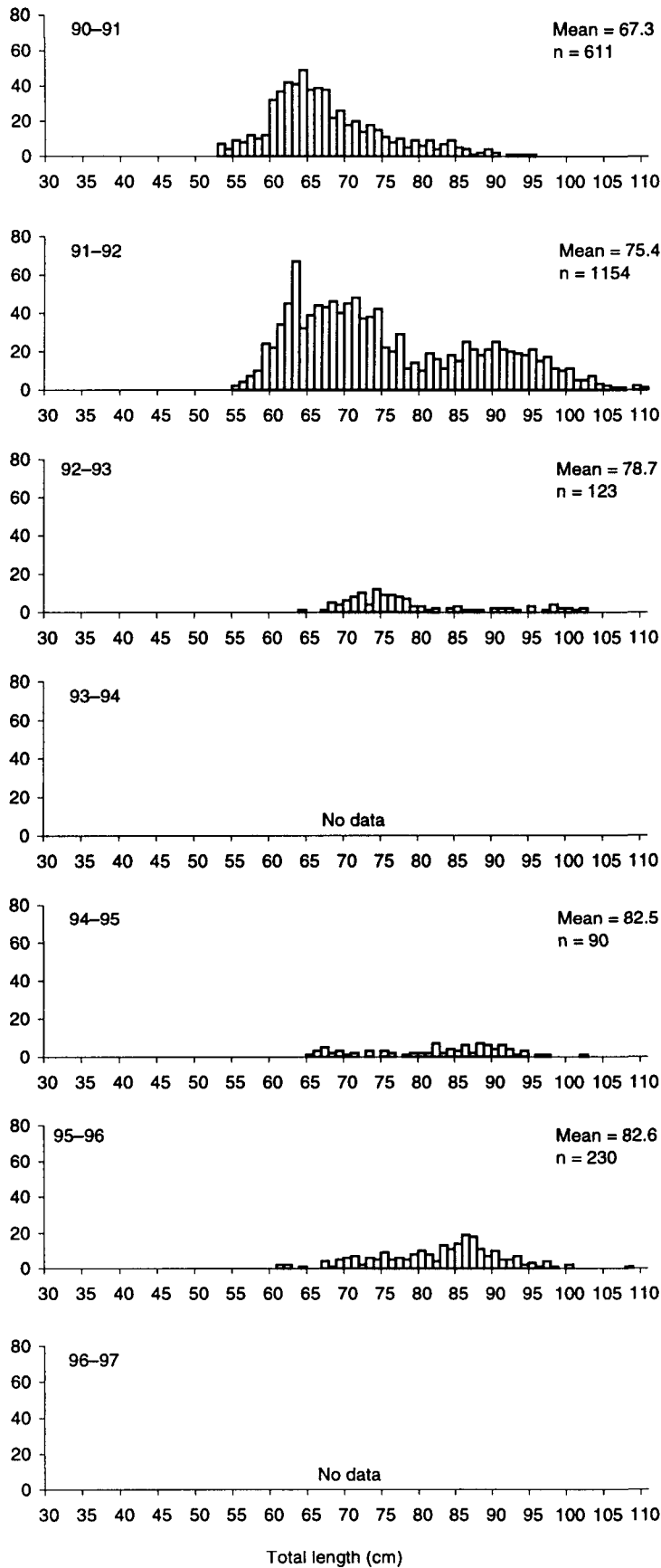
Figure 20: Length frequency distributions for hoki measured by scientific observers on board scampi trawlers in QMA 1 (observer area AKE).
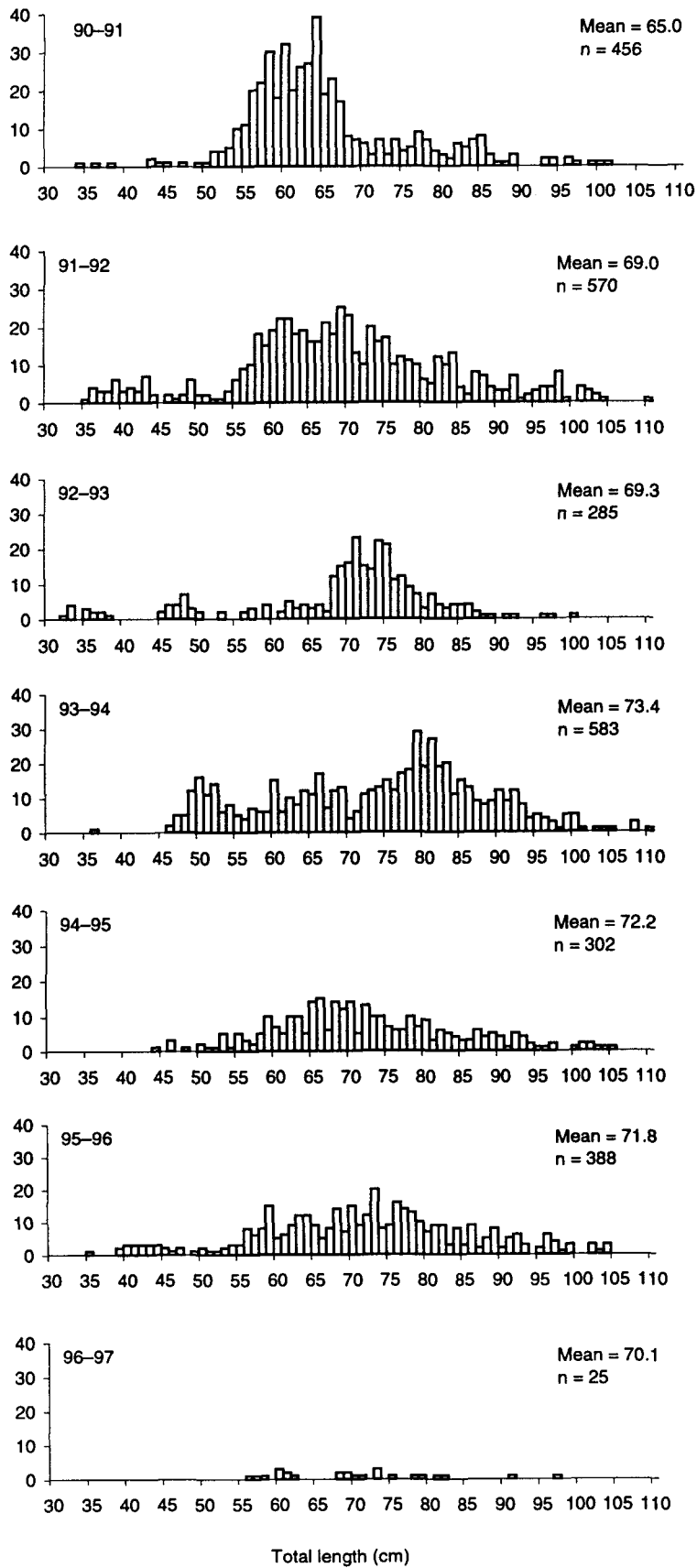
Figure 21: Length frequency distributions for hoki measured by scientific observers on board scampi trawlers in QMA 2 (observer area CEE).
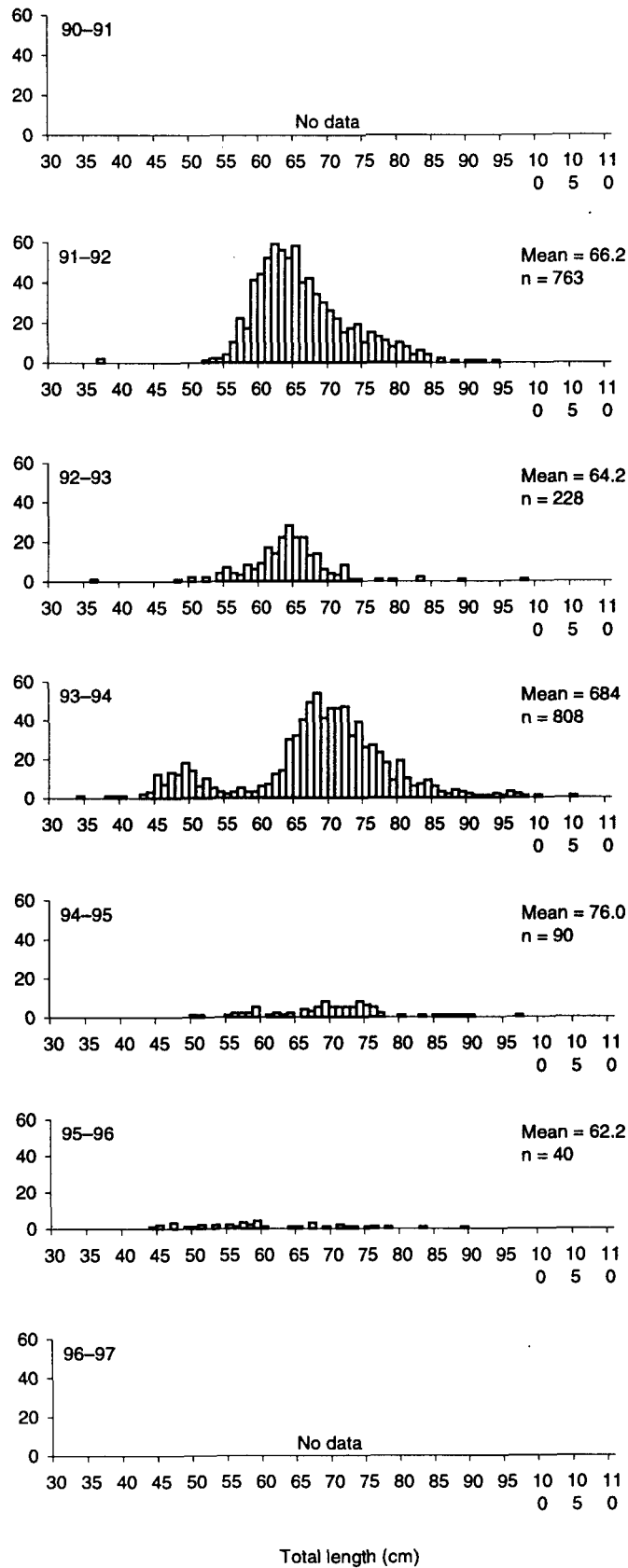
Figure 22: Length frequency distributions for hoki measured by scientific observers on board scampi trawlers in QMAs 3 and 4 (observer areas SOE and SEC).

Figure 23: **Length frequency distributions for hoki measured by scientific observers on board scampi trawlers in QMAs 6 (observer areas SOI).**

Figure 24: **Length frequency distributions for ling measured by scientific observers on board scampi trawlers in QMA 1 (observer area AKE).**

Figure 25: **Length frequency distributions for ling measured by scientific observers on board scampi trawlers in QMA 2 (observer area CEE).**

Figure 26: Length frequency distributions for ling measured by scientific observers on board scampi trawlers in QMAs 3 and 4 (observer areas SOE and SEC).
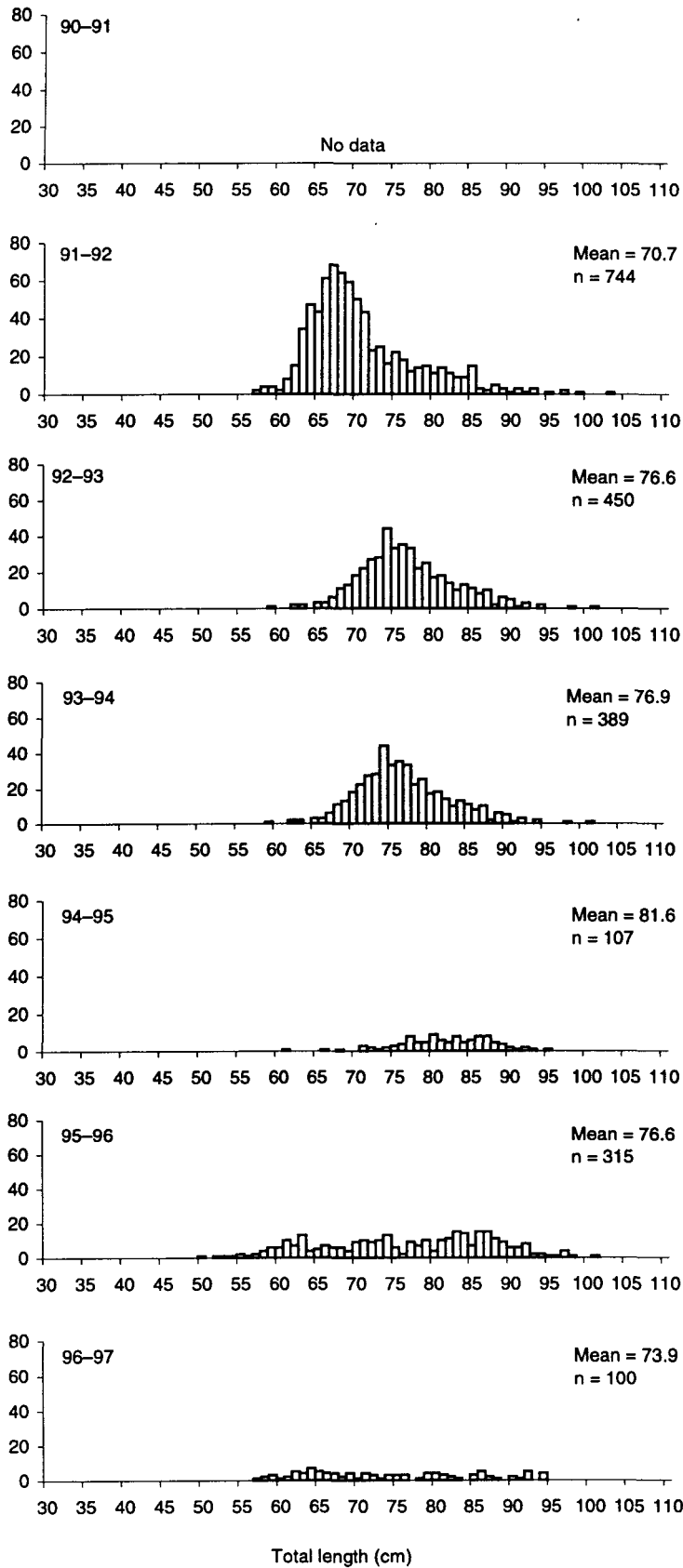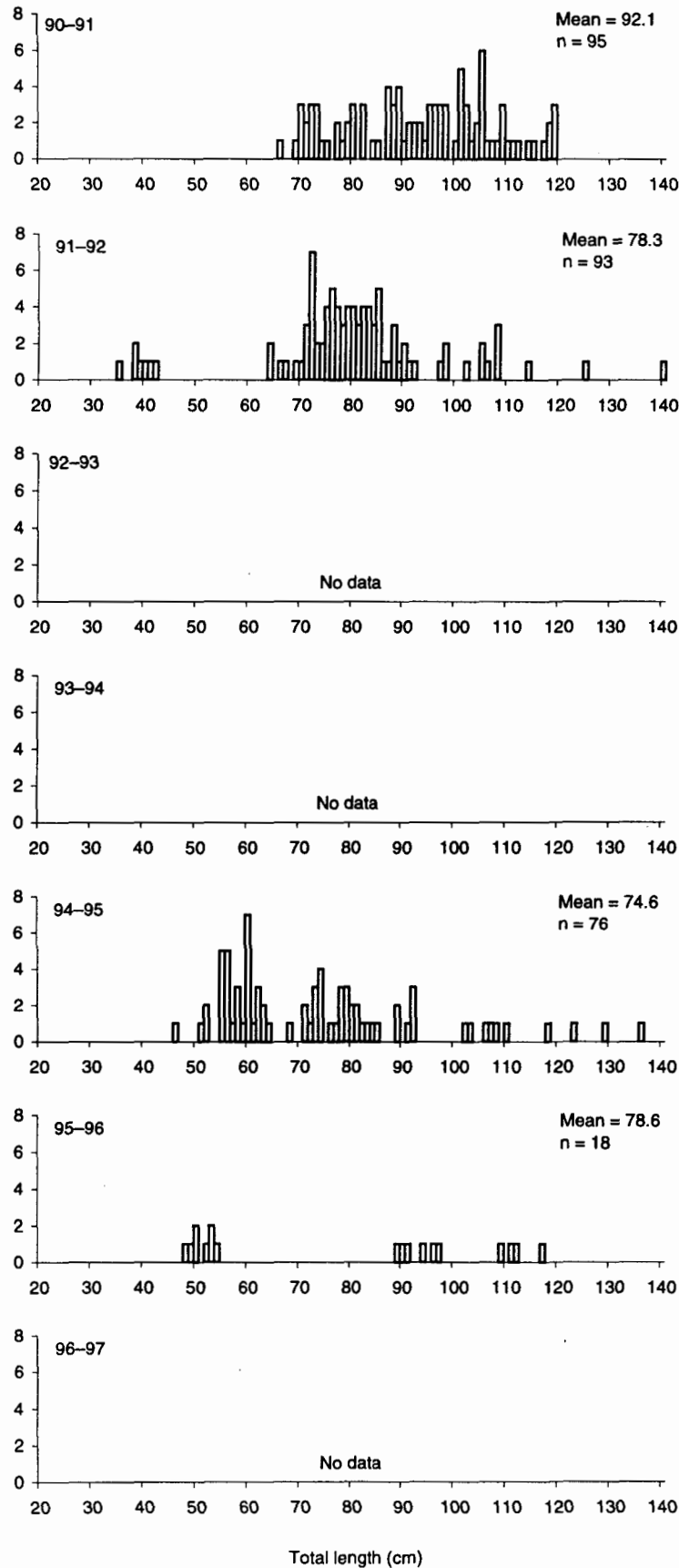
Figure 27: Length frequency distributions for ling measured by scientific observers on board scampi trawlers in QMA 6 (observer areas SOI).
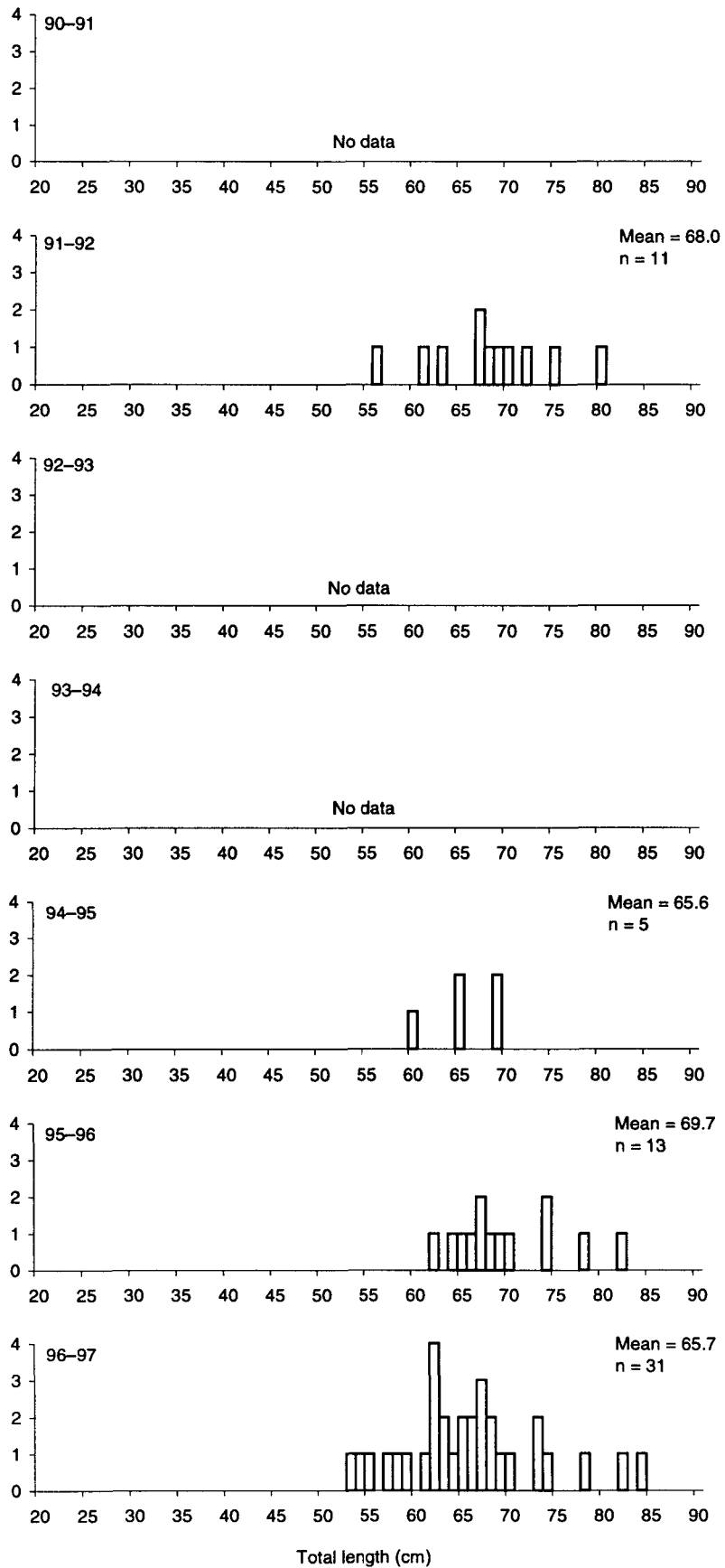
Figure 28: Length frequency distributions for giant stargazer measured by scientific observers on board scampi trawlers in QMA 1 (observer area AKE).
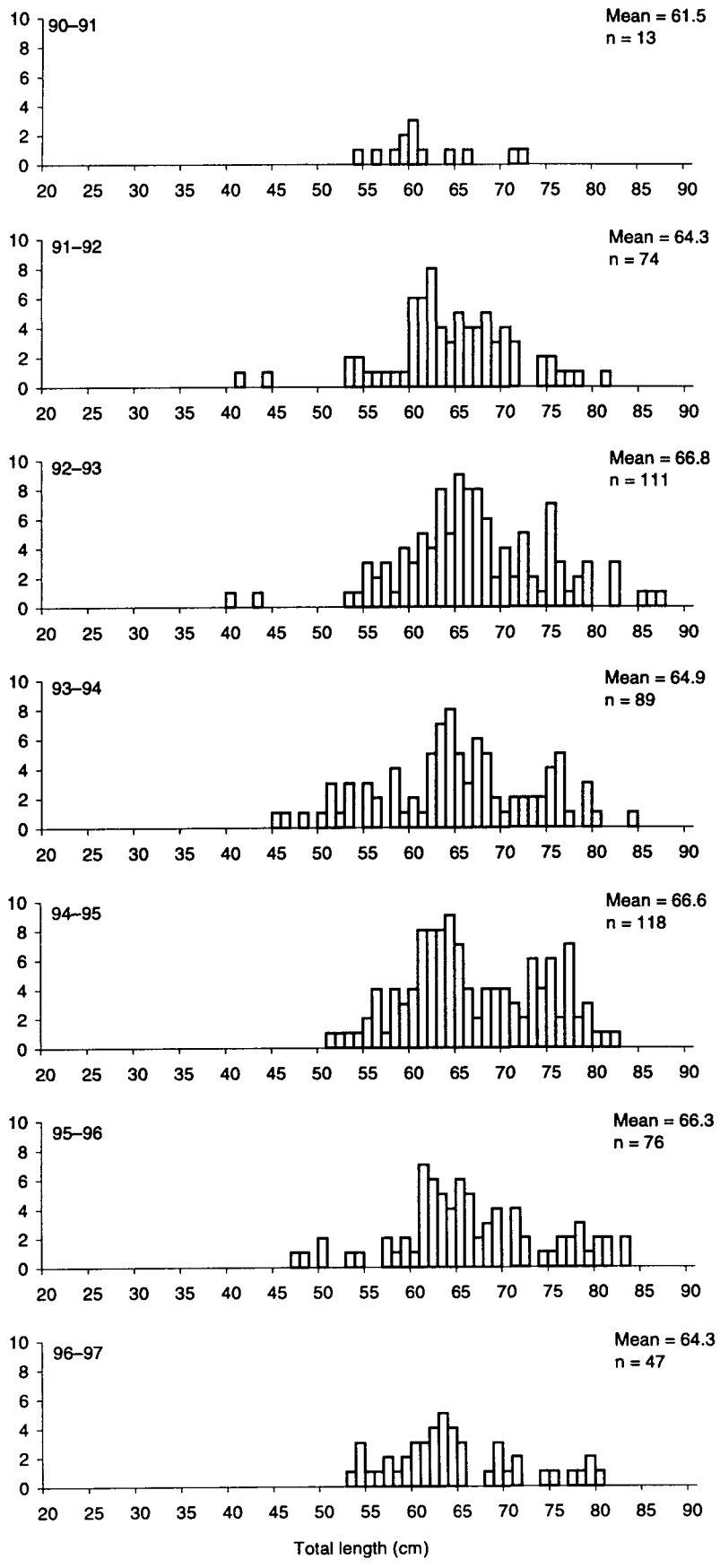
Figure 29: Length frequency distributions for giant stargazer measured by scientific observers on board scampi trawlers in QMA 2 (observer area CEE).
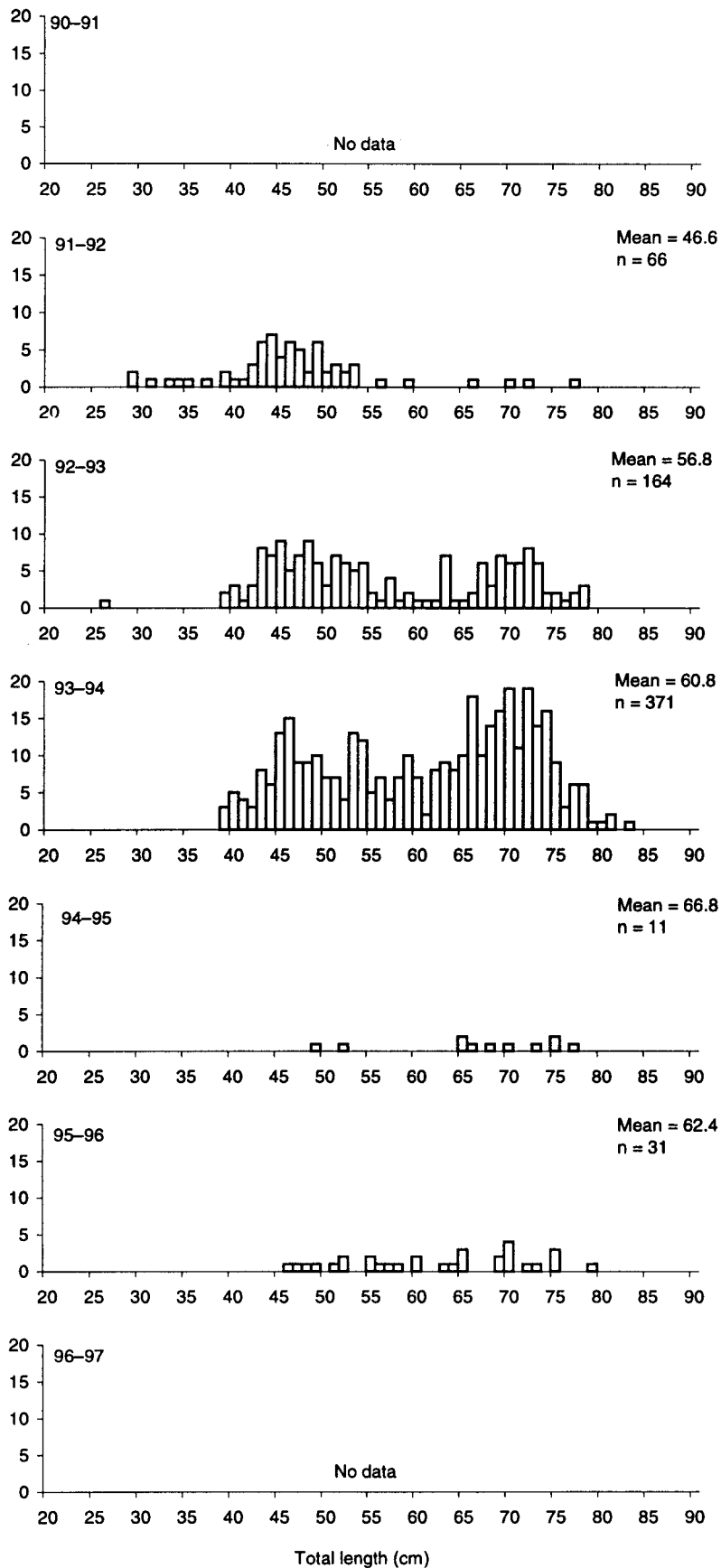
Figure 30: **Length frequency distributions for giant stargazer measured by scientific observers on board scampi trawlers in QMAs 3 and 4 (observer areas SOE and SEC).**

Figure 31: Length frequency distributions for giant stargazer measured by scientific observers on board scampi trawlers in QMA 6 (observer area SOI).

Figure 32: **Length frequency distributions for gemfish measured by scientific observers on board scampi trawlers in QMA 1 (observer area AKE).**
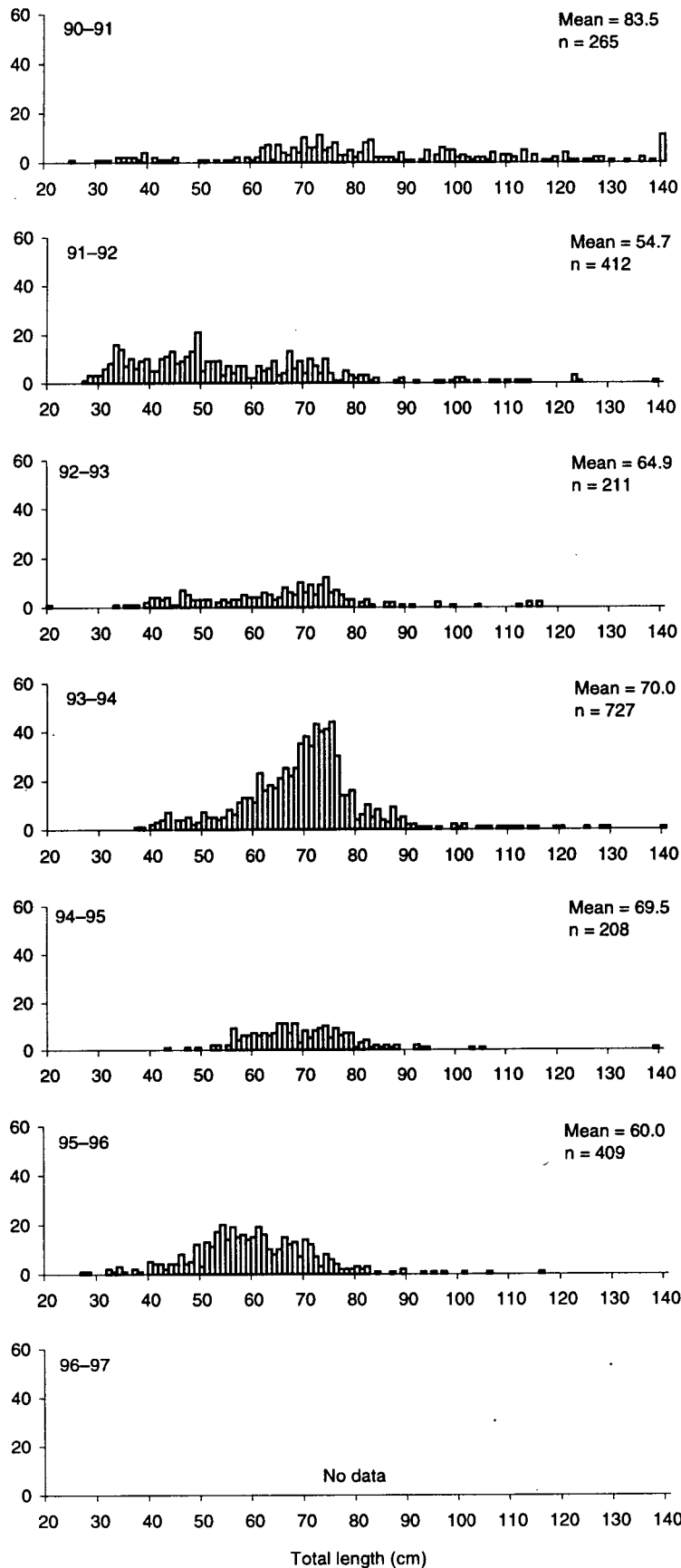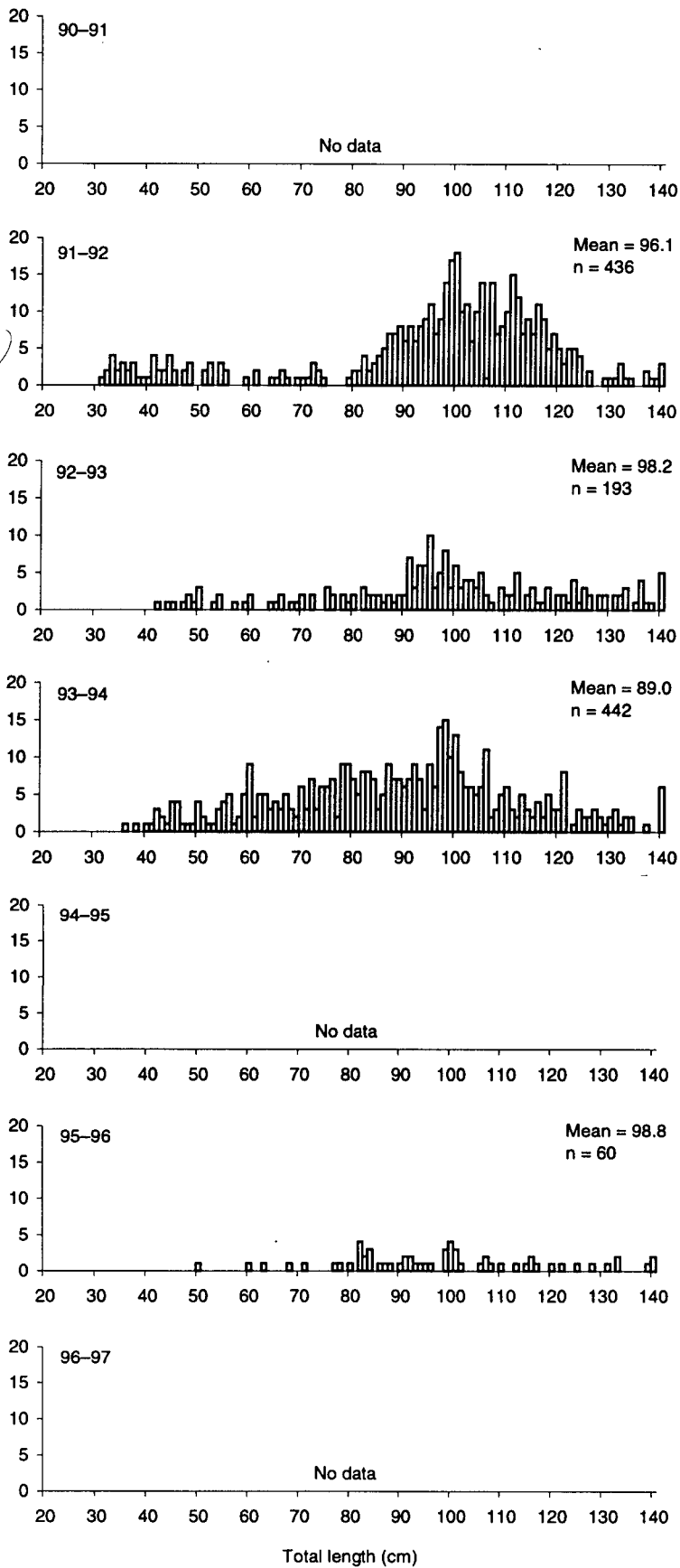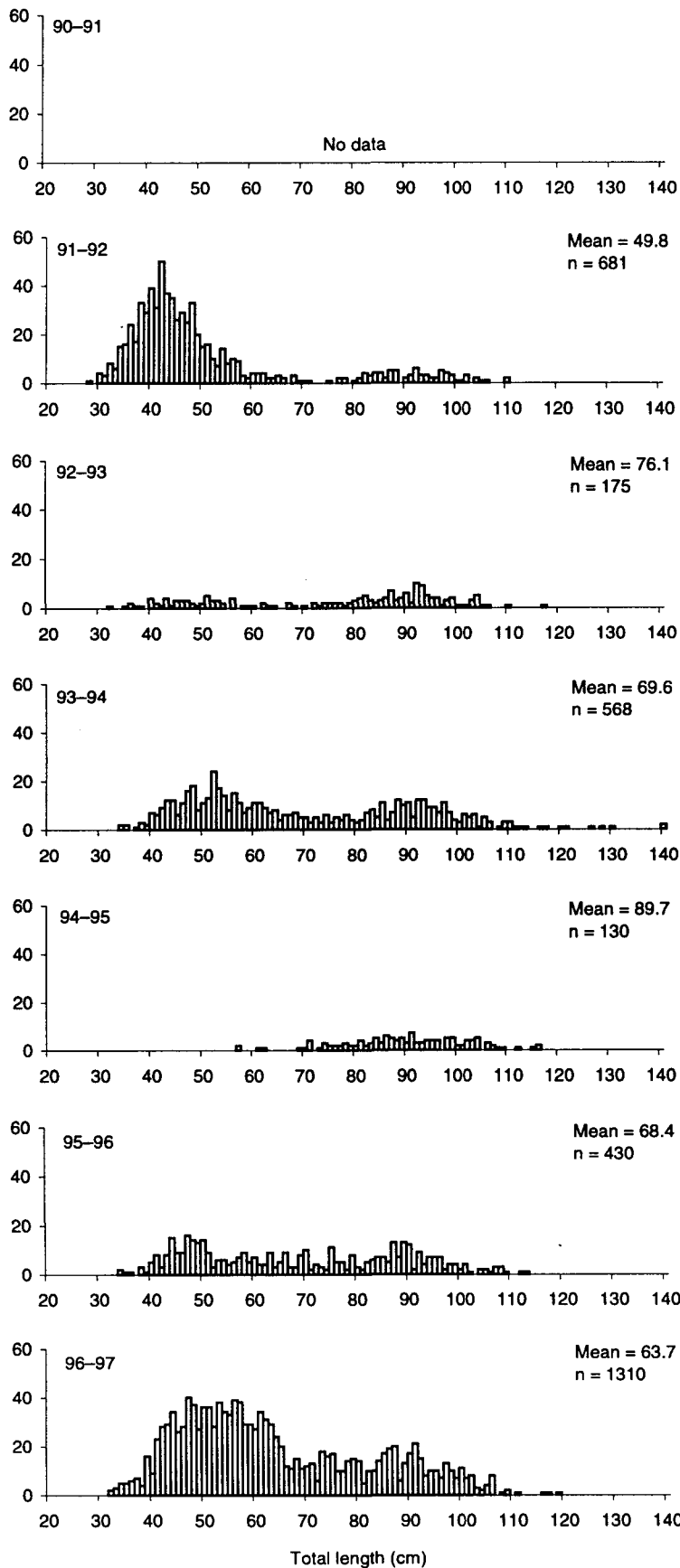
Figure 33: Length frequency distributions for gemfish measured by scientific observers on board scampi trawlers in QMA 2 (observer area CEE).
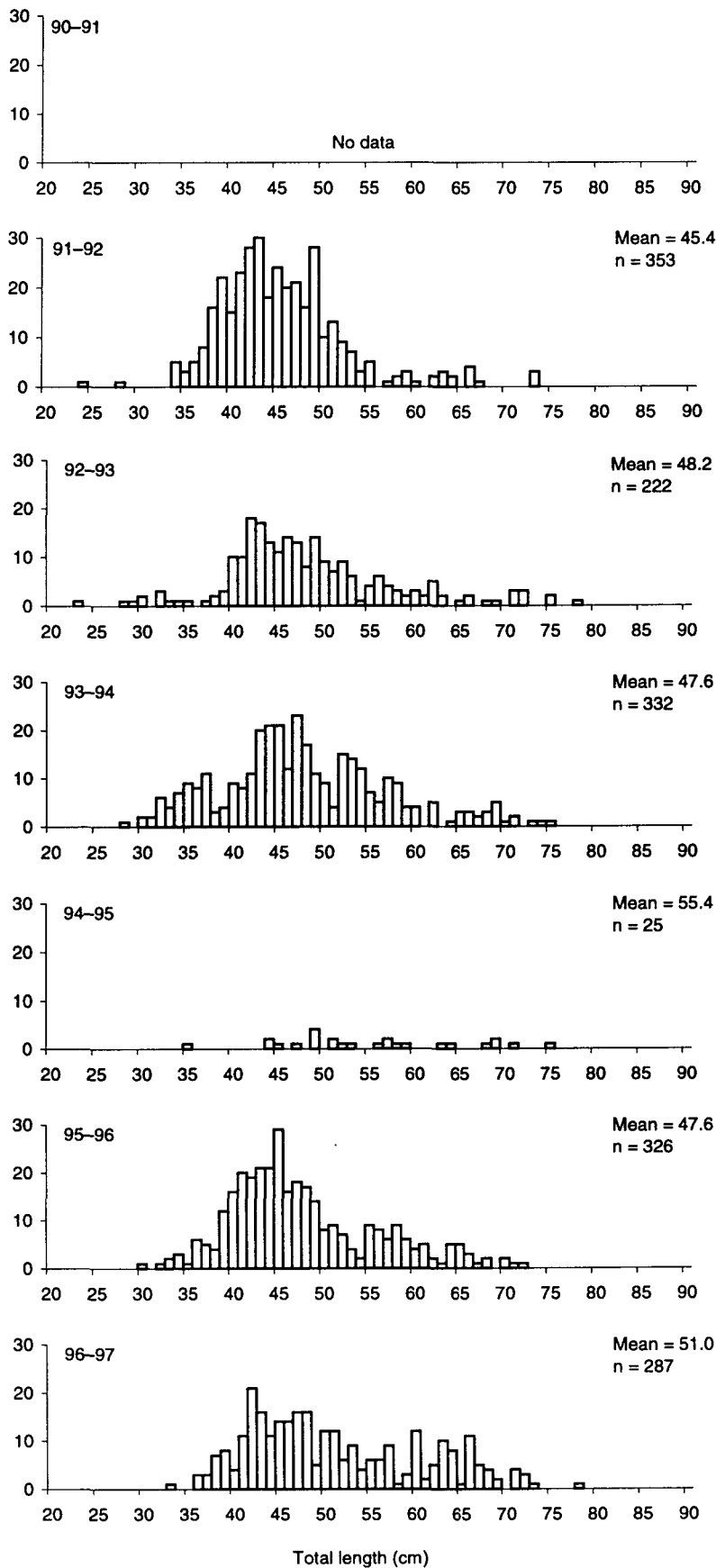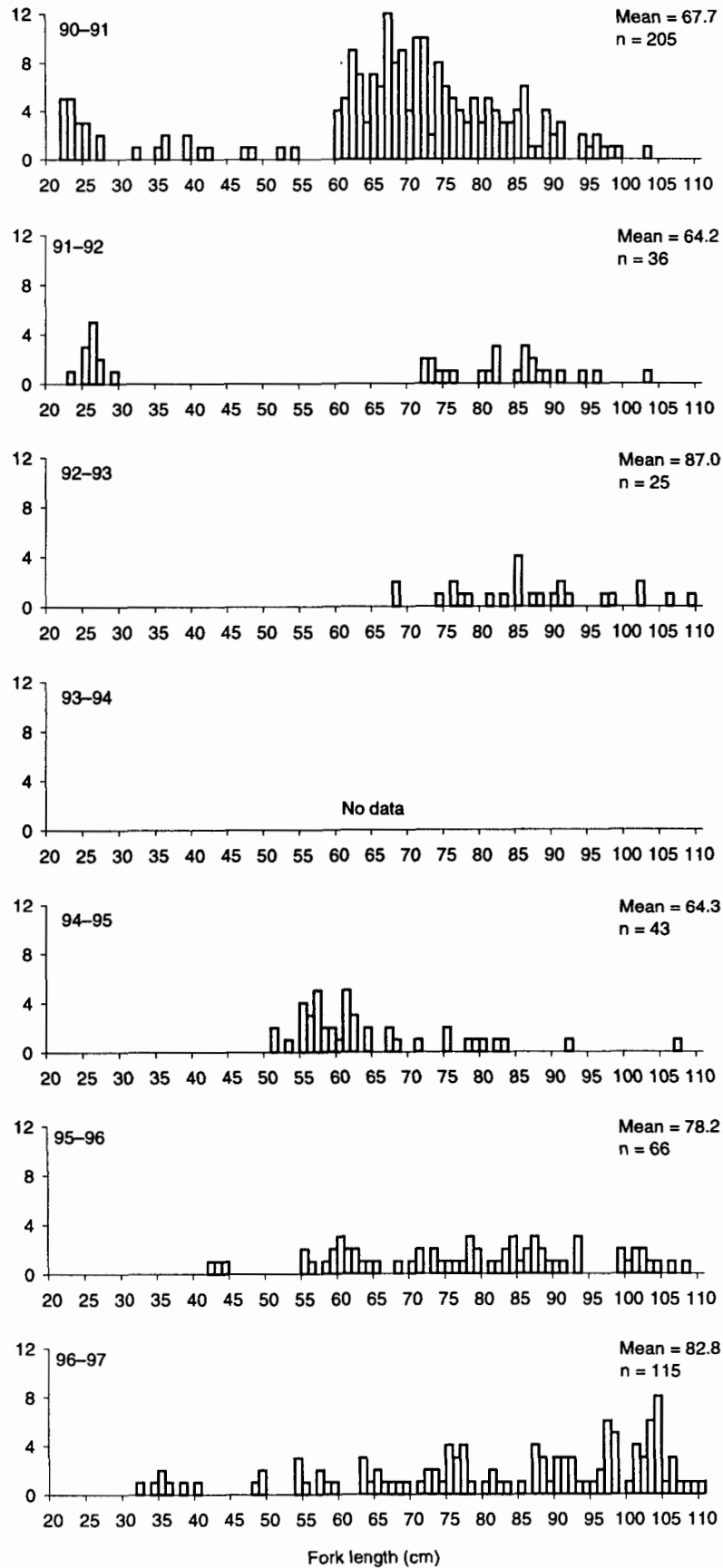
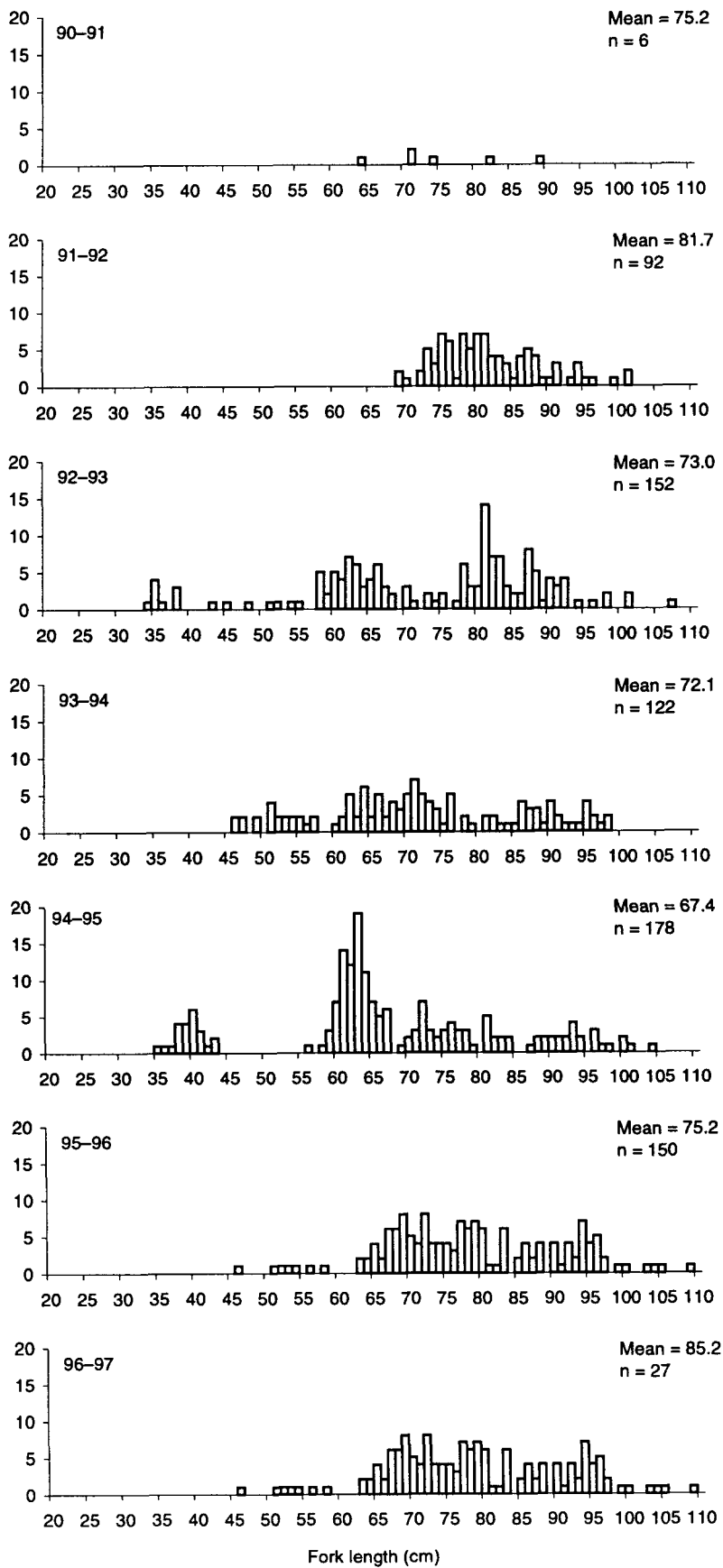### 3.2.4 Characterisation of invertebrate bycatch

Invertebrate bycatch, other than for commercially important species such as arrow squid (*Nototodarus gouldi, N. sloanii*), octopus (*Pinnoctopus cordiformis = Octopus maorum*), and "prawn killers" (*Ibacus alticrenatus*), is rarely reported in any detail by commercial fishers, by scientific observers, nor, until very recently, even by research staff. This complicates any serious temporal analysis of the invertebrate bycatch (Grove & Probert 1998).

However, detailed taxonomic analysis has been conducted of the entire invertebrate bycatch taken during 1996 and 1997 research voyages (MFV *Drysdale* voyages DRY9601 and DRY9602 where scampi tagging was the major focus, and RV *Kaharoa* voyage KAH9801 where a comparison of trawl and photographic assessment methods was conducted). The availability of these data allows, for the first time, an examination of patterns in the bycatch of scampi trawls, standardised to a single gear type (as the same research gear towed at the same speed using similarly sized and powered vessels was used in all three trips). This spatial analysis can be considered as a "surrogate" for a temporal analysis of changes in bycatch if the detailed fishing history of each of the sites sampled is known.

While it is acknowledged that scampi trawl gear cannot be considered as fully quantitative when sampling a wide variety of invertebrate taxa, strong signals in benthic invertebrate community structure should still be discernible if the gear is only semi-quantitative. Indeed, some of the analyses presented here can be conducted using presence-absence data and give similar results.

All invertebrates recovered from each of these 66 trawl shots were identified to the lowest possible taxonomic level, enumerated and, for the *Kaharoa* samples, weighed. The species composition of bycatch was then analysed in relation to a variety of possible influential factors, including depth, location, and the historical level of fishing pressure. Some taxa, such as sea pens (e.g., *Anthoptilum murrayi*) were not included in the analysis because there is a strong tendency for them to become tangled in the belly and wings of the trawl gear and contaminate subsequent samples.

Historical fishing pressure was estimated for each of the 66 sites using shot location information from commercial returns (Trawl Catch Effort & Processing Returns, TCEPR). Using a Geographical Information System (GIS, Arc Info), a count was made of the number of times each research trawl shot was crossed (or approached within 100 m) by a commercial shot for scampi reported on a TCEPR for each fishing year since the start of this fishery. These counts were adopted as indices of the frequency of occurrence of (scampi) fishing at each site. In addition, an estimate was made of the area of overlap of all intersections between commercial shots and each of the research shots, again assuming a nominal width of 100 m. These intersect areas were summed for each research site in each fishing year since the start of this fishery to give a second index of the total areal extent of (scampi) fishing at each site.

Probably because of the highly consistent nature of scampi fishing (commercial and research shots being conducted parallel to depth contours), these two indices were very highly correlated ($R^2_{64} = 0.992$). For ease of subsequent analysis, therefore, the former index (the frequency with which each research shot has been crossed by commercial shots) was adopted, and the data were grouped into three year blocks representing early fishing (1988–89 to 1990–91), intermediate fishing (1991–92 to 1993–94), and recent fishing (1994–95 to date).
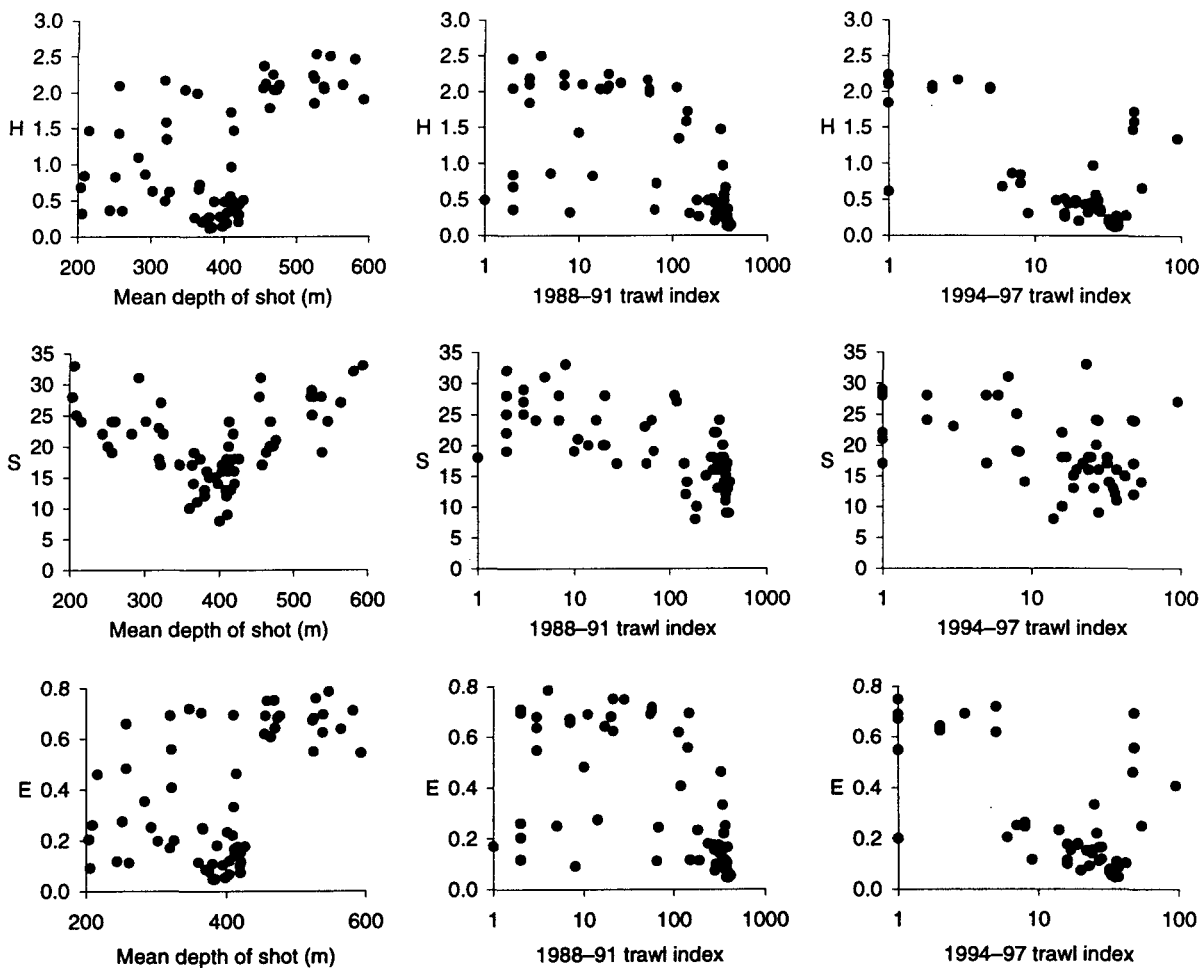
Figure 34: Indices of invertebrate species diversity (Shannon-Wiener index, H), species richness (total number of species, S) and equitability of distribution among taxa (H/H$_{max}$, E) for the 66 research trawl stations for which invertebrate bycatch has been quantified. The three indices are plotted against depth and against two indices of fishing intensity at each of the sites between 1988 and 1991 (1988–91 trawl index) and between 1994 and 1997 (1994–97 trawl index). Both trawl indices were derived using reported fishing locations from commercial catch and effort returns by scampi trawlers.

There were apparent univariate trends in species diversity (measured as the Shannon-Wiener index, H, as species richness, S, and as equitability, E,) with depth and with some indices of fishing pressure (Figure 34), and linear modelling identified significant relationships with historical fishing intensity, with depth, and, to a lesser extent, with latitude (Table 26). There was a decrease in species diversity with increasing historical fishing pressure, an increase in diversity with increasing depth, and an increase in diversity with increasing (absolute) latitude. The relationship with historical fishing intensity was strongest for the early fishing years (1988–91), suggesting that any modifications made by trawling may be relatively enduring, that subsequent fishing does not modify the environment as much as "new" fishing in a relatively undisturbed environment, or that fishers have become more adept at avoiding areas where invertebrate bycatch is rich and diverse.

This analysis is based entirely on reported fishing for scampi on TCEPR forms. There may be some other trawl fishing in this area (for tarakihi and gemfish, for instance), and a full analysis should include an examination of the spatial distribution and intensity of any other fisheries in this area and depth band (200–600 m). Some such fishing may be reported on Catch Effort and Landing (CELR) forms rather than TCEPR forms, and the former do not contain individual shot positions.

Table 26: **Summaries of significant variables included in linear models of species diversity (H), species richness (S), and species equitability (E) of invertebrate trawl bycatch samples. Variables are listed in order of their inclusion in a stepwise procedure**

Effect	Coefficient	SE	Standardised coefficient	df	F	p
Diversity (H):						
1988–91 trawl index	-0.004	0.000	-0.754	1	71.417	0.000
Depth	0.005	0.001	0.550	1	71.220	0.000
Latitude	0.727	0.211	0.261	1	11.851	0.001
1994–97 trawl index	0.012	0.004	0.281	1	9.092	0.004
Richness (S)						
1988–91 trawl index	-0.026	0.004	-0.665	1	34.914	0.000
Depth	-0.289	0.157	-0.189	1	3.385	0.071
Latitude	-3.694	2.215	-0.176	1	2.783	0.100
Equitability (E)						
1988–91 trawl index	-0.001	0.000	-0.731	1	57.046	0.000
Depth	0.001	0.000	0.535	1	57.212	0.000
Latitude	0.246	0.071	0.283	1	11.851	0.001
1994–97 trawl index	0.004	0.001	0.300	1	8.796	0.004

The composition of communities or assemblages of taxa can be examined in a more holistic manner using similarity indices. The Bray-Curtis index (Bray & Curtis 1957) was calculated for all combinations of stations using numerical counts of each of 163 invertebrate taxa. This index defines the extent to which two samples are biologically similar to one another. Following the calculation of a matrix of similarity indices among all samples, non-metric multi-dimensional scaling (nMDS, e.g., Kruskal & Wish 1978) was used to represent the stations in multi-dimensional space such that as much as possible of the structure in the relative similarities of stations was retained. In such ordinations (usually represented in two or three dimensions), stations which are very similar in their community composition should appear close together, and stations which are very dissimilar should appear far apart. Faith *et al.* (1991) found the Bray-Curtis index the most powerful of several community dissimilarity measures for benthic invertebrates, and MDS is usually considered to be one of the methods of choice for representation and comparison of community structures among several samples (*e.g.* Clark & Ainsworth 1993, Clarke & Warwick 1994, Chapman & Underwood 1998, Thrush *et al.* 1998). Thrush *et al.* (1995, 1998) used similar approaches to assess, respectively, benthic community composition with respect to scallop dredging at an experimental scale in Mercury Bay, and with respect to trawling and scallop dredging throughout the Hauraki Gulf.
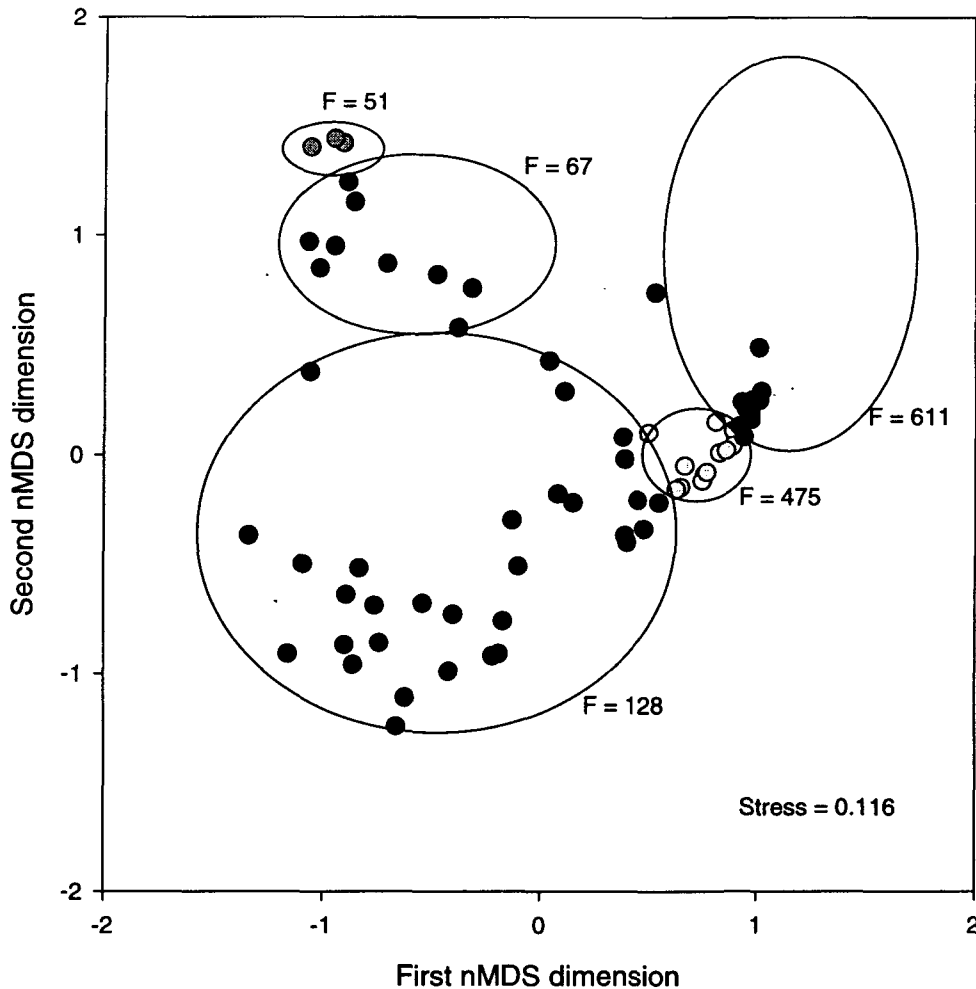
Figure 35: **Non-metric multidimensional scaling (nMDS) ordination based on Bray-Curtis similarity indices calculated using counts of 163 invertebrate bycatch taxa for 66 research trawl stations from which detailed and precise invertebrate bycatch data were collected. Stations are grouped into five clusters (indicated by shading and lines) based on a separate cluster analysis. The mean index of historical fishing activity across sites is specified as F for each of the clusters. The first dimension is highly correlated with the index of fishing pressure at each site, and the second dimension is highly correlated with depth.**

Ordination (Figure 35) suggested very strongly that there were patterns in the composition of the invertebrate bycatch which were correlated with historical reported use of sites by scampi trawlers. Sites were plotted in two (nMDS) dimensions based on Bray-Curtis similarity indices calculated using the highest possible level of taxonomic resolution (which was to species in about 90% of taxa). The estimated stress of the nMDS plot was 0.116 at two dimensions ($R^2 = 0.943$), and 0.091 at three dimensions ($R^2 = 0.955$). The additional explanatory power of the third dimension was not considered worthwhile, given the complexity of its representation. Further, the first two nMDS dimensions are correlated highly significantly ($p \ll 0.001$) with the index of fishing pressure and with depth, respectively (Figure 36), further supporting the importance of these two variables in predicting community

composition. The third nMDS dimension is not significantly correlated with any of the measured variables.

Spence (1979) gave a method of estimating the likely value of stress for nMDS plots made using essentially random data. Using this method, the estimated values of stress for 66 random data points are 0.367 and 0.209 for two and three dimensions respectively. Spence (1979) cautioned that these estimates should not be used in a "hypothesis testing fashion" (i.e., by posing a question such as "are these data significantly different from a random cloud?"), but rather to provide an intuitive feel for the value of the data. He suggested that computed stress values of "a third or a half as large" as those derived using random data would tend to indicate that the data contain substantive information. Stress for the scampi bycatch data was 31% of that derived using random data at two dimensions, but increased to 44% at three dimensions. This suggests that there is some real information content in the data, but that the value of the third dimension is much less than that of the first two (its stress is considerably closer to that predicted for random data than is that for the two dimensional plot).
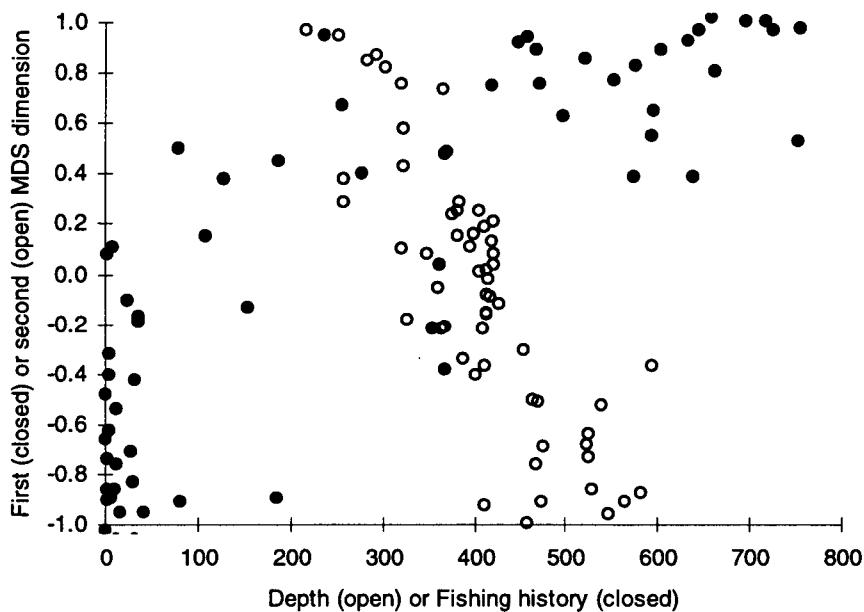
Figure 36: Relationships between depth and the second nMDS dimension (open circles, $R^2 = 0.759$) and the index of fishing pressure and the first nMDS dimension (closed circles, $R^2 = 0.702$). In both cases, p<<0.001.

The organisation of the 66 stations in the two dimensional nMDS plot corresponds well with the results of a statistical clustering technique allocating each station to one of five clusters. Essentially non-overlapping lines denoting the clusters can be drawn around the appropriate sets of stations. The average attributes of the stations within each of the clusters are shown in Table 27.

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Table 27: **Average values for position, depth, scampi fishing history, and species diversity for stations in each of the five identified clusters. "Early" fishing is 1988–91 and "Recent" fishing is 1994–97. "S" denotes species richness, "H" denotes the Shannon-Wiener index of species diversity, "inv" denotes invertebrate bycatch, and "fish" denotes fish catch (all species)**

Cluster	n	Lat. (S)	Long. (E)	Average Depth	Early	Recent	Total	S(inv)	H(inv)	S(fish)	H(fish)
					Fishing	pressure				Diversity	
1	31	37° 14'	176° 32'	447	70	8	128	21.9	1.77	18.2	2.07
2	3	37° 00'	176° 12'	207	4	12	51	28.7	0.61	21.7	2.19
3	9	37° 14'	176° 30'	277	23	14	67	23.6	0.82	22.2	2.11
4	12	37° 00'	176° 19'	398	295	23	475	16.2	0.52	19.9	2.06
5	11	36° 58'	176° 17'	396	344	30	611	15.1	0.28	21.2	2.09

For each of the 163 taxa identified from the samples, a multiple linear regression analysis of abundance on depth and (separately) each of the three temporal indices of fishing pressure was calculated. For each of these (163 * 3 = 489) analyses, the nominal significance of the partial slope associated with fishing pressure was assessed using the value of Student's "t". These analyses essentially filter out the relationship each taxon has with depth from the analysis of any relationship with historical fishing pressure (and depth has been shown to be the other measured variable of importance in predicting community structure in these data). Six taxa (including the target species *Metanephrops challengeri*) showed (nominally) significant positive partial correlation with all three temporal indices of fishing pressure (Table 28). A further 15 taxa showed consistent significant negative partial correlation with the indices of fishing pressure, and 118 taxa showed no significant partial correlations with the indices of fishing pressure. The remaining 24 taxa had inconsistent relationships with the temporal indices of fishing pressure.

The likelihood of detecting an apparent partial correlation (either positive or negative) with an index of fishing pressure seemed to increase with increasing number of individuals enumerated in the samples. Only about 6% of (109) taxa represented by less than 20 individuals showed nominally significant trends, compared with 48% of (27) taxa represented by 20–50 individuals and 62% of (27) taxa represented by more than 50 individuals. On this basis, it does not seem appropriate to test for real relationships when a taxon is represented by less than about 20 animals: the likelihood of demonstrating such a relationship appears to be low, and there may be a greater likelihood of drawing false conclusions.

For taxa represented by more than (arbitrarily) 24 individuals, there was a significant trend with time in the proportion of taxa showing negative correlation with the index of fishing pressure (Table 29). More than half of 47 taxa showed a (nominally) significant negative correlation with the index of "early" fishing pressure, whereas only about one-quarter showed this correlation with the index of "recent" fishing pressure. There was a much less significant change (in terms of the contribution to χ^2) in the number of taxa showing (nominally) positive partial correlations with fishing pressure.

Table 28: **Frequency of negative and positive partial correlations (excluding the effects of depth, and nominally significant at p = 0.05) between the abundance of those 47 invertebrate bycatch taxa represented in samples by at least 24 individuals and the historical intensity of fishing at each of 66 research sites. "Early" fishing is 1988–91, "Intermediate" fishing is 1991–94, and "Recent" fishing is 1994–97**

| | Fishing pressure | | |
	Early	Intermediate	Recent
Negative correlations	25	22	14
No correlation	12	17	27
Positive correlations	10	8	6

$$\chi^2_4 = 10.43$$
$$p = 0.03$$

The size distribution of invertebrate bycatch has not been determined (although many of the specimens have been retained and such measurements could be considered for the fu...re if there were to be a need). However, the total weight and total number of animals retained were recorded for each of the 40 stations covered by *Kaharoa* in 1998, and these data can be used to estimate the mean weight of individuals of each taxon at each site. Again, it is possible that the size of animals could vary with depth (as it does for scampi), so partial correlation coefficients between the three indices of fishing pressure and mean weight (excluding the effects of depth) were calculated for each of the 38 taxa represented in (arbitrarily) 10 or more samples (Table 30). Significant relationships between fishing pressure and average size of animals were much rarer than significant relationships between fishing pressure and abundance, and correlations tended to occur mostly with recent fishing pressure. The taxa for which significant negative partial correlations with the index of recent fishing pressure (excluding the effects of depth) are *Sepioloidea* sp. nov. (a small squid intimately associated with sea pens), *Heteromolpadia marenzelleri* (a holothurian), *Iredalina mirabilis* (a gastropod mollusc), and *Phormosoma bursarium* (a sea urchin). Thrush *et al.* (1998) observed a decrease in the average size of the infaunal urchin *Echinocardium cordatum* (= *E. australe* of Thrush *et al.* 1998) along a putative gradient of increasing fishing pressure.

In summary, spatially explicit indices of scampi fishing pressure have been estimated for the years 1988–91, 1991–94, and 1994–97 using commercial fishing returns containing shot by shot information. These indices are negatively correlated (after excluding the effects of depth and, where possible, latitude) with invertebrate species richness and diversity, with the abundance of a variety of invertebrate taxa, and with the average size of a small number of invertebrate taxa. Correlations with diversity and abundance are strongest for the early index of fishing pressure, while correlations with size are strongest for the recent index of fishing pressure. Continental slope benthic community structure, 200–600 m (as inferred from the bycatch of research scampi trawling), appears to be predictable, given information on depth, fishing pressure and, to a lesser extent, latitude.

Table 29: **Number of individuals enumerated from samples, and the results of t tests for the difference from zero of partial correlation coefficients (excluding the effect of depth) between the abundance of each taxon and indices of early, middle and recent fishing pressure. Nominal significance levels are indicated by p: *** = <0.001; ** = <0.01; * = <0.05. Taxa are sorted in order of increasing average value for t. Only taxa where a total of 24 individuals were enumerated from samples are included**

Taxon	N	Early	p	Middle	p	Recent	p
Campylonotus rathbunae	141	-5.7005	***	-4.7161	***	-3.0839	**
Diacanthurus rubricatus	150	-4.0108	***	-4.2117	***	-4.1192	***
Alcithoe lutea	47	-4.5561	***	-4.0007	***	-2.7317	**
Ogmocidaris benhami	1 896	-3.4974	***	-3.3794	***	-2.3816	*
Gorgonocephalus dolichodactylus	74	-3.5458	***	-3.2131	**	-2.4268	*
Psilaster acuminatus	1 948	-2.8997	**	-3.0982	**	-2.8567	**
Calliostoma turnerarum	23	-3.1329	**	-3.0947	**	-2.5262	*
Suberites sp.	29	-3.0633	**	-3.0758	**	-2.5660	*
Iredalina mirabilis	31	-3.3993	***	-3.0185	**	-2.1157	*
Laetmogone sp.	271	-3.0215	**	-2.8064	**	-2.0621	*
Paromola petterdi	81	-2.8257	**	-2.6351	**	-2.0548	*
Nototodarus gouldi	74	-2.5081	*	-2.5137	*	-2.3862	*
Phormosoma bursarium	428	-2.8729	**	-2.5264	*	-1.7058	
Heteromolpadia marenzelleri	131	-3.0615	**	-2.4949	*	-1.5168	
Paguristes barbatus	167	-2.6675	**	-2.4707	*	-1.9122	
Ibacus alticrenatus	29 577	-3.0203	**	-2.3589	*	-1.3930	
Alcithoe larochei	612	-2.3192	*	-2.2618	*	-2.1707	*
Trichopeltarion fantasticum	40	-2.5369	*	-2.3141	*	-1.7799	
Penion dilatatus	32	-2.6626	**	-2.3246	*	-1.5783	
Actinaria sp. 3	25	-2.4573	*	-2.3392	*	-1.7643	
Amalda mucronata	33	-1.6790		-2.1364	*	-2.1713	*
Pseudarchaster garricki	546	-2.0820	*	-1.9389		-1.6011	
Hormathia lacunifera	669	-1.7964		-1.8646		-1.7411	
Uroptychus sp.	170	-2.0524	*	-1.7855		-1.4597	
Propagurus deprofundis	28	-2.0490	*	-1.7943		-1.2874	
Actinaria sp. 7	79	-2.5389	*	-2.0888	*	-0.3874	
Austrofusus glans	44	-1.3135	·	-1.5481		-1.6839	
Plesionika martia	691	-2.2522	*	-1.9012		-0.1156	
Ophiomyxa brevirima	537	-1.4288		-1.3336		-1.2582	
Euciroa galatheae	67	-1.0847		-1.0964		-1.0008	
Sergestes sp.	40	-1.2607		-0.9837		-0.5211	
Notopandalus magnoculus	398	-1.3661		-0.8189		0.0119	
Leptomithrax australis	35	-0.1262		-0.2087		-0.3696	
Aphrodita talpa	44	1.4451		0.9137		0.5641	
Sepioloidea sp. nov.	29	1.0539		1.2741		1.2315	
Carcinoplax victoriensis	54	1.0007		1.1088		1.5164	
Aristaeomorpha foliacea	3 610	2.0202	*	1.7130		0.7577	
Octopus kaharoa	68	1.3906		1.7698		1.8651	
Semicassis pyrum	33	2.1969	*	1.7197		1.4366	
Malluvium calcareus	39	2.1520	*	3.0843	**	2.5222	*
Tetillid sponge	36	3.6865	***	2.8814	**	1.3674	
Actinaria sp. 2	45	3.6451	***	3.2877	**	2.0056	*
Anthoptilum murrayi	42	4.3156	***	3.2325	**	1.6375	
Luidia neozelanica	44	4.4208	***	3.3190	**	2.7898	**
Munida gracilis	210	2.5519	*	3.0867	**	6.2956	***
Haliporoides sibogae	1 998	2.3006	*	3.5089	***	7.7889	***
Metanephrops challengeri	70 291	11.3338	***	11.1332	***	4.7972	***

Table 30: Results of t tests for the difference from zero of partial correlation coefficients (excluding the effect of depth) between the mean weight of individuals of each taxon and indices of early, middle and recent fishing pressure. Nominal significance levels are indicated by p: *** = <0.001; ** = <0.01; * = <0.05. Taxa are sorted in order of increasing value for t for the index of recent fishing. Only taxa taken at 10 sites or more are included

Taxon	Early	p	Middle	p	Recent	p
Sepioloidea sp. nov.	-1.230		-4.392	***	-5.488	***
Heteromolpadia marenzelleri	-2.386	*	-2.344	*	-3.321	**
Iredalina mirabilis	-0.917		-0.591		-2.053	*
Phormosoma bursarium	-1.362		-1.236		-2.044	*
Gorgonocephalus dolichodactylus	0.390		-0.704		-1.471	
Actinaria sp. 3	-0.126		-0.514		-1.376	
Aphrodita talpa	-1.960		-1.142		-1.284	
Alcithoe lutea	-1.068		0.522		-1.211	
Paguristes barbatus	-0.562		-0.142		-1.206	
Ranella olearium	0.973		-0.219		-0.998	
Diacanthurus rubricatus	-0.370		-0.358		-0.978	
Nototodarus gouldi	-0.774		-1.134		-0.846	
Aristaeomorpha foliacea	-1.086		-1.203		-0.803	
Semicassis pyrum	-0.068		-0.122		-0.790	
Propagurus deprofundis	1.217		1.070		-0.789	
Notopandalus magnoculus	-0.758		-1.014		-0.677	
Actinaria sp. 7	-0.317		0.026		-0.660	
Suberites sp.	-0.637		-1.102		-0.584	
Plesionika martia	0.539		-0.893		-0.535	
Haliporoides sibogae	-1.246		-0.231		-0.367	
Hormathia lacunifera	-0.870		-0.381		-0.352	
Laetmogone sp.	0.207		0.659		-0.249	
Metanephrops challengeri	-0.668		0.269		-0.161	
Uroptychus sp.	-0.037		0.321		-0.123	
Trichopeltarion fantasticum	-2.158	*	-1.914		-0.102	
Calliostoma turnerarum	0.248		0.215		-0.088	
Munida gracilis	-0.372		-0.406		-0.057	
Ogmocidaris benhami	0.260		0.069		0.021	
Penion dilatatus	-1.811		-0.038		0.037	
Campylonotus rathbunae	-0.704		-1.674		0.037	
Mediaster sladeni	0.201		0.295		0.091	
Pseudarchaster garricki	0.167		-0.903		0.210	
Ophiomyxa brevirima	-0.522		0.509		0.324	
Paromola petterdi	0.052		-0.809		0.454	
Psilaster accuminatus	1.136		0.946		0.701	
Octopus kaharoa	-0.841		0.025		0.784	
Alcithoe larochei	0.337		1.104		1.241	
Carcinoplax victoriensis	2.987	***	1.532		1.802	

This group of analyses is based on the results of three recent research voyages using research trawl gear. It does not demonstrate unequivocally that there have been changes in the composition of the invertebrate bycatch of commercial scampi trawlers or that benthic community structure has necessarily changed in response to fishing. However, in the absence of a time series of reliable data from the commercial fleet and more quantitative data on benthic community structure, this approach is considered to be the best available surrogate for a temporal analysis of change.

Given that scampi trawl gear is probably not the most appropriate gear for sampling benthic community structure, it is perhaps surprising that the apparent relationship between fishing history and invertebrate composition is so clear, suggesting that there are major differences among the sites examined. The nature of the relationship permits three general types of inference: benthic community structure has been modified by fishing, or scampi fishing has been conducted preferentially (especially in the early years of the fishery) in areas of particular community structure and consequent bycatch composition, or scampi, being a vigorous burrowing species as well as the target of the fishery, dominates and modifies the benthic environment and community in a manner similar to other disturbances (e.g., Murphy 1985, Posey 1986, Posey et al. 1991). The information available to judge which of these general hypotheses is the most likely to be true is limited, and such an analysis is outside the scope of this project. The types of relationships found between fishing pressure and benthic community structure are, however, consistent with the predicted and actual effects of fishing worldwide (Dayton et al. 1995, Thrush et al. 1998). The results of this study could be used to assist in the design of further work to examine the issue.

3.3 Recreational and Maori customary fisheries

There is no quantitative information on the level of recreational or Maori customary take, but both are probably non-existent.

3.4 Other sources of fishing mortality

Other sources of fishing mortality could include illegal catch, mortality of discarded scampi (this is currently a non-QMS fishery and discarding is legal, although unusual), and incidental mortality associated with trawling. There is no quantitative information on the level of such other sources of mortality other than a single experimental estimate of the mortality of trawl-caught scampi reported by Cryer & Stotter (1997). The estimated mortality of 40% over 6 days for lively, undamaged animals (considered suitable for tagging) could be used as a minimum estimate of the mortality rate of discards. In the commercial fishery, discarded scampi are probably damaged or very soft, so a survival rate of 60% is probably very optimistic.

4. Research

4.1 Stock structure

The stock structure of scampi in New Zealand waters is not well known. Preliminary electrophoretic analyses showed substantial genetic heterogeneity in samples collected in QMAs 1, 2, 4, and 6A (P. Smith, NIWA Wellington, *pers. comm.*). Most of this variation stemmed from differences between scampi from QMA 6A and those from other areas, but there was some evidence of differences elsewhere. The abbreviated larval phase (Wear 1976) and lack of large scale migration (Cryer & Stotter, in press) of this species may lead to low rates of gene mixing. Size at maturity varies between areas, and other differences among QMAs, such as depth distribution, diel changes in catchability, and catch to bycatch ratios, also suggest that treatment as separate management units is appropriate.

4.2 Resource surveys

Fully scaled length frequency distributions and sex ratios from trawl surveys in QMAs 1 and 2 were presented by Cryer (1997). Further fully scaled information is available from gear selectivity in April 1996 (MFish project SHSP05, voyage KAH9604), and tagging and its associated trawling activities to estimate growth in September and October 1995 and 1996 (Cryer & Stotter 1997, in press; MFish project SHSP08, voyages KAH9511, DRY9601, and DRY9602). Unscaled length frequency distributions are available from commercial voyages where scientific observers were carried (*see* Figures 7–11). During the 1997–98 year, trawling and photographic studies were carried out at 40 stations in the Bay of Plenty (Cryer & Hartill 1998).

4.3 Other studies

4.3.1 Estimates of growth rate and natural mortality

4.3.1.1 Tagging studies in QMA 1

The growth rate of scampi was estimated by tagging in the Bay of Plenty 1995–96. Tagged animals were released in late September 1995 (voyage KAH9511, Cryer & Stotter 1997), and target fishing to recapture these animals was conducted in September and October 1996 (voyages DRY9601 and DRY9602 Cryer & Stotter, in press). Despite considerable target fishing in the area of release, a large proportion of returns was provided by industry from recaptures made during normal fishing activities. It is fortunate that most such returns came in the last few weeks of the fishing year when the tagged animals had been at liberty for close to the 12 months ideal. Unfortunately, only females were recaptured in sufficient numbers to estimate the parameters of a von Bertalanffy growth model with any certainty, leading to parameter estimates of $K = 0.11$–0.14 yr^{-1} and $L_\infty = 48$–49 mm OCL. Given that the growth rate of females of the related *Nephrops norvegicus* slows after maturity (at about 30 mm OCL), and that almost all of the tagged animals recovered were mature, the tagging estimate of growth rate may be negatively biased for females. In addition, males may grow more quickly than females. However, using published relationships (e.g., Pauly 1980, Charnov *et al.* 1993), M can be predicted from K, albeit with poor precision. The estimate of M for

female scampi in the Bay of Plenty at 400 m depth was $M = 0.20–0.25$ with a *c.v.* of over 30%.

4.3.1.2 Length frequency analysis

Length frequency analysis can be conducted for all scampi fishery areas where sufficient length frequency distributions have been collected. Data are available from trawl surveys, other research trawling (for tagging and mesh selectivity studies), and from scientific observers. The long-established fisheries in QMAs 1 and 2 have the most comprehensive data, despite low levels of coverage by scientific observers at times.

Length frequency analyses using MULTIFAN software (Fournier *et al.* 1990) have been condu :ted using data from the Aldermen Islands in QMA 1 (380–415 m depth), and from the Napier–Wairarapa area (320–360 m depth) in QMA 2. For QMA 1, data from scientific observers and research voyages were combined and analysed in their entirety, then a subset of "research only" data from 1995–97 was analysed separately. For QMA 2, the combined observer and research data were analysed first, followed by a "research only" subset from 1993–95. The tagging study reported by Cryer & Stotter (1997) was conducted in the same part of QMA 1 as that selected for multiple length frequency analysis, so the two methods can be compared with one another.

All MULTIFAN analyses were conducted in the same manner. Length frequency data were entered and analysed with a grouping of 1 mm, using 46 length classes from 20 to 65 mm OCL (very few scampi larger or smaller than these extremes have been measured). Models were fitted for each sex in each area, using starting values for the von Bertalanffy K of 0.025, 0.050, 0.075, 0.100, 0.125, 0.150, 0.175, 0.020, 0.025, and 0.030, and 3, 5, 7, 9, 12, and 15 age classes. Four separate model variants were examined in each case: a simple model assuming a constant cohort standard deviation and no seasonal variation in growth, a model including a cohort standard deviation which was allowed to vary in a linear manner with age, a model including two parameter (phase and amplitude) sinusoidal variation in growth within years, and a model including both the variable cohort standard deviation and seasonal growth. Systematic searches were conducted for each of the model variants first, followed by the fitting of K. The best fitting model for each analysis was selected using the "SIGTEST" module. Full details of the MULTIFAN method can be found in Fournier *et al.* (1990, 1991).

In almost all cases, the maximum possible number of age classes and a relatively low value for the von Bertalanffy K (less than 0.10) were selected by MULTIFAN as the best fitting model (Table 31). Estimates of L_∞ were often unrealistically large (70–90 mm OCL), considering the maximum observed size in QMAs 1 and 2 (about 65 and 55 mm for males and females, respectively). Because K and L_∞ are usually very highly correlated (r > 0.95), an overestimate of L_∞ usually implies an underestimate of K. The standard deviation describing the average cohort width varied between 1.2 and 2.1 mm, implying that a range of 2.4–4.2 mm would contain 95% of the length measurements for scampi of a given age in most models. The model variants including a variable cohort width and seasonal variation in growth were selected over simpler models in only about half of cases. Where a model incorporating a trend in cohort width was selected, the standard deviation describing the cohort width sometimes exceeded 2 mm.

Table 31: Summary of results from multiple length frequency analyses (using "MULTIFAN") for scampi in QMA 1 (Aldermen Islands, 380–415 m depth) and QMA 2 (Napier and Wairarapa fisheries, 320–360 m depth). N is the number of length frequency samples used (each of at least 300 individuals), "Ages" is the number of age classes in the best fitting model (15 being the maximum allowed by MULTIFAN), K and L_∞ are the best fitting parameters for the von Bertalanffy model, "Av. SD" is the average cohort width, "SD" and "SSN" indicate whether the best fitting model incorporates parameters for variable cohort width and seasonality, respectively, and "Penalty" and "Gradient" are measures of the quality of the model fit (with values of more than about 10 and about 0.5, respectively, usually being considered as "suspect"). Standard errors for K, L_∞ and the cohort width are given below the estimates

QMA	Sex	Data	N	Ages	K	L_∞	Av. SD	SD	SSN	Penalty	Gradient
1	M	All	12	15	0.080 ±0.010	72.6 ±0.3	1.174 ±0.012	N	Y	20.867	0.0003
1	M	95–97	7	12	0.054 ±0.002	92.5 ±1.9	1.316 ±0.018	N	N	18.462	0.0005
1	F	All	12	15	0.045 ±0.002	97.1 ±2.9	1.243 ±0.029	Y	Y	22.556	0.0009
1	F	95–97	7	7	0.072 ±0.016	80.5 ±6.8	2.074 ±0.017	Y	Y	0.376	0.0001
2	M	All	12	15	0.045 ±0.003	95.9 ±3.3	1.953 ±0.029	Y	Y	19.252	0.0008
2	M	93–95	3	15	0.084 ±0.075	64.5 ±0.7	1.548 ±0.032	Y	N	0.064	0.0004
2	F	All	12	15	0.038 ±0.002	93.3 ±1.8	1.281 ±0.017	Y	N	20.119	0.0002
2	F	93–95	3	15	0.053 ±0.007	71.6 ±1.8	1.393 ±0.008	N	N	0.024	0.0009

Few of the von Bertalanffy parameters generated by MULTIFAN using research and/or observer length frequency distributions are, prima facie, consistent with what is known of this species. Most of the estimates of L_∞ were unrealistically large, and this strongly suggests that the estimate of K will be, on the average, negatively biased. This interpretation is broadly supported by the results of the tagging study off the Aldermen Islands which suggested that K for female scampi was probably in the range 0.10–0.15 (although this estimate too may be negatively biased because it was estimated using returns from mature scampi only, and growth of the related *Nephrops norvegicus* is known to slow markedly at maturity, especially in females, e.g., Anon.1995). The von Bertalanffy curves generated using multiple length frequency analysis for scampi of both sexes in QMA 1 (380–420 m depth) suggest annual increments of the order of 2.0–4.0 mm for relatively large, mature animals, whereas the observed range was -1.0–4.0, with most observations falling below 2.5 mm (Figure 37). However, although detailed comparison of the estimates of K and L_∞ with existing data suggest that the MULTIFAN estimates may be aberrant, the overall results produced by length frequency and tagging suggest that the growth of this species is relatively slow, it has a great longevity (in the order of 25 years), and its general productivity is low.
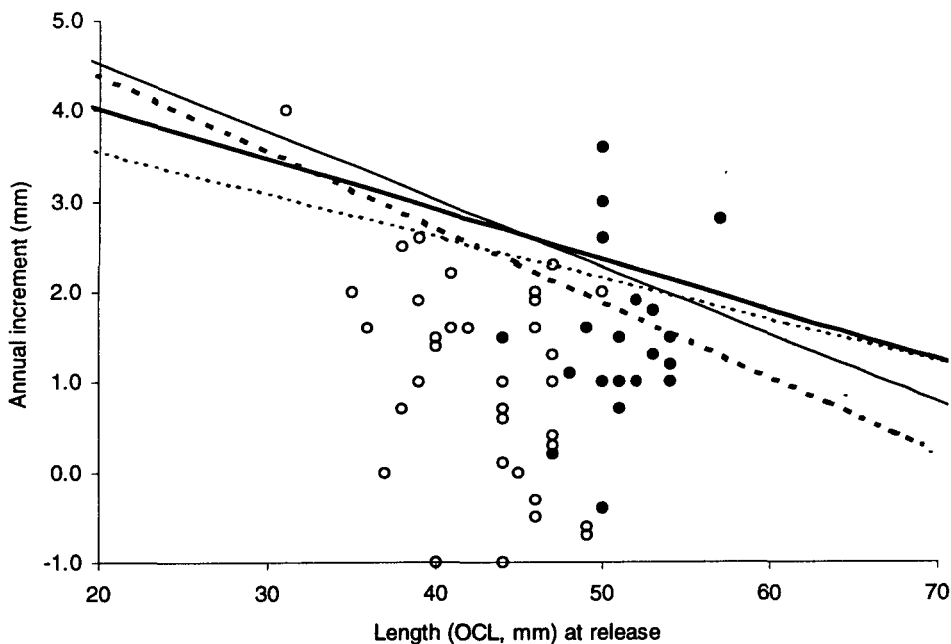
Figure 37: **Comparison of the expected annual increment for scampi generated by length frequency analysis (lines) and tagging (dots). Solid lines, research length frequency only; dashed lines, observer data included. Heavy lines, males; normal lines, females. Solid circles, tagged males; open circles, tagged females.**

4.3.2 Work for the 1998–99 year

Work tendered for the 1998–99 fishing year includes an update of all CPUE analyses (where additional fishing has taken place), and a fuller examination of changes in bycatch composition and length frequency with fishery development.

4.4 Biomass estimates

4.4.1 Trawl surveys

No new trawl survey estimates of relative biomass are available. Relative estimates from trawl surveys in QMAs 1 and 2 between 1993 and 1995 are presented in Table 32, and described in detail in Cryer *et al.* (1997).

4.4.2 Comparison of trawl and photographic estimates of scampi abundance

Inter-annual changes in catchability appear to militate against the suitability of trawl survey or CPUE indices of abundance for scampi in New Zealand waters (Cryer *et al.* 1997). Without an index of biomass, modelling and yield assessment will continue to be problematic.

European work on *Nephrops norvegicus* has shown that photographic and video methods can give realistic estimates of biomass for that species (Tuck *et al.* 1997), prompting an experimental photographic survey in the Bay of Plenty (QMA 1) in early 1998 (Cryer & Hartill 1998). The survey covered historical trawl survey strata between Red Mercury and White Islands, 200–600 m depth. Forty stations were occupied, first by trawl (3 mile shots), then using a still camera system with flash. About 40 photographs were taken at each site, nominally 10 each on each of 4 transects distributed approximately evenly along the trawl track. The densities of putative *M. challengeri* burrow entrances (and the range of densities by strata) observed in photographs (Table 33) were very similar to densities observed overseas for *Nephrops norvegicus*.

Table 32. Relative biomass estimates (t) for QMA 1 (top: strata from Great Barrier Island to White Island included) and QMA 2 (bottom: strata from Mahia Peninsula to Castle Point included) estimated from *Kaharoa* trawl surveys

	Kaharoa voyage		
	KAH9301	KAH9401	KAH9501
QMA 1			
Biomass estimate:	222.7	275.7	337.8
Standard error:	22.6	39.6	45.9
c.v. (%)	10.1	14.4	13.6
Index relative to KAH9301	1.00	1.24	1.52
QMA 2			
Biomass estimate:	166.5	125.5	154.4
Standard error:	22.1	19.9	25.9
c.v. (%)	13.3	15.9	16.8
Index relative to KAH9301	1.00	0.75	0.93

Table 33: The mean density, standard deviation of mean density, and estimated number of burrow entrances and discrete burrows in each of the sampled strata. The estimate of burrows is known to be positively biased by edge effects. There were five replicate sites within each stratum, and an average of 40 photographs was taken at each site

Stratum	Area (km^2)	Entrances Density (m^{-2})	SD	Estimated number	Burrows Density (m^{-2})	SD	Estimated number
301	315	0.0691	0.0444	21 761 157	0.0382	0.0232	12 022 268
302	262	0.4526	0.2366	118 589 319	0.2484	0.1389	65 070 518
303	266	0.6646	0.3400	176 796 429	0.3493	0.1863	92 901 771
304	209	0.3980	0.1918	83 176 812	0.2049	0.0821	42 819 416
401	237	0.1902	0.1017	45 068 781	0.1122	0.0615	26 585 248
402	378	0.4967	0.1378	187 739 309	0.2732	0.0753	103 265 858
403	290	0.4236	0.1756	122 853 679	0.2151	0.0929	62 376 056
404	420	0.3015	0.2716	126 648 953	0.1497	0.1187	62 856 823
Total	2377	0.3713	0.0340	882 634 439	0.1968	0.0172	467 897 958

Photographic estimates of scampi abundance can be made in several ways, but all are higher than estimates made by trawl (Table 34). If only those scampi visible in photographs and

walking free of all burrows are used to estimate abundance in the survey area, then trawl catch rates are about one-third of the visual estimates. If all scampi visible in photographs are used, then trawl catch rates are about 6% of the visual estimates. If the best estimate of scampi abundance from burrow entrances in photographs is used, then trawl catch rates are less than 1% of the visual estimates. These estimates were treated more fully by Cryer & Hartill (1998).

Table 34: Survey estimates of mean density (m^{-2} or, for trawl methods, kg m^{-2}), its standard deviation and coefficient of variation (c.v.) for various methods of estimation. Methods as follows: "Burrow entrances" = density of burrows estimated by assuming 2.5 entrances per burrow, "Burrows" = a direct (positively biased) estimate of burrow density, "Scampi at entrance" = density of scampi visible but partly obscured by a burrow, "Scampi exposed" = density of scampi entirely visible, "All scampi visible" = total density of visible scampi, "Trawl survey" = standard trawl survey method using catch weight at each station

Method	Mean density (m^{-2})	SD density (m^{-2})	c.v.	Estimated numerical abundance (*10^{-6})
Burrow entrances	0 3713	0.0340	0.092	353.0
Burrows	0.1968	0.0172	0.087	467.9
Scampi at entrance	0.0117	0.0017	0.145	27.9
Scampi exposed	0.0027	0.0007	0.259	6.4
All scampi visible	0.0144	0.0020	0.141	34.3
Trawl survey	0.0009	0.0002	0.195	2.2

The results from this camera survey have been used to estimate the minimum absolute abundance of scampi from direct observations of emergent animals (Table 35). This analysis suggests that there were at least 34 million animals in the survey area between Cuvier Island and White Island in early 1998. Using a photographic estimate of mean weight (35 g, Cryer & Hartill 1998), it can be estimated that the minimum absolute biomass in this area is about 1200 t.

Table 35: The mean density, standard deviation of mean density, and estimated number of individual visible scampi in each of the sampled strata. There were 5 replicate sites within each stratum, and an average of 40 photographs was taken at each site. The total estimated abundance by this method can be considered as a minimum estimate of absolute abundance in the survey area

Stratum	Density (m^{-2})	SD	c.v.	Estimated abundance
301	0.0007	0.0010	0.62	215 421
302	0.0159	0.0106	0.30	4 162 768
303	0.0362	0.0196	0.24	9 638 360
304	0.0114	0.0086	0.34	2 373 991
401	0.0041	0.0046	0.50	963 105
402	0.0308	0.0200	0.29	11 654 909
403	0.0144	0.0148	0.46	4 164 508
404	0.0027	0.0027	0.44	1 148 174
Total	0.0144	0.0020	0.14	34 321 236

Given assumed values for the number of entrances per burrow and the average occupancy rate (from Cryer & Hartill 1998, also Figure 38), the total absolute abundance of scampi can be estimated from the density of their burrows, Table 36). These estimates of abundance were converted to estimates of absolute biomass using estimates of average weight derived from parallel trawling (60 g) and from photographic measurements (35 g). The former is known to be positively biased by the selectivity of trawl gear, and the latter may be positively biased by changes in the emergence behaviour of scampi of increasing size (Cryer & Hartill 1998).

Table 36: **Estimated total biomass (t) of scampi in the area between Cuvier and White Island, 200–600 m depth, from the 1998 photographic survey. Assumed numbers of entrances per burrow and burrow occupancy rates are used in conjunction with estimates of mean weight from a parallel trawl survey (60.45 g) and from photographic measurements (35.44 g)**

						Biomass (t)
	Trawl wt.	60.45 g		Photo wt.	35.44 g
No. of entrances:	2.0	2.5	3.0	2.0	2.5	3.0
Occupancy:						
75%	20 008	16 006	13 339	11 717	9 384	7 820
90%	24 010	19 207	16 007	14 060	11 261	9 384
100%	26 678	21 342	17 785	15 640	12 512	10 426
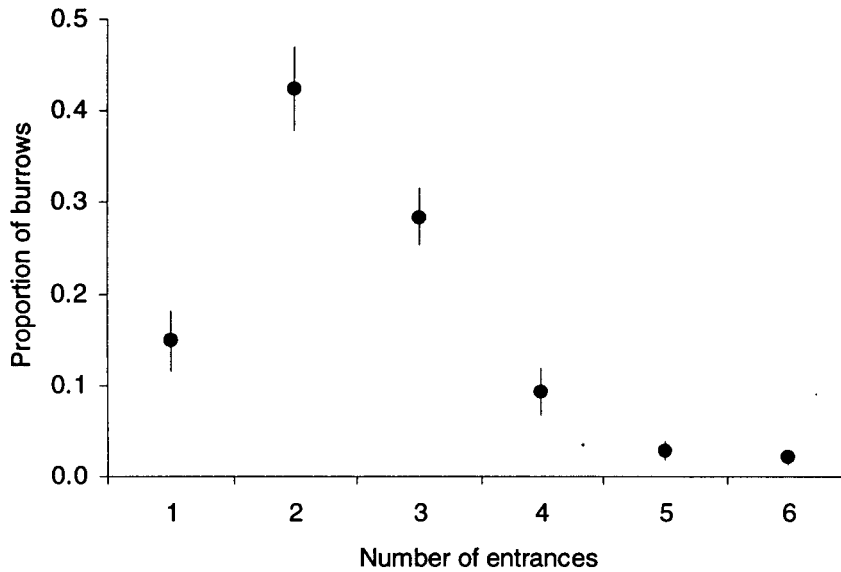
Figure 38: **The mean proportion (from nine European "burrow mapping" studies on *Nephrops norvegicus* cited by Cryer & Hartill 1998) of scampi burrows having increasing number of entrances. Error bars represent plus or minus one standard error of each mean proportion. The overall average is 2.5 entrances per burrow.**

4.5 Yield estimates

4.5.1 Estimation of MCY

MCY cannot be estimated for any scampi stock because there are no reliable estimates of biomass for any QMA, and catches have been constrained by catch limits since 1991–92.

4.5.2 Estimation of CAY

CAY cannot be estimated for any scampi stock because there are no estimates of current biomass for any QMA other than the small section of QMA 1 where the experimental photographic survey was undertaken in 1998.

4.5.3 Other yield estimates

The minimum estimate of abundance and absolute biomass for that part of QMA 1 which was surveyed photographically can be used to estimate the lower bound of MCY and CAY for that portion of the QMA. MCY can be estimated using methods 1 and 2 (Annala *et al.* 1998), method 1 giving the more conservative estimate. Both estimates are inherently conservative because of the assumption that emergence of scampi at the time of the photographic survey was 100% (i.e., all scampi were visible).

$$MCY = 0.25 * F_{0.1} * B_0 \qquad \text{or}$$
$$MCY = 0.50 * F_{0.1} * B_{av}$$

There is no estimate of $F_{0.1}$ for any scampi stock, but Cryer & Stotter (in press) estimated M for female scampi in this area as 0.20–0.25 (with a *c.v.* of about 30%), and this can be used as a surrogate for $F_{0.1}$ (Annala *et al.* 1998).

$$MCY = 0.25 * (0.20\text{–}0.25) * 1200 \, t = 60\text{–}75 \, t \qquad \text{or}$$
$$MCY = 0.50 * (0.20\text{–}0.25) * 1200 \, t = 120\text{–}150 \, t$$

CAY can be estimated using the full version of the Baranov catch equation (from Annala *et al.* 1998) as fishing is carried on year round, or with no particular seasonality.

$$CAY = \frac{F_{ref}}{F_{ref} + M}\left(1 - e^{-\left(F_{ref} + M\right)}\right)B_{beg}$$

Again, there is no estimate of F_{ref} for any scampi stock, but Cryer & Stotter (in press) estimated M for female scampi in this area as 0.20–0.25 (with a *c.v.* of about 30%), and this can be used as a surrogate for F_{ref} (Annala *et al.* 1998).

$$CAY = 0.50 * 0.330 * 1200\ t = 198\ t \qquad \text{or}$$
$$CAY = 0.50 * 0.393 * 1200\ t = 236\ t$$

All of these minimum estimates of yield have an associated *c.v.* of at least 30% (that associated with the estimate of M for female scampi) and relate only to the area between Cuvier and White Islands, 200–600 m depth.

Because the extent of bias in the estimates of population average weight (as opposed to the average weight of visible scampi) from the photographic survey has not been estimated, no estimates of the probable yield from the survey area in QMA 1 are given.

5.   Management Implications

There are no reliable estimates of biomass and yield for any QMA, but CPUE analyses developed here and length frequency distributions collected to date (e.g., Cryer 1997) do not suggest serious problems in any scampi stock. Length frequency analyses and tagging studies both suggest that the productivity of this species is relatively low, however, with estimates of the von Bertalanffy K being of the order 0.05–0.15, and M being of the order 0.20.

Tentative estimates of abundance, biomass, and yield for a portion of QMA 1 suggest that recent landings and catch limits from this area are not likely to lead to rapid reductions in biomass in the short to medium term. Further work is required to confirm this tentative view, and to extend this analysis to other areas. For most scampi stocks, CPUE has risen over the past few years, markedly in some instances. The index for QMA 6A declined to a level of just over one-quarter of the index year in 1994–95, but appears to have increased in the past 2 years to a little over one-third of the index year. It is, however, not known whether CPUE is a good index of stock size, and there are reasons to suspect that CPUE indices (whether commercial or trawl survey) may be sensitive to changes in catchability. It may be that changes in the catchability of one or both sexes are responsible for the observed changes in CPUE indices.

There are indications in the analyses of the invertebrate bycatch of research trawling for scampi (though not, at this stage, in our preliminary analysis of finfish bycatch) that benthic community structure may have been modified by scampi trawling during the 10 year history of this fishery in the Bay of Plenty. The observed differences in community structure among sites with wide contrast in their histories of scampi trawling are consistent with the predicted and observed effects of bottom contact fisheries worldwide, and so are not necessarily cause for surprise or concern. However, given the possibility that such modifications have occurred (and there are several alternative hypotheses which might be explored), then the possible implications for associated or dependent species (*sensu* Fisheries Act 1996), for local and regional biodiversity, and for fishery recruitment should probably be explored.

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6. Acknowledgments

7. References

Annala, J.H., Sullivan, K.J., O'Brien, C.J., & Iball, S.D. (Comps.) 1998: Report from the Fishery Assessment Plenary, May 1998: stock assessments and yield estimates. 409 p. Unpublished report held in NIWA library, Wellington. Ministry of Fisheries, May 1998.

Anon. 1995: Report of the working group on *Nephrops* stocks. International Council for the Exploration of the Sea meeting, Lowestoft, 1995. *CM 1995/Assess:12.*

Ballara, S.L., Cordue, P.L., & Livingston, M.E. 1997: A review of the 1994–95 hoki fishery and assessment of hoki stocks for 1996. N.Z. Fisheries Assessment Research Document 97/10. 44 p.

Bray, J.R. & Curtis, J.T. 1957: An ordination of the upland forest communities of southern Wisconsin. *Ecological Monographs 27*: 325–349.

Chapman, M.G. & Underwood, A.J. 1998: Inconsistency and variation in the development of rocky intertidal algal assemblages. *Journal of Experimental Marine Biology and Ecology 224*: 265–289.

Charnov, E. L., Berrigan, D., & Shine, R. 1993: The M/k ratio is the same for fish and reptiles. *American Naturalist 142*: 707–711.

Clark, K.R. & Ainsworth, M. 1993: A method of linking multivariate community structures to environmental variables. *Marine Ecology Progress Series 92*: 205–219.

Clark, K.R. & Warwick, R.M. 1994: Change in marine communities: an approach to statistical analysis and interpretation. Natural Environment Research Council, Plymouth. 144 p.

Cryer, M. 1996: Scampi stock assessment for 1996. N.Z. Fisheries Assessment Research Document 96/10. 25 p.

Cryer, M., Doonan, I., Coburn, R. & Hartill, B. 1998. Scampi stock assessment for 1997. N.Z. Fisheries Assessment Research Document 98/28. 78 p.

Cryer, M. & Hartill, B. 1998. Final research report to MFish on experimental comparison of photographic and trawl methods of estimating scampi biomass in QMA 1. Unpublished report, copy held at NIWA, Auckland. 23 p.

Cryer, M. & Stotter, D.J. 1997: Trawling and tagging of scampi off the Alderman Islands, western Bay of Plenty, September 1995 (KAH9511). *N.Z. Fisheries Data Report No. 84.* 26 p.

Cryer, M. & Stotter, D.J. in press: Movement and growth rates of scampi inferred from tagging, Alderman Islands, western Bay of Plenty. *NIWA Technical Report.*

Cryer, M., Vignaux, M., & Gilbert, D.J. 1995: Scampi stock assessment for 1995. Working document for MAF Fisheries Shellfish Stock Assessment Working Group (currently draft N.Z. Fisheries Assessment Research Document).

Dayton, P.K., Thrush, S.F., Agardy, M.T., & Hofman, R.J. 1995: Environmental effects of fishing. *Aquatic Conservation: Marine and Freshwater Ecosystems 5*: 205–232.

Fournier, D.A., Sibert, J., Majkowski, J., & Hampton, J. 1990: MULTIFAN, a likelihood-based method for estimating growth parameters and age composition for multiple length frequency data sets illustrated using data for southern bluefin tuna (*Thunnus maccoyi*). *Canadian Journal of Fisheries and Aquatic Sciences 47*: 301–317.

Fournier, D.A., Sibert, J. & Terciero, J. 1991: Analysis of length frequency samples with relative abundance data for the Gulf of Maine northern shrimp (*Pandalus borealis*) by the MULTIFAN method. *Canadian Journal of Fisheries and Aquatic Sciences 48*: 591–598.

Grove, S.L. & Probert, P.K. 1998: Bycatch of megabenthic invertebrates from bathyal trawl fisheries off southern and eastern New Zealand. *NIWA Technical Report 13*. 28 p.

Kruskal, J.B. & Wish, M. 1978: Multidimensional Scaling. Sage Publications, Beverley Hills, CA, USA.

Murphy, R.C. 1985: Factors affecting the distribution of the introduced bivalve, *Mercenaria mercenaria*, in a California lagoon — the importance of bioturbation. *Journal of Marine Research 43*: 673–692.

Pauly, D. 1980: On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *Journal du Conseil international pour L'exploration de la Mer 39*: 175–192.

Posey, M.H. 1986: The effects upon the macrofaunal community of a dominant burrowing deposit feeder, *Callianassa californiensis*, and the role of predation in determining its intertidal distribution. Abstract only, in *Dissertation Abstracts International, Part B: Science & Engineering 46*.

Posey, M.H., Dumbauld, B.R. & Armstrong, D.A. 1991: Effects of a burrowing mud shrimp, *Upogebia pugettensis* (Dana), on abundances of macro-infauna. *Journal of Experimental Marine Biology and Ecology 148*: 283–294.

Spence, I. 1979: A simple approximation for random ranking stress values. *Multivariate Behavioural Research 14*: 355–365.

Thrush, S.F., Hewett, J.E., Cummings, V.J., & Dayton, P.K. 1995: The impact of habitat disturbance by scallop dredging on marine benthic communities: what can be predicted from the results of experiments? *Marine Ecology Progress Series 129*: 141–150.

Thrush, S.F., Hewett, J.E., Cummings, V.J., Dayton, P.K., Cryer, M., Turner, S.J., Funnell, G.A., Budd, R.G., Milburn, C.J., & Wilkinson, M.R. 1998: Disturbance of the marine benthic habitat by commercial fishing: impacts at the scale of the fishery. *Ecological Applications 8*: 866–879.

Tuck, I.D., Chapman, C.J., Atkinson, R.J.A., Bailey, N., & Smith, R.S.M. 1997: A comparison of methods for stock assessment of the Norway lobster, *Nephrops norvegicus*, in the Firth of Clyde. *Fisheries Research 32*: 89–100.

Vignaux, M. & Gilbert, D.J. 1993: Production model for the FMA 1 scampi fishery, 1989–1991. N.Z. Fisheries Assessment Research Document 93/18. 16 p.

Vignaux, M. & Gilbert, D.J. 1994: A production model for the FMA 1 scampi fishery, 1989–1992. N.Z. Fisheries Assessment Research Document 94/8. 12 p.

Wear, R.G. 1976: Studies on the larval development of *Metanaphrops challengeri* (Balss, 1914) (Decapoda, Nephropidae). *Crustaceana 30*: 113–122.