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Scampi stock assessment for 1999

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EXECUTIVE SUMMARY

Cryer, M. & Coburn, R. 2000: Scampi stock assessment for 1999.
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Catch, effort, and landing information for scampi trawl fisheries in QMAs 1, 2, 3, 4 (eastern and western portions), 6A, and 6B are updated to include data from the 1997–98 fishing year. Unstandardised CPUE indices are calculated and standardised indices estimated using a multiple regression approach. The two indices continue to be highly correlated in all areas except QMA 6B.

Standardised indices for 1997–98 in QMAs 1, 3, and 4 were all slightly lower than those for 1996–97, although still considerably higher than their respective index years. In QMA 2, the 1997–98 index is slightly higher than the 1996–97 index and remains lower than that for the index year. The standardised index for SCI 6A in 1997–98 is about 0.6 after three years at about 0.3–0.4. A new standardised index is presented for QMA 6B, but fishing in this area has been very patchy and the data are inadequate to support useful modelling. No significant year effect was included in the QMA 6B model.

Estimated finfish bycatch composition varies with geographical area; the three "natural" groupings being QMAs 1 and 2 (east coast North Island), QMAs 3 and 4 (Mernoo Bank and Chatham Rise), and QMA 6 (Subantarctic). In contrast with previous work on the invertebrate bycatch, there is little evidence of consistent change in the finfish bycatch with time. Similarly, the length frequency distributions of important species in the finfish bycatch do not show any consistent trend and, apart from ling in QMA 6, appear to be broadly similar to those derived from target and other fisheries. In QMA 6, the proportion of (probably) juvenile ling in the scampi bycatch is high (about 75%) compared with that in trawl fisheries for hoki and southern blue whiting (about 50%) and, especially, with the ling bottom longline fishery (less than 20%). The extent to which these comparisons are realistic has not been determined.

Raw observed catch rates were examined for all important QMS finfish bycatch species, but few trends were evident other than a possible decline of ling and giant stargazer in QMAs 3 and 4, and a possible increase in alfonsino in QMA 2. None of these trends is marked, and there are many possible explanations for changes in the catch rate of bycatch species. Catch rates of a wide variety of non-QMS finfish bycatch species recorded by observers varied seemingly without trend.

No estimates of yield are presented other than (probably) minimum estimates for that part of QMA 1 between Great Mercury and White Islands, 200–600 m depth. This area was surveyed photographically in 1998.

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1. INTRODUCTION

1.1 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 (Cryer *et al.* 1998), and only updates are given here. Unstandardised and standardised indices of CPUE are generated for QMAs 1, 2, 3, 4 (east and western portions), 6A, and 6B, based on catch and effort information. Composition and length frequency distributions from scientific observers are examined for major finfish bycatch species.

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). There has been sporadic fishing elsewhere, especially in QMA 6B, that part of QMA 6 which is greater than 50 miles from the Auckland Islands.

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.

1.3 Literature review

Cryer (1996) reviewed the international literature on the genus *Metanephrops* and little new work has been published since of relevance to *M. challengeri*. Cryer *et al.* (1998) described new standardised indices of CPUE for the commercial fisheries in QMAs 2, 3, 4, and 6A and these were updated by Cryer *et al.* (1999) and are further updated here. 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, 1999). Cryer & Hartill (1998) described the results of an experimental photographic survey of scampi in the Bay of Plenty in January 1998.

2. REVIEW OF THE FISHERY

2.1 TACCs, catch, landings and effort data

2.1.1 Estimated landings

Until 1992, access to the scampi fishery was restricted by non-QMS permitting policies, but there were no limits on catches. For 1991–92 and subsequent fishing years, catch limits were applied to all QMAs (Table 1).

In 1991–92, 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. Cryer (1996) wrongly ascribed the QMA 3 fishery to the former category.

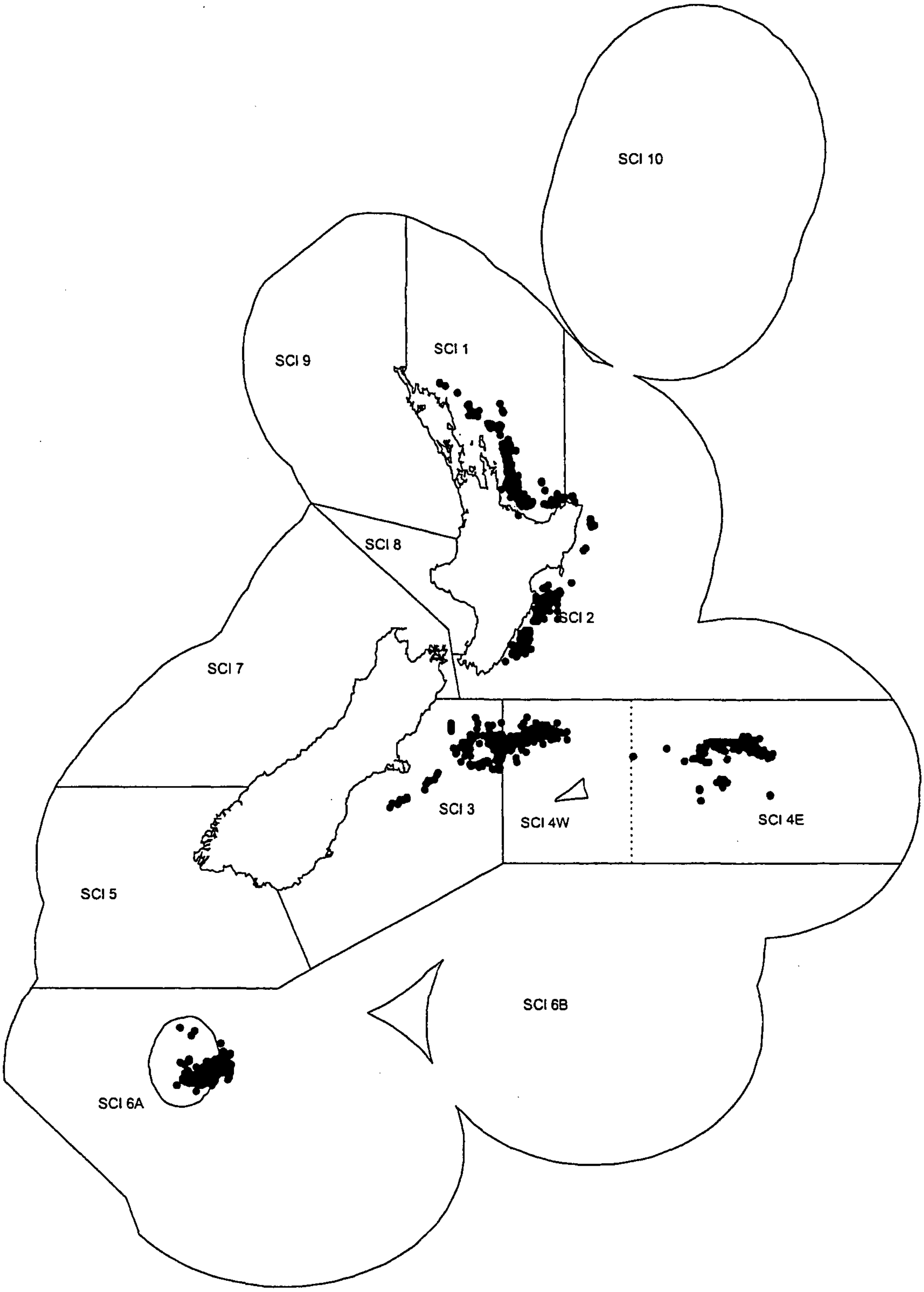

Figure 1: Fishery management areas and the location of the main fishing areas for scampi, *Metanephrops challengeri*, in New Zealand waters. Dots indicate the start positions of trawl shots targetting scampi up to and including 1996–97. SCI 6A is a separate regulated management area containing all waters within 50 nautical miles of the Auckland Islands, whereas SCI 4 is informally separated into eastern and western portions at longitude 180 ° (indicated by the dotted line).

Table 1: **Estimated commercial landings (t) from the 1986–87 to 1997–98 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 1997–98 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 for QMA 6, 300 t**

	QMA 1		QMA 2		QMA 3		QMA 4		QMA 5	
	Landings	Limit	Landings	Limit	Landings	Limit	Landings	Limit	Landings	Limit
1986–87	5		–		–		–		–	
1987–88	15		5		–		–		–	
1988–89	60		17		–		–		–	
1989–90	103		138		–		–		–	
1990–91	179		295		–		33		–	
1991–92	132	120	221	245	0	60	246	250	0	60
1992–93	125	120	210	245	84	60	224	250	2	60
1993–94	115	120	244	245	64	60	261	250	1	60
1994–95	114	120	226	245	66	60	226	250	0	60
1995–96	117	120	230	245	76	60	228	250	0	60
1996–97	117	120	213	245	72	60	232	250	2	60
1997–98	107	120	224	245	60	60	236	250	0	60

	QMA 6A		QMA 6B		QMA 7		QMA 8		QMA 9	
	Landings	Limit	Landings	Limit	Landings	Limit	Landings	Limit	Landings	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	242	250	61	50	0	75	0	60	1	60
1994–95	215	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
1997–98	244	250	35	50	0	75	0	60	0	60

2.1.2 CPUE analyses

2.1.2.1 General methodology

Data were taken from MFish databases (Trawl Catch, Effort, and Processing Returns, TCEPR). All records (as at late December 1998) for which scampi was the target species were extracted. All were by 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 records were rigorously screened for obvious errors. 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 were reported at the same time and in the same place. Range checks were applied to these "diagnostics" (Table 2).

Records that 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, dates, or times. 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 QMAs 6A and 6B).

Table 2: **Diagnostic criteria applied to reported commercial trawl shots for scampi**

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. mile

For the base analyses using all available data, 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. Conversely, the exclusion of all tows with a zero catch of scampi often materially affects CPUE models for scampi (Cryer *et al.* 1999) and this approach is used as a sensitivity test here.

Standardised indices of CPUE were calculated using a multiple regression approach described by Vignaux & Gilbert (1993, 1994) for QMA 1 and developed for scampi fisheries in QMAs 2, 3, 4, and 6A by Cryer *et al.* (1998). The model was used to estimate multiplicative effects on scampi CPUE (kg greenweight per hour trawled) of environmental, vessel, and year variables:

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

where C_t is the logarithm of catch per hour 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 (month), time of day, depth, areal location within each QMA, and vessel. Gear descriptors have not usually been found to be influential in CPUE models of scampi fisheries, perhaps because most vessels use similar gear and these fields are often reported inconsistently. 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 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).

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 criterion for inclusion of further variables is subjective and requires striking a balance between achieving the highest possible explanatory power while reducing the number of nonsense or nuisance variables. The R^2 values for the final models using temporal variables in 12 bins are usually different, occasionally very different from those of the developmental models using 8 categorical bins. 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

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

where

$$s^2 = \mathrm{Var}(Y_i) + \mathrm{Var}(Y_0) - 2\,\mathrm{Cov}(Y_i, Y_0)$$

These models are called the base case models for a given QMA. Base models were fitted for QMAs 1, 2, 3, 4W, and 6A in the 1998 assessment (Cryer *et al.* 1999) and are updated here. A new model for QMA 6B was developed for the 1999 assessment.

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 are "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 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 discovered by Cryer *et al.* (1999) 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 might 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, or re-power).

Because few vessels fish in each QMA, aberrant behaviour or reporting by one vessel tends to distort the overall index and cause undesirable interaction terms in the model. To examine this effect, each vessel in turn was dropped from the base model for each QMA. This usually indicated that the exclusion of most vessels had little effect in the overall shape of the index, but that the exclusion of one, sometimes two vessels, had a major impact. Some vessels appeared quite consistently in this category, and these vessels had previously been found to be relatively poor reporters (large proportions of zero estimated catches, missing fields, etc.).

Because we consider that shots with a zero catch should be very rare in scampi fisheries (the best fishing locations are relatively consistent and easy to re-locate), we examined the sensitivity of each base model to the exclusion of tows with no catch of scampi. This was simply effected by re-fitting each base model without the shots where no catch of scampi was reported. To ensure as direct a comparison as possible, we did not go through the stepwise procedure of including variables from scratch, but used the variables included in the base model.

2.1.2.2 QMA 1 (Bay of Plenty)

The QMA 1 CPUE model was refitted using data up to the end of the 1997–98 fishing year (Table 3) and standardised to the 1988–89 fishing year. The year and time of day effects remained the most important (Table 4). The standardised index for QMA 1 shows an initial decrease, followed by a steady increase between the 1990–91 and 1995–96 fishing years (Figure 2), and a decrease since then. There is a highly significant correlation between the standardised and unstandardised indices (r_8 = 0.95, p = 0.0003).

Table 3: **Data and CPUE indices 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 tows with a reported zero catch of scampi. Unstandardised (A, total catch divided by total effort) and standardised (B, from a multiple regression model) indices of relative abundance for scampi (with standard errors, S.E., for the latter) are shown for the years 1988–89 to 1997–98. The index year was chosen as 1988–89 and the final standardised model explained 26.1% of the variation in log (cpue)**

Year	N tows	N vessels	Catch (t)	% zeros	Mean kg h^{-1}	Index A	Index B	S.E (B).
1988–89	443	2	39	7.2	32.9	1.00	1.00	0.00
1989–90	872	5	104	2.8	31.8	0.97	0.94	0.06
1990–91	1 545	9	163	2.3	22.7	0.69	0.84	0.05
1991–92	1 086	8	129	1.4	21.7	0.66	0.98	0.06
1992–93	744	7	115	7.4	28.3	0.86	1.19	0.08
1993–94	570	5	111	3.5	36.3	1.10	1.47	0.10
1994–95	427	6	114	1.4	49.0	1.49	1.93	0.14
1995–96	371	6	117	3.0	60.4	1.84	2.27	0.17
1996–97	382	6	117	7.3	59.0	1.79	1.94	0.14
1997–98	356	5	107	2.3	45.4	1.38	1.76	0.14

Table 4: **Choice of significant variables for 1995, 1997, 1998, and 1999 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 1999**

Assessment				
1995	1997	1998	1999	1999 R^2 (%)
area	year	year	year	7.7
month	time of day	time of day	time of day	14.1
time	area	depth	depth	19.0
year	month	area	month	22.0
depth	depth	month	area	24.7
vessel				

The exclusion of all tows with a zero reported catch of scampi resulted in a large increase in R^2 (from 24.7% to 37.2%), but little change in the shape of the index. There was a decrease in both indices between 1988–89 and about 1991–92, followed by an increase (to well above the value for the index year), followed by another decline since about 1995–96. In 1998, this sensitivity suggested that there was something about the zero catches in 1996–97 which distorted the base index. Cryer *et al.* (1999) concluded from other sensitivity analyses that this was caused by one vessel making several unsuccessful shallow shots in 1996–97. Such effects were much less apparent in 1997–98.

The most influential second order interaction term in the base model (as in the 1998 assessment, Cryer *et al.* (1999)) was between the year and depth effects, implying that the pattern of fishing success with depth (as modelled using eight categorical bins) varied among years. The increase in R^2 over the base model after the inclusion of this term was about 4.9%, a little less than the 5.4% reported in 1998. Cryer *et al.* (1999) reported that 1996–97 was an unusual year, and most of the interaction term was generated by poor catch rates in the shallowest depth bin. The continued presence of this interaction term (caused largely by relatively unsuccessful shallow fishing, and mainly by a single vessel in 1996–97) suggests that models excluding zero catches, or very shallow shots may be preferred to the base model.

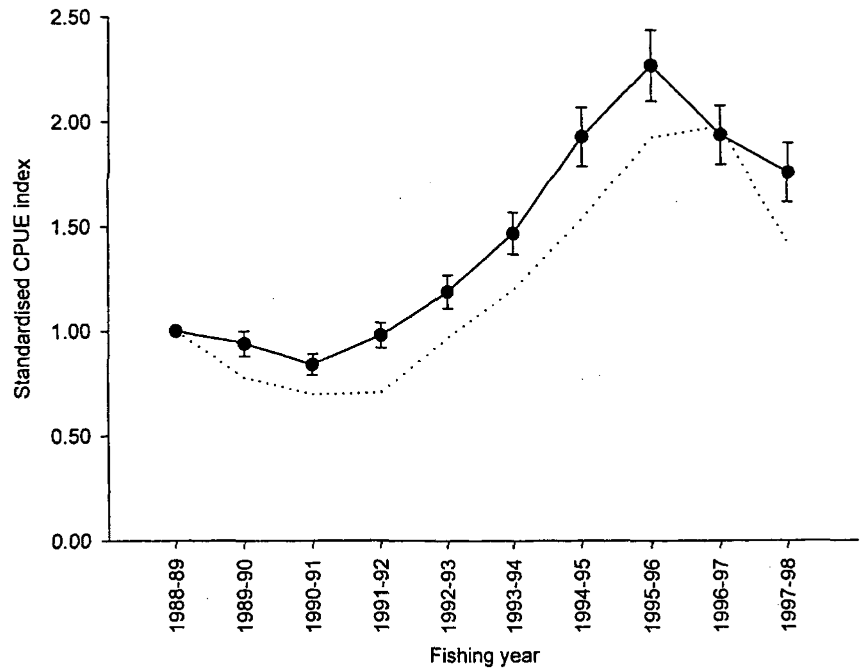

***Figure 2*: Indices of relative abundance from a multiple regression CPUE model for QMA 1 (Bay of Plenty). The solid line and closed circles indicate the base model fitted in 1999 including data up to and including 1997–98, and the dotted line represents the sensitivity test excluding all shots with a zero catch of scampi. Error bars represent plus or minus one standard error for the base model.**

2.1.2.3 QMA 2 (Hawke Bay, Wairarapa coast)

The QMA 2 model has been refitted using data up to the end of the 1997–98 fishing year (Table 5) and standardised to the 1988–89 fishing year. The month effect in the model 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.

The standardised index for QMA 2 seems to have cycled without long term trend although the year effect remains the most influential in the model (Table 6). The index for 1997–98 is slightly higher than that for 1996–97 and is close to that of the reference year (Figure 3). There is a highly significant correlation between the standardised and unstandardised indices ($r_8 = 0.90$, $p = 0.0004$).

The exclusion of all tows with a zero reported catch of scampi resulted in a large increase in R^2 (from 10.0 to 21.2%), but only minor changes in the shape of the index. This sensitivity test gave a more stable index than did the base model and may be preferred.

The most influential second order interaction term in both the 1998 and 1999 base models 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 6.4%. Inspection 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 was unfortunate, as the most appropriate response to an interaction caused by just one year would be to exclude data from that year. 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, suggesting that excluding vessels with poor reporting or all shots with a zero reported catch of scampi may be preferred to the base model.

***Table 5*: Data and CPUE indices 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 tows with a reported zero catch of scampi. Unstandardised (A, total catch divided by total effort) and standardised (B, from a multiple regression model) indices of relative abundance for scampi (with standard errors, S.E., for the latter) are shown for the years 1988–89 to 1997–98. The index year was chosen as 1988–89 and the final standardised model explained 10.0% of the variation in log (cpue)**

Year	N tows	N vessels	Catch (t)	% zeros	Mean kg h^{-1}	Index A	Index B	S.E (B).
1988–89	187	3	16.7	5.4	34.0	1.00	1.00	0.00
1989–90	1 246	6	138.4	3.8	29.6	0.87	0.82	0.07
1990–91	2 267	8	259.9	2.7	25.4	0.75	0.71	0.06
1991–92	1 594	10	212.0	0.9	26.0	0.76	0.79	0.07
1992–93	1 343	9	208.5	1.6	30.6	0.90	0.86	0.07
1993–94	1 416	8	229.9	1.6	29.7	0.87	0.90	0.07
1994–95	912	6	231.1	1.8	47.9	1.41	1.51	0.13
1995–96	924	8	229.6	3.5	41.9	1.23	1.19	0.10
1996–97	1 144	9	212.4	9.9	32.5	0.96	0.70	0.06
1997–98	1 077	8	224.2	5.9	33.6	0.99	0.77	0.07

***Table 6*: Choice of significant variables for the 1997, 1998, and 1999 QMA 2 scampi assessments (in the order chosen) and the percent of variation in log (cpue) (R^2) explained following the inclusion of each variable in 1999**

Assessment			
1997	1998	1999	1999 R^2 (%)
year	year	year	4.22
time of day	time of day	time of day	7.73
month	month	month	9.97

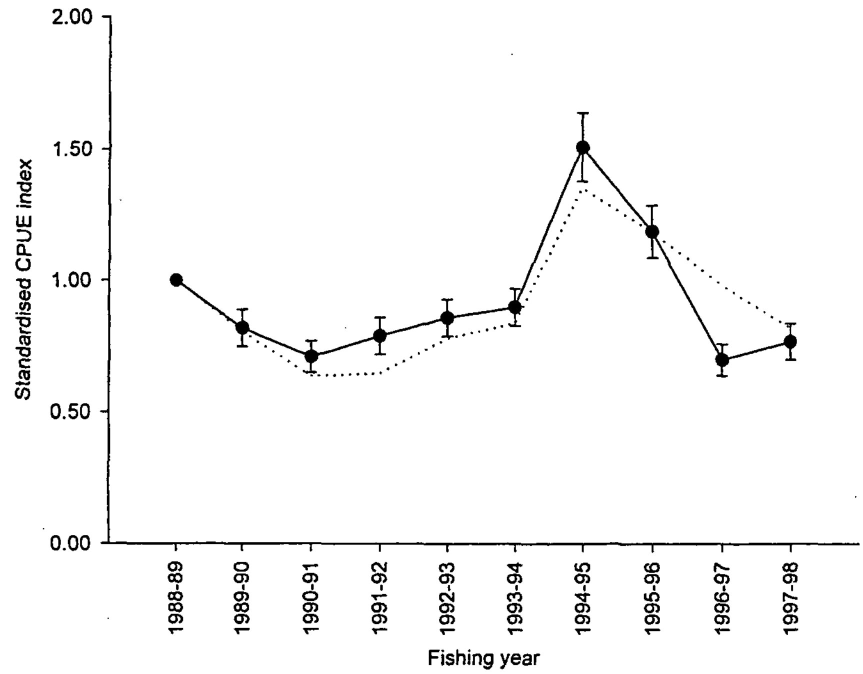

Figure 3: **Indices of relative abundance from a multiple regression CPUE model for QMA 2 (Hawke Bay, Wairarapa coast). The solid line and closed circles indicate the base model fitted in 1999 including data up to and including 1997–98, and the dotted line represents the sensitivity test excluding all shots with a zero catch of scampi. Error bars represent plus or minus one standard error for the base model.**

2.1.2.4 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 (Table 7). The QMA 3 model was therefore standardised to the 1992–93 fishing year and has been updated including data from the 1997–98 year.

Year, vessel, and month effects were included in the final model (Table 8). Because fishing in this area is highly seasonal (driven by the competitive catch limit of 60 t), almost all fishing is between October and December. Records for months other than this period were therefore included in a "catch-all" category giving a total of 4 seasonal bins in the final model compared with 12 for most other areas. The year effect for this fishery was strong, more than doubling over the 4 years up to 1996–97 (Figure 4).

Six vessels were in the fishery throughout the period analysed (1992–3 to 1997–98) 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 1 month. The selection of a vessel effect contrasts with the models for most other QMAs where vessel was not often important. 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 that is very different from that observed in the neighbouring QMA 4.

Because there are so few 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 in summer. The explanatory power of the final model including 12 bins for the month effect is considerably lower than that of the developmental model using only 4 bins (R^2 16.2 *vs* 27.6%). This may be because there are so few data in most of the bins in the former model. The "time of day" effect is not selected as an important explanatory variable in QMA 3.

***Table 7*: Data and CPUE indices 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 tows with a reported zero catch of scampi. Unstandardised (A, total catch divided by total effort) and standardised (B, from a multiple regression model) indices of relative abundance for scampi (with standard errors, S.E., for the latter) are shown for the years 1992–93 to 1997–98. The 1992–93 year was chosen as the index year because the pattern of fishing changed dramatically at this time. The final standardised model explained 16.2% of the variation in log (cpue)**

Year	N tows	N vessels	Catch (t)	% zeros	Mean kg h^{-1}	Index A	Index B	S.E (B).
1988–89	5	1	0	100	0	–	–	–
1989–90	7	1	<0.1	14.3	2.1	–	–	–
1990–91	13	4	0.2	30.8	6.2	–	–	–
1991–92	26	7	0.4	46.2	5.6	–	–	–
1992–93	763	8	82.8	2.6	29.2	1.00	1.00	0.00
1993–94	677	8	59.6	0.7	20.5	0.70	0.99	0.08
1994–95	537	9	65.7	1.1	24.8	0.82	1.24	0.11
1995–96	405	9	75.7	2.0	36.6	1.25	1.82	0.17
1996–97	248	9	72.3	2.8	51.5	1.76	2.48	0.24
1997–98	202	9	59.8	6.4	58.7	2.01	2.21	0.23

***Table 8*: Choice of significant variables for the 1997, 1998, and 1999 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 1999**

	Assessment		1999 R^2(%)
1997	1998	1999	
vessel	year	year	20.20
year	vessel	vessel	24.93
month	month	month	27.56

The standardised index for QMA 3 increased markedly between 1992–93 and 1996–97 to more than double the initial CPUE. However, the standardised index for 1997–98 shows a (non-significant) decline from the high in 1996–97. There is a significant correlation between the standardised and unstandardised indices ($r_4 = 0.92$, $p = 0.009$).

The exclusion of all tows with a zero reported catch of scampi resulted in a large increase in R^2 (from 27.6 to 43.9%), and a change in the behaviour of the index in 1997–98. Whereas the index declines slightly in the base model, it continues to increase in the sensitivity test. This is a very marked change in the model following the deletion of only about 6% of the data. The large increase in R^2 following the deletion of shots with no reported catch of scampi strongly suggests that this approach may be preferred to the base model.

The most influential second order interaction term in the 1999 assessment base 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 large (about 14.2%). Inspection revealed that one vessel reported a particularly large proportion of tows with zero catch in 1997–98, and most of the interaction term seemed to be generated by this vessel. Exclusion of this vessel affected the standardised index quite markedly (in a similar way to the exclusion of all tows with zero catch), further suggesting aberrant behaviour or poor reporting.

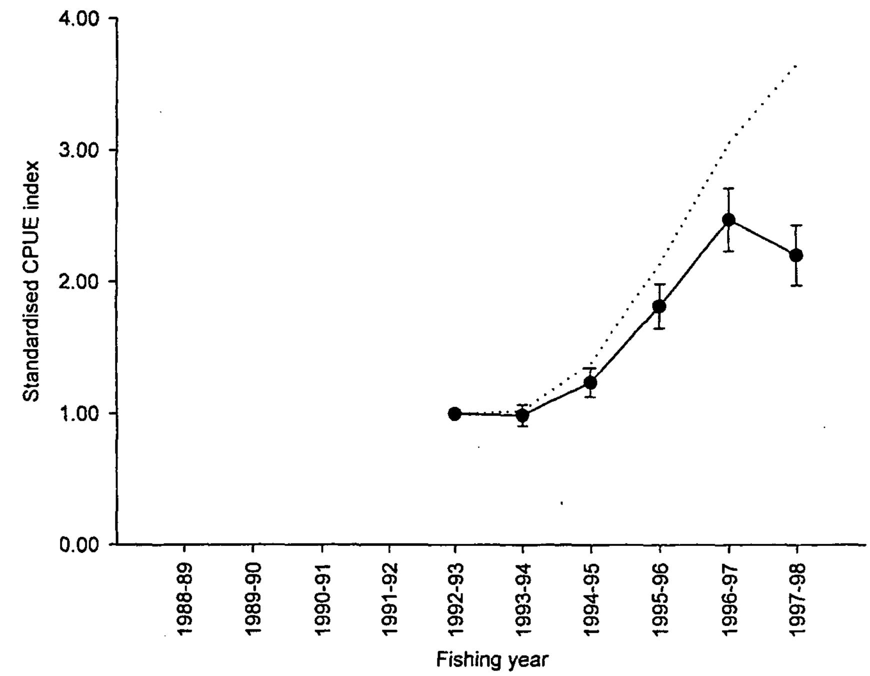

Figure 4: **Indices of relative abundance from a multiple regression CPUE model for QMA 3 (Mernoo Bank). The solid line and dots indicate the fully refitted model including data from *1997–98*, and the dotted line represents the sensitivity test excluding all shots with a zero catch of scampi. Error bars represent plus or minus one standard error for the base model.**

2.1.2.5 QMA 4W (western Chatham Rise)

The QMA 4W model was updated including data for the 1997–98 year and standardised to the 1991–92 fishing year (the first year of fishing on the western Chatham Rise, Table 9). The model accounts for 30% of the variation in log(cpue), including a strong year effect (Table 10). The standardised index for QMA 4W increased markedly between 1991–92 and 1996–97, but there was a slight (non-significant) decline in the index for 1997–98. There is a significant correlation between the standardised and unstandardised indices ($r_s = 0.95$, $p = 0.0009$), although the standardised index is consistently lower than the unstandardised index. Standardised catch rates have, for the past 3 years, been more than double those in 1991–92 (Figure 5).

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.

The exclusion of all tows with a zero reported catch of scampi resulted in a very large increase in R^2 (from 32.0 to 63.5%), and a modest change in the behaviour of the index; the index in the sensitivity test increases to a much higher level to that in the base model, although both show a decline in 1997–98. The large increase in R^2 following the deletion of shots with no reported catch of scampi strongly suggests that this approach may be preferred to the base model.

Table 9: **Data and CPUE indices for QMA 4W. "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 tows with a reported zero catch of scampi. Unstandardised (A, total catch divided by total effort) and standardised (B, from a multiple regression model) indices of relative abundance for scampi (with standard errors, S.E., for the latter) are shown for the years 1991–92 to 1997–98. The 1991–92 year was chosen as the index year because very little fishing was conducted in this area before then. The final standardised model explained 29.7% of the variation in log (cpue)**

Year	N tows	N vessels	Catch (t)	% zeros	Mean kg h^{-1}	Index A	Index B	S.E (B).
1991–92	1376	13	155.7	1.2	25.3	1.00	1.00	0.00
1992–93	1350	11	213.3	1.6	30.1	1.19	1.01	0.05
1993–94	1123	10	253.2	1.6	42.0	1.66	1.57	0.08
1994–95	602	8	225.6	7.6	69.4	2.74	1.63	0.10
1995–96	501	8	228.1	6.6	94.9	3.75	2.16	0.15
1996–97	547	9	232.1	5.3	101.3	4.00	2.73	0.19
1997–98	516	8	235.9	3.1	90.1	3.56	2.47	0.18

Table 10: **Choice of significant variables for the 1997, 1998, and 1999 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 1999**

		Assessment	
1997	1998	1999	1999 R^2(%)
year	year	year	16.97
time of day	vessel	vessel	24.02
vessel	time of day	time of day	28.33
month	month	month	32.00

The most influential 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 15%. Inspection revealed that two vessels had patterns of the year and month effects that were markedly different from other vessels in the fleet, and most of the interaction term seemed to be generated by these two vessels. Exclusion of these vessels almost entirely removed the interaction effects, suggesting that the interaction term is probably spurious (although, *a priori*, important as it explains 15% 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 for "developed" fisheries based on a stable fishing area.

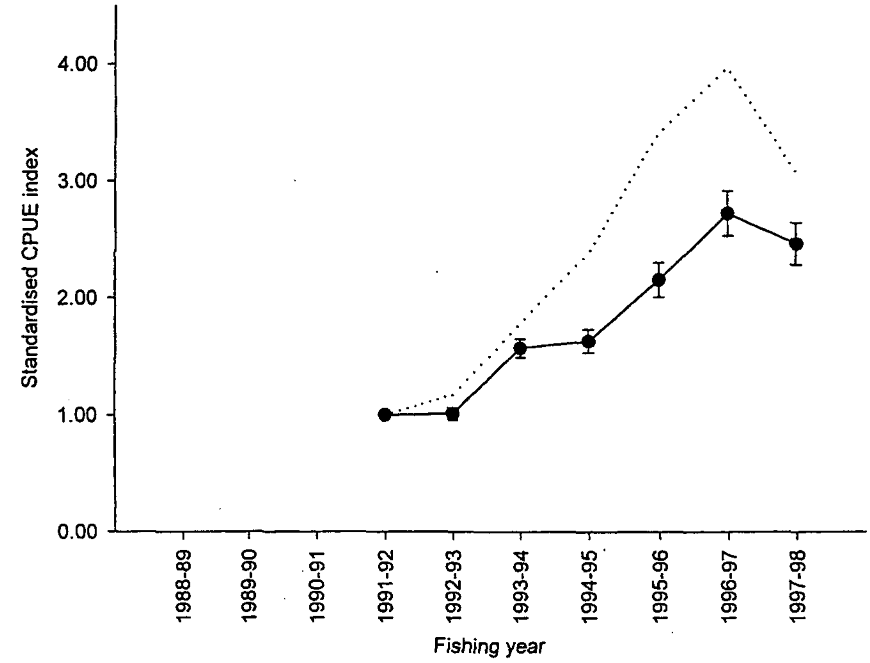

Figure 5**: Indices of relative abundance from a multiple regression CPUE model for QMA 4W (western Chatham Rise and eastern Mernoo Bank). The solid line and dots indicate the fully refitted model including data from 1997–98, and the dotted line represents the sensitivity test excluding all shots with a zero catch of scampi. Error bars represent plus or minus one standard error for the base model.**

2.1.2.6 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 on the Chatham Rise has been concentrated close to the Mernoo Bank (Table 11). No changes to the standardised analysis presented in the 1997 assessment (Cryer *et al.* 1998) have been made because there has been no substantive fishing since 1992–93.

Table 11**: Data and CPUE indices 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 tows with a reported zero catch of scampi. Unstandardised (A, total catch divided by total effort) and standardised (B, from a multiple regression model) indices of relative abundance for scampi (with standard errors, S.E., for the latter) are shown for the years 1990–91 to 1997–98. The 1990–91 year was chosen as the index year because very little fishing was conducted in this area before then. The final standardised model explained 46.6% of the variation in log (cpue). Note that this year effect was not influential in the model and is poorly determined. This analysis has not been updated since 1997 because there has been no fishing since 1992–93**

Year	N tows	N vessels	Catch (t)	% zeros	Mean kg h^{-1}	Index A	Index B	S.E (B).
1990–91	224	2	32.5	3.1	36.0	1.00	1.00	0.00
1991–92	687	11	72.5	3.4	20.6	0.56	0.95	0.22
1992–93	77	1	11.1	0.0	30.1	0.84	2.17	0.68

The model was unbalanced as most effort occurred in the second year (1991–92) and very few vessels fished in the first or third year. This means that any year effect is poorly determined and a year effect was not automatically included. The model accounts for almost 47% of the variation in log (cpue) (Table 12). Most of this (about 40%) is accounted for by vessel, time of day, and month variables. Position had modest explanatory power (a further 5% in R^2).

Table 12: **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**

Variable	R^2(%)
vessel	24.56
time of day	35.10
month	40.84
longitude	44.32
latitude	45.96
year (forced)	46.61

There was a daily cycle of catch rates with the best (late morning) being over double the worst (late evening). Effort was a little heavier during daylight. There was 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. 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 of fishing.

2.1.2.7 QMA 6A (Auckland Islands)

The QMA 6A model has been updated using data from the 1997–98 year (Table 13). The few records for 1990–91 (11 tows) were not included in the analysis and the model was standardised to the 1991–92 year. Year, month, and time of day were included in the final model (Table 14). 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 occurs from January to April, probably to coincide with relatively settled weather. 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.

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. There has also been an increasing trend in recent years to fish a ribbon further away from the Auckland Islands than that initially exploited. However, depth is not an important variable in the model (*see* Table 14). Standardised catch rates declined to about one-quarter of 1991–92 catch rates in 1994–95, but have increased significantly (but not back to their starting level) since (Figure 6). There is a highly significant correlation between the standardised and unstandardised indices ($r_5 = 0.97$, $p = 0.0003$).

The exclusion of all tows with a zero reported catch of scampi resulted in a large increase in R^2 (from 21.6 to 40.4%), and a "flattening" of the index. This flattening was probably the result of the high proportion of tows (almost 12%) where no catch of scampi was reported in the years when the standardised catch rates were estimated to have been low. The large increase in R^2 following the deletion of shots with no reported catch of scampi strongly suggests that this approach may be preferred to the base model.

Table 13: **Data and CPUE indices 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 tows with a reported zero catch of scampi. Unstandardised (A, total catch divided by total effort) and standardised (B, from a multiple regression model) indices of relative abundance for scampi (with standard errors, S.E., for the latter) are shown for the years 1991–92 to 1997–98. The 1991–92 year was chosen as the index year because very little fishing was conducted in this area before then. The final standardised model explained 21.8% of the variation in log (cpue)**

Year	N tows	N vessels	Catch (t)	% zeros	Mean kg h^{-1}	Index A	Index B	S.E (B).
1990–91	11	1	0.9	18.2	38.1	–	–	–
1991–92	959	10	320.5	2.4	67.4	1.00	1.00	0.00
1992–93	660	8	193.4	2.1	51.6	0.77	0.73	0.05
1993–94	1 267	10	241.6	1.7	34.5	0.51	0.44	0.02
1994–95	1 347	8	214.6	12.0	25.7	0.38	0.27	0.01
1995–96	1 284	7	219.2	6.7	26.4	0.39	0.32	0.02
1996–97	1 133	8	228.1	5.4	30.4	0.45	0.37	0.02
1997–98	1 012	9	244.4	3.0	35.3	0.52	0.62	0.04

Table 14: **Choice of significant variables for the 1997, 1998, and 1999 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 1999**

Assessment			
1997	1998	1999	1999 R^2(%)
year	year	year	9.25
month	month	vessel	13.86
time of day	vessel	time of day	18.00
	time of day	month	21.60

The most influential 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 15%. Inspection revealed that two vessels had a very different pattern of reported fishing success by year than the other vessels involved, with particularly unusual years between 1994–95 and 1996–97. Most of the interaction term seemed to be generated by these two vessels, and their exclusion removed almost all of the interaction and modified the index in a similar way to removing all shots with a zero reported catch of scampi.

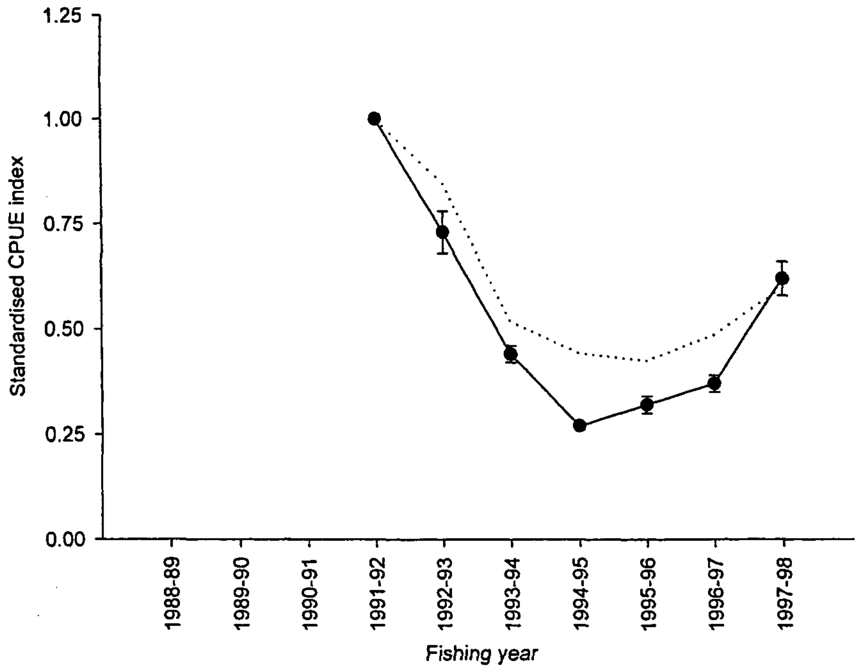

Figure 6**: Indices of relative abundance from a multiple regression CPUE model for QMA 6A (within 50 miles of the Auckland Islands). The solid line and closed circles indicate the base model fitted in 1999 including data up to and including 1997–98, and the dotted line represents the sensitivity test excluding all shots with a zero catch of scampi. Error bars represent plus or minus one standard error for the base model.**

2.1.2.8 QMA 6B (Subantarctic, more than 50 n. miles from Auckland Islands)

A fully standardised CPUE index for the Subantarctic QMA 6B was developed for the 1999 assessment using data up to and including the 1997–98 fishing year. All trawl shots within QMA 6, but with reported start and finish locations both more than 50 n. miles from any of the Auckland Islands were considered to be within QMA 6B. Other definitions are possible. Because trawl tracks typically follow depth contours and are not always linear, it is possible that some of the shots selected as being in QMA 6B came within 50 n. miles of the Auckland Islands at some time. The boundary between QMAs 6A and 6B passes through the scampi fishing grounds close to the Auckland Islands and should be considered arbitrary (Figure 7).

Fishing in QMA 6B has been very patchy, probably because it represents the outlying areas of the grounds primarily enclosed in QMA 6A. The few records for 1990–91, 1991–92, 1994–95, and 1995–96 (a total of 35 tows) and for five vessels with very few shots in the remaining years (a further 15 tows) were excluded from the analysis. This left just 4 fishing years and only 6 vessels, only 2 of which had fished in more than 2 years. This is a very unbalanced design unlikely to support useful modelling (Table 15).

Month, vessel, depth, headline height, and time of day were included in the final model (Table 16). The seasonal cycle of catch rates is not well described because fishing has been patchy and little effort occurs between about June and October. The daily cycle of catch rates suggests better catch rates in the late morning than at other times. Effort is spread about evenly over the day, however.

Although the model explains a relatively high proportion of variance in log (cpue), there is no significant year effect (Figure 8). Headline height effects have not been included in any other scampi CPUE model, and this one is probably spurious given that this field is poorly reported. The exclusion of all tows with a zero catch of scampi resulted in an increase in R^2 (from 31.1 to 40.0%), but did not change the conclusion that there is no trend in the index. This lack of impact and the fact that the year effect is not automatically included in the model suggest that there is no objective way of preferring one model over the other. The two most influential interaction terms in the base model were between the headline height and depth and vessel. The increases in R^2 over the base model after the inclusion of these terms were about 5%, and inspection did not suggest any sensible explanation. These interaction effects may be spurious, and may have been caused by the poor reporting of headline height typical in this fishery.

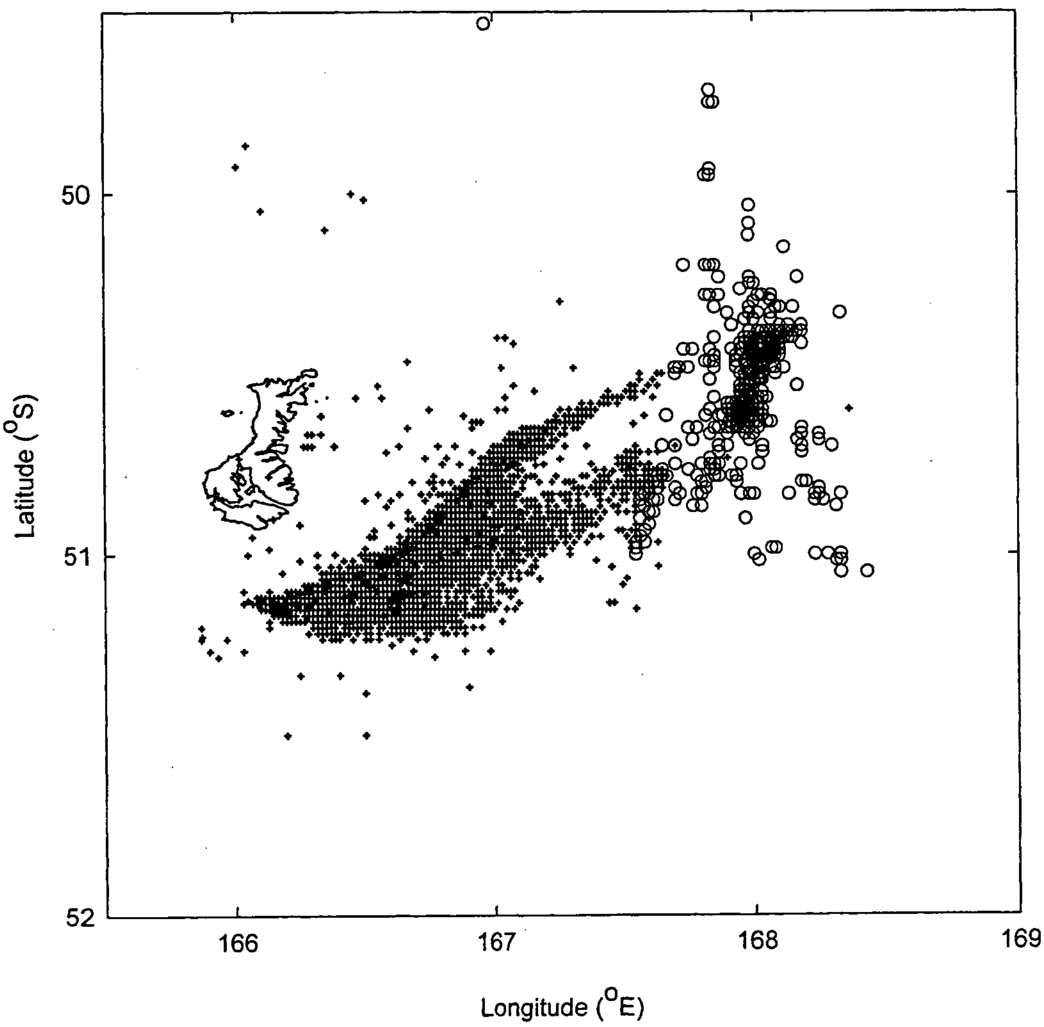

Figure 7: **Start positions of all shots targeting scampi near the Auckland Islands since 1991–92. Shots within QMA 6A are shown as crosses and those in QMA 6B as open circles. Shots were allocated to QMAs on the basis that a reported start or finish location closer than 50 miles to any of the islands places a shot in QMA 6A.**

Table 15: **Data and CPUE indices 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 tows with a reported zero catch of scampi. Unstandardised (A, total catch divided by total effort) and standardised (B, from a multiple regression model) indices of relative abundance for scampi (with standard errors, S.E., for the latter) are shown for the years 1992–93, 1993–94, 1996–97, and 1997–98. The 1992–93 year was chosen as the index year because very little fishing was conducted in this area before then. The final standardised model explained 33.2% of the variation in log (cpue)**

Year	N tows	N vessels	Catch (t)	% zeros	Mean kg h^{-1}	Index A	Index B	S.E (B).
1990–91	4	1	1.1	0.0	131.7	–	–	–
1991–92	9	3	0.0	100.0	0.0	–	–	–
1992–93	217	4	59.4	1.4	42.1	1.00	1.00	0.00
1993–94	136	4	27.1	7.4	31.9	0.76	0.93	0.25
1994–95	1	1	0.1	0.0	29.2	–	–	–
1995–96	21	3	3.6	0.0	29.9	–	–	–
1996–97	155	5	44.1	2.6	44.3	1.05	1.31	0.45
1997–98	131	3	34.9	1.5	35.4	0.84	1.48	0.41

Table 16: **Choice of significant variables for the new QMA 6B scampi assessment model (in the order chosen) and the percent of variation in log(cpue) (R^2) explained following the inclusion of each variable**

Variable	R^2(%)
month	12.83
vessel	18.70
depth	24.38
headline height	28.43
time of day	31.08

The new model does not seem to be a useful addition to our understanding of the scampi fishery off the Auckland Islands. The data are sparse and cannot be assembled into anything approaching a balanced design for the multiple regression analysis. The year effect has little explanatory power, but the month and time of day effects seem broadly similar to those observed in other scampi fisheries. It might be more appropriate to consider shots in this area close to the Auckland Islands (say, within 100 n. miles) together with those in QMA 6A, and to develop new models for fisheries which might develop elsewhere in QMA 6 (perhaps close to the Bounty Islands or Pukaki Rise).

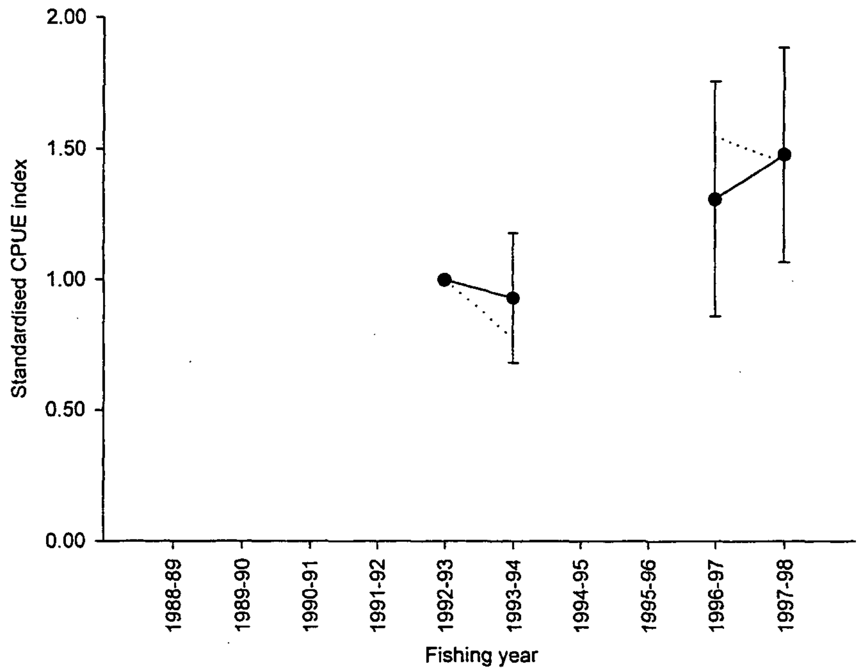

Figure 8: **Indices of relative abundance from a multiple regression CPUE model for QMA 6B (defined as shots for which both the reported start and finish locations were greater than 50 miles of the Auckland Islands). The solid line and closed circles indicate the base model fitted in 1999 including data up to and including 1997–98, and the dotted line represents the sensitivity test excluding all shots with a zero catch of scampi. Error bars represent plus or minus one standard error for the base model. The year effect in the base model had no significant explanatory power and is poorly estimated.**

2.1.2.9 Summary of standardised CPUE analyses

Sensitivity analyses conducted by Cryer *et al.* (1999) showed that the exclusion of shots with a zero estimated catch of scampi markedly increased the explanatory power of most models, and increased the 1996–97 level of the standardised index of CPUE in all QMAs. These changes are large considering the relatively small proportion of shots involved (usually less than 10%). This year, the effect on R^2 of excluding shots with a zero catch was similarly large (Table 17), but effects on the current status and recent pattern in the index were inconsistent.

Table 17: **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 1998 assessment 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 1997–98 relative to the base year, and "Change" indicates whether this index was larger or smaller than the index for 1996–97**

	R^2		Status		Change since '96–97	
QMA	Base	No zero	Base	No zero	Base	No zero
1	24.7	37.2	1.83	1.42	Down	Down
2	10.0	21.2	0.81	0.82	Up	Down
3	27.6	43.9	2.32	3.65	Down	Up
4W	32.0	63.5	2.52	3.08	Down	Down
6A	21.6	40.4	0.64	0.60	Up	Up
6B	31.1	40.0	1.48	1.45	Up	Down

Because of the large increase in explanatory power and the general lack of substantive interaction effects in models without shots with zero catch, we consider that such models should be preferred over the base models incorporating all data in "developed" fishery areas with little exploratory fishing activity.

2.2 Other information

2.2.1 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 (1996) and Cryer *et al.* (1998, 1999) and the length frequency distributions are updated here (Figures 9–13). These length frequency distributions do not show any gross changes that 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 showed generally increasing proportions of larger individuals between 1991–92 and 1996–97 (other than for the appearance of a "shoulder" of smaller animals in QMA 1 in 1997–98). Further, in samples taken mostly from QMA 4 (mostly from QMA 4W, which supports a catch of 250 t), the proportion of very large males (greater than 65 mm OCL, orbital carapace length) has remained relatively high in the catch for several years.

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 (Cryer *et al.* 1999). Without a very large number of samples, it is difficult to generate the standardised length frequency distributions that 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.

However, 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, 4, and 6A are not easy to explain. An increasing or consistently high proportion of large individuals is not usually consistent with a stock responding to heavy exploitation, but could (in the case of an increase) be consistent with a stock in which recruitment has recently been relatively poor. The information available to judge these alternative explanations is scant, given that our knowledge of changes in stock biomass is so poor.

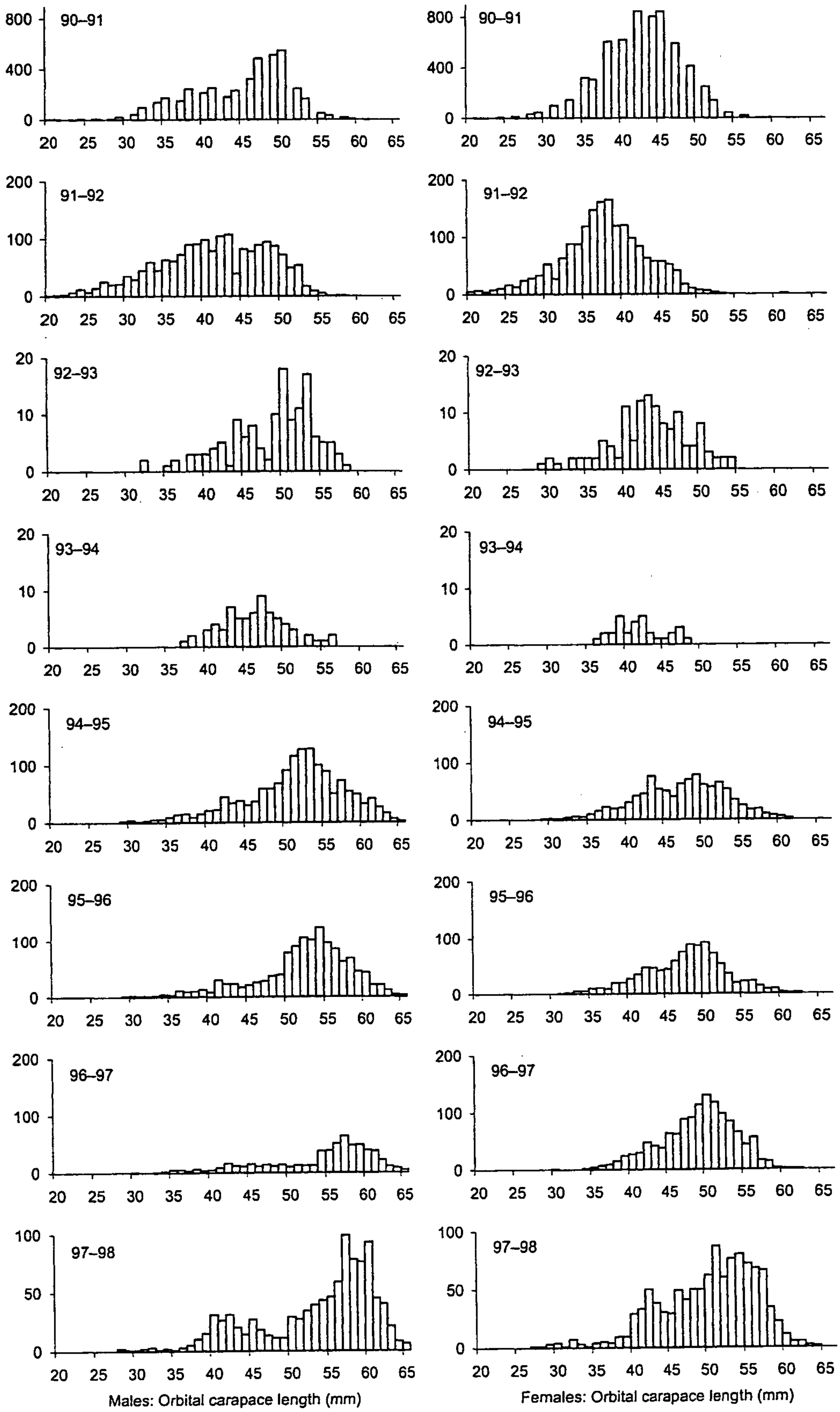

Figure 9: Unscaled length frequency distributions from scientific observers for male (left) and female (right) scampi measured on board scampi trawlers in QMA 1.

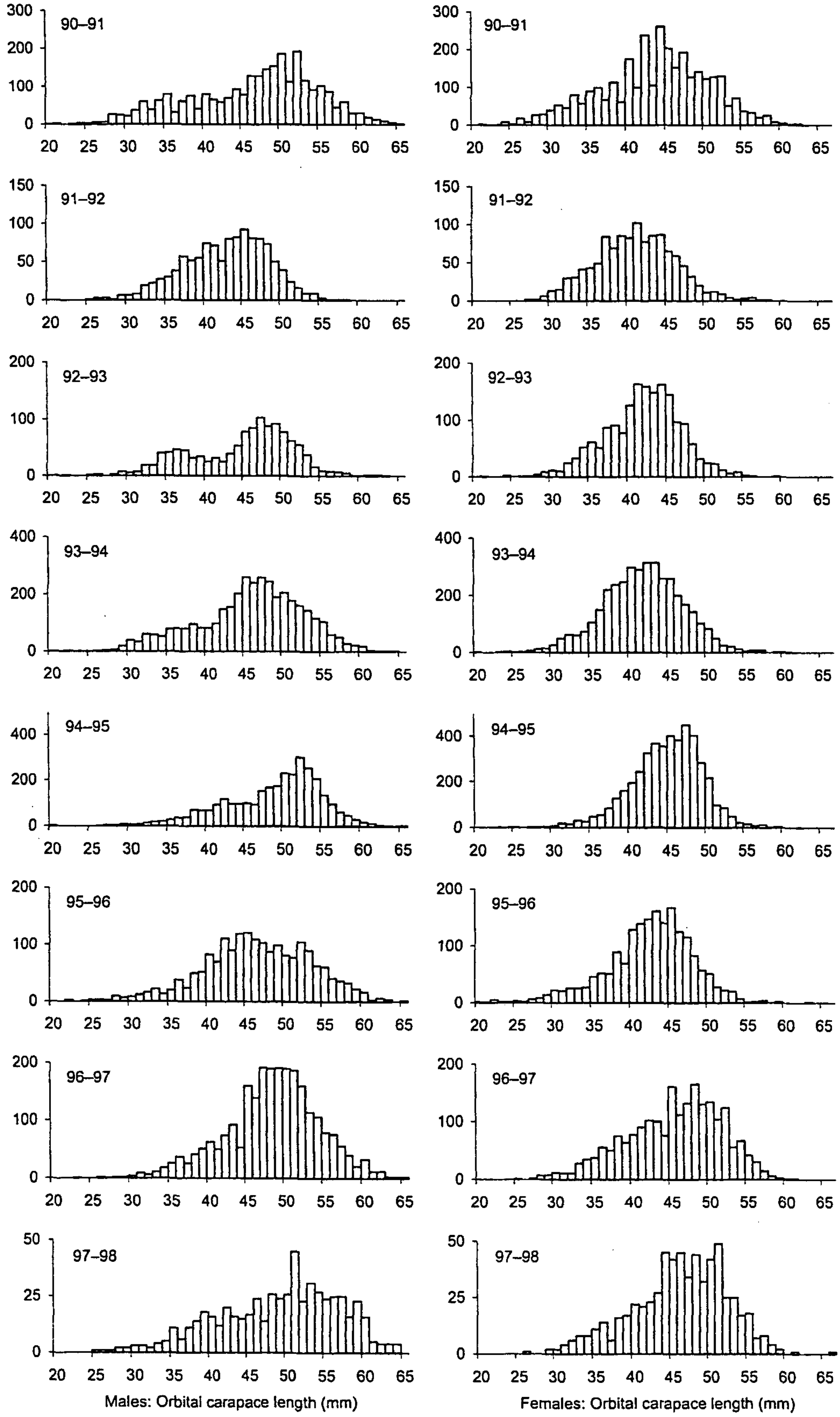

Figure 10: Unscaled length frequency distributions from scientific observers for male (left) and female (right) scampi measured on board scampi trawlers in QMA 2.

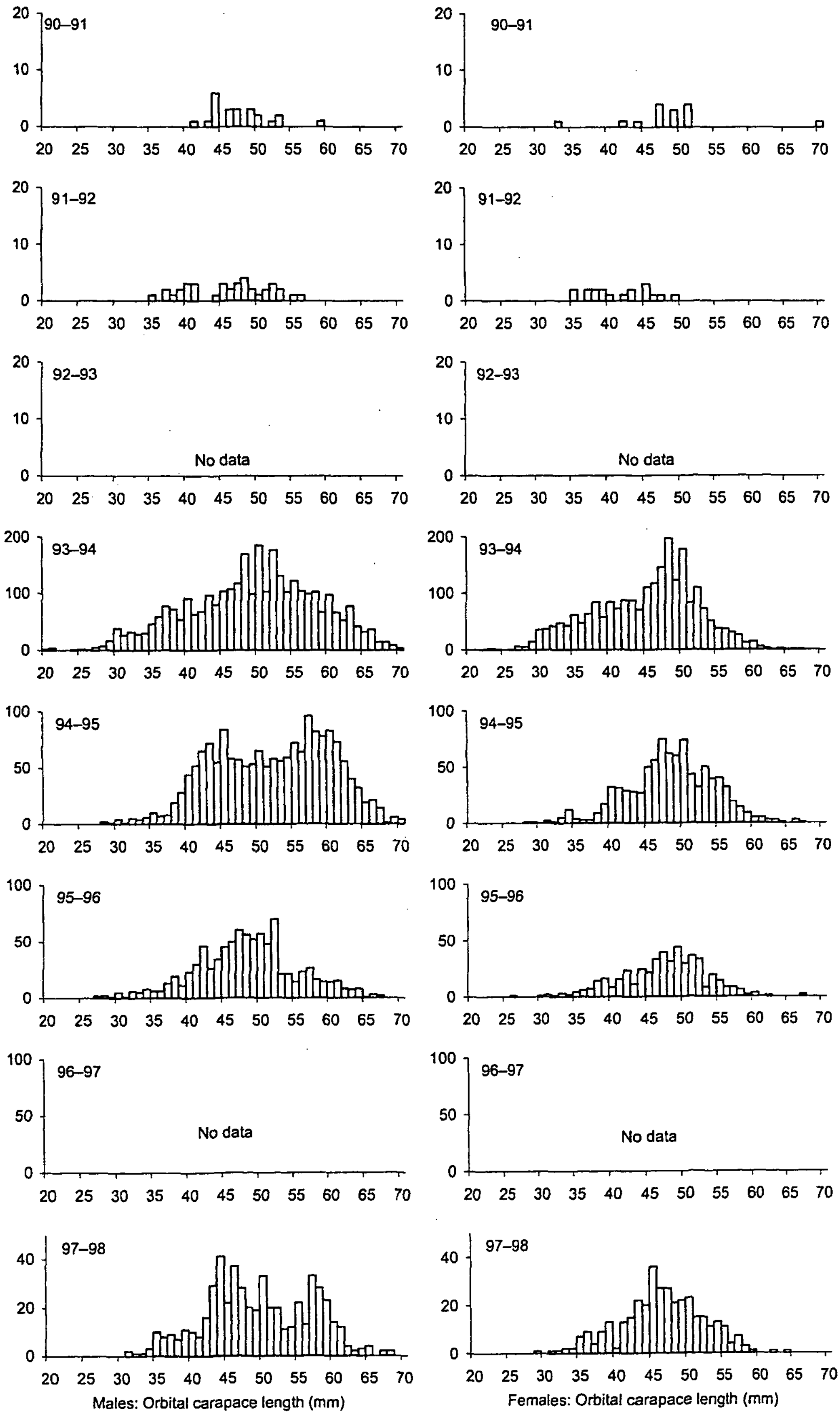

Figure 11: Unscaled length frequency distributions from scientific observers for male (left) and female (right) scampi measured on board scampi trawlers in QMA 3. The Mernoo Bank fishery on which the standardsied CPUE model is based, has been in operation since 1992–93.

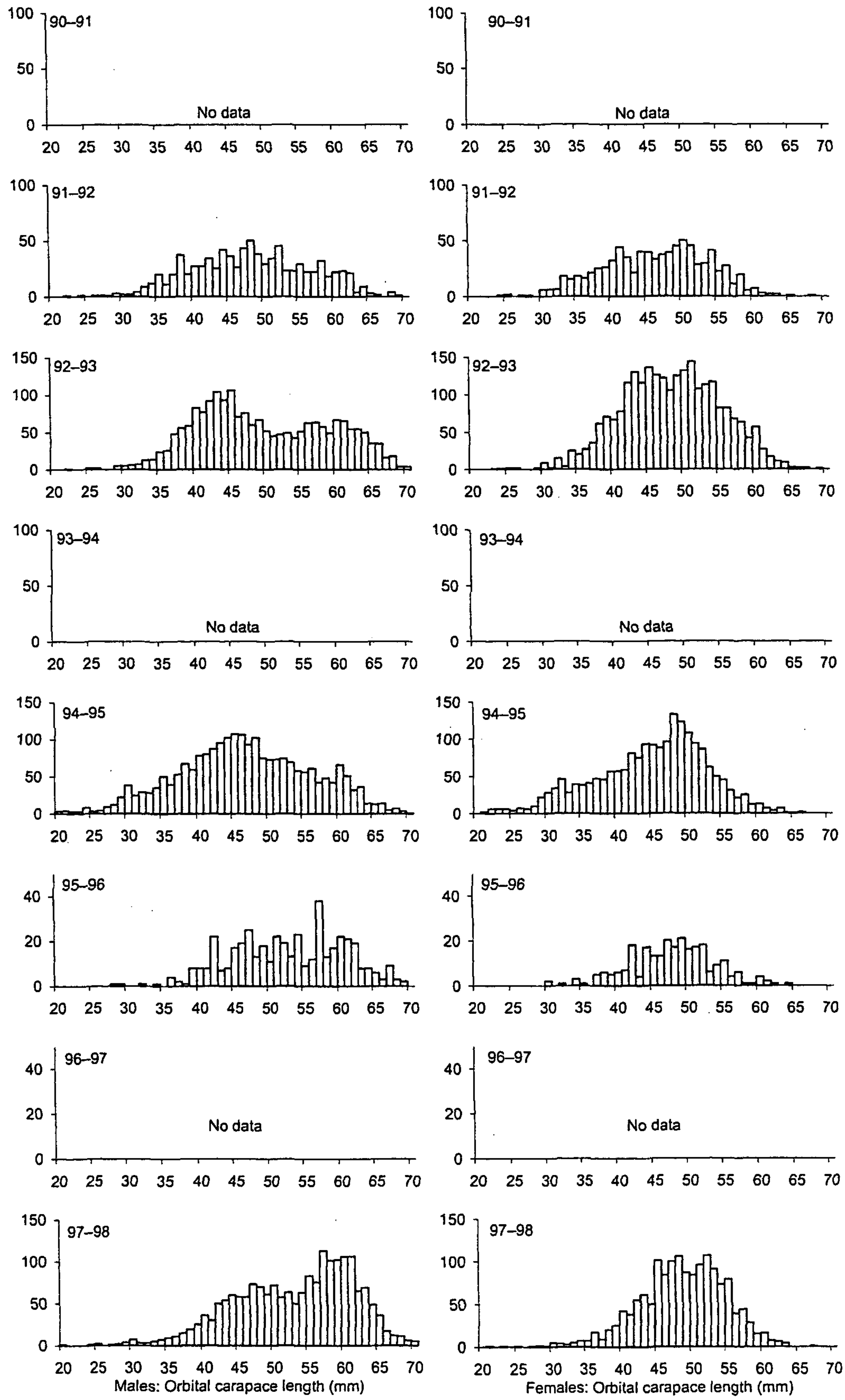

Figure 12: Unscaled length frequency distributions from scientific observers for male (left) and female (right) scampi measured on board scampi trawlers in QMA 4. This area includes shots to the west of 180 degrees longitude (SCI 4W), and shots to the east of this line (SCI 4E).

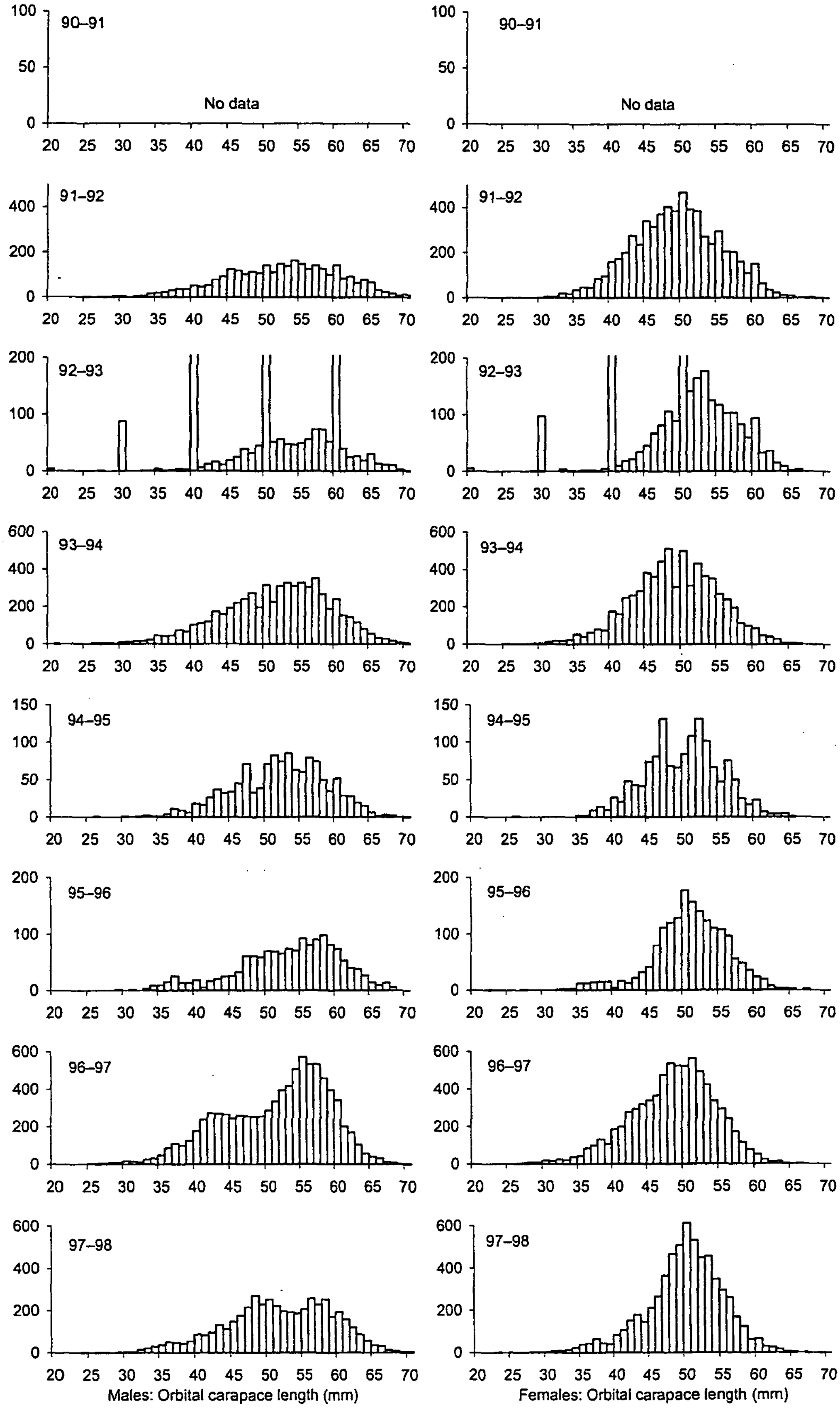

Figure 13: **Unscaled length frequency distributions from scientific observers for male (left) and female (right) scampi measured on board scampi trawlers in QMA 6. This area includes shots within 50 miles of the Auckland Islands (SCI 6A) and those further than 50 miles from the islands (SCI 6B).**

2.2.2 Composition of finfish bycatch

The most widespread source of data on the finfish bycatch of scampi trawlers is that generated by scientific observers. Such data have been collected from most QMAs annually since about 1992, often from substantial numbers of trawls. Usually, the weight of all species caught is estimated, although the taxonomy can sometimes be quite crude. In contrast, although Trawl Catch, Effort, and Processing Returns (TCEPRs) are completed for every commercial trawl shot, they contain information on only the five most important species for each shot. This is frequently limited to large QMS species such as hoki, ling, stargazers, red cod, and gemfish. Small, non-QMS finfish such as conger eels, Lucifer's dogfish, silver roughy, and capro dory are almost never reported on TCEPRs although they are commonly caught in large numbers. Similarly, research databases contain considerable detail of the catch of all finfish, but these are available only for QMAs 1 and 2 when research voyages were undertaken. Further, research gear is not the same as commercial scampi trawl gear, and the finfish bycatch taken during research trawling may not be representative of the commercial bycatch. The analysis presented here is therefore restricted to use of information from scientific observers as this offers the most complete coverage.

Data were extracted from the observer catch and effort database for all tows where scampi was the target species. Time and location details were extracted from the station table, and catch by species from the catch table. A total of 244 different "species" codes was recorded in these data: 1 mammal species, 2 bird species, 175 fish taxa (not mutually exclusive), 53 invertebrate taxa (not mutually exclusive), and 13 codes which were either nonsensical or related to inanimate classifications such as plastic trash (Appendix 1).

Because information on the detailed composition of the finfish bycatch is collected sporadically by observers, the data were pooled such that all data from a given QMA in a given year were used to estimate the average catch rate (kg h^{-1}) for each of the 35 most commonly reported finfish taxa. Categories that were not mutually exclusive (such as SKA, RSK, SSK, etc.) were excluded. These estimates of catch rate were then combined to estimate the percentage composition of the common finfish bycatch in each QMA by year.

The composition of observer estimates of finfish bycatch was examined using the Bray-Curtis similarity index (Bray & Curtis 1957). This index has been found to be one of the most powerful methods of assessing the extent to which two samples are similar in composition (Faith *et al.* 1991). 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 (Figure 14). In such ordinations (usually represented in two or three dimensions), stations that are very similar in their community composition should appear close together, and stations that are very dissimilar should appear far apart. Non-metric MDS is usually considered to be one of the methods of choice for representation and comparison of community structures among several samples (Clark & Ainsworth 1993, Clarke & Warwick 1994, Chapman & Underwood 1998).

Spence (1979) gave a method of estimating the likely value of stress for nMDS plots made using random data. Using this method, the estimated stresses for 66 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", but rather to provide an intuitive feel for the value of the data. He suggested that stress of "a third or a half as large" as those from random data would indicate that the data contain substantive information. Stress for the finfish bycatch data at two and three dimensions (0.16 and 0.10, respectively) was just under half of that derived using random data, suggesting that there is some real information content in the data.

The organisation of the 35 "samples" in the nMDS ordination corresponds well with the results of a separate statistical clustering technique (Figure 15). Lines denoting the groups of samples from the cluster analysis could be drawn, broadly separating samples from the east coast of the North Island (QMAs 1 & 2), the Chatham Rise (QMAs 3 & 4), and the SubAntarctic (QMAs 6A & 6B). This suggests that, at this coarse level of resolution, the finfish bycatch of scampi trawling is relatively consistent within quite large geographical areas, but there are distinct differences, especially north and south of Cook Strait. Some pooled observer samples deviate substantively from this generalisation, most especially those from QMA 1 in 1993–94 (when very few samples were collected) and 1997–98.

Changes in the catch rates of particular species within the finfish bycatch were examined by calculating the average catch rate of a variety of taxonomic groups (not all mutually exclusive) for all observed tows (Appendix 1). The important QMS finfish bycatch species were all examined (hoki, ling, giant stargazer, gemfish, and hake, Figures 16–18). Only a selection of the more important non-QMS species was examined, but this included some large species (such as skates and spiny dogfish) and some very small species (such as capro dory and silver roughy) (Figures 19–22).

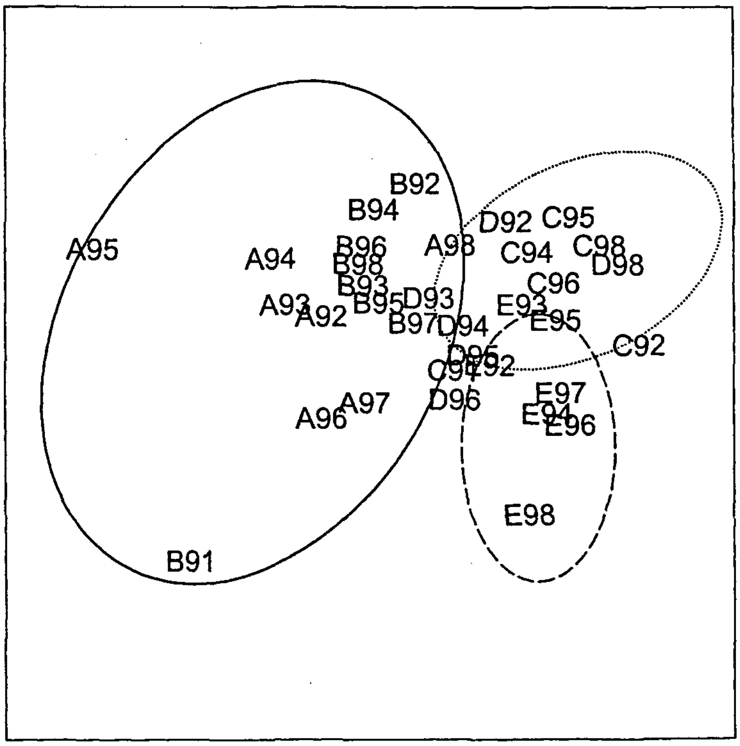

Figure 14: **Multidimensional scaling (nMDS) ordination of observer estimates of the composition of finfish bycatch, pooled by QMA and year. Estimated stress was 0.16 at two dimensions and 0.10 at three dimensions (not plotted). Each data point is identified by a letter (QMA 1 = "A", QMA 2 = "B" ... QMA 6 = "E") and a number (1991–92 = "92", etc.). The ordination is broadly consistent with the results of a separate cluster analysis (Figure 15), and shows a separation of samples from different geographical areas denoted by lines: solid line, eastern North Island; dotted line, Chatham Rise; dashed line, Subantarctic.**

The calculated average catch rates relate only to observed tows, and could differ from the fleet average if the observed tows were not representative. As an approximate test of the reliability of the method, therefore, the average catch rate of scampi from observed tows was estimated. This index shows similar trends to the unstandardised and standardised indices of CPUE, with broadly decreasing catch rates in QMA 6, broadly increasing catch rates in QMAs 3 and 4, and an increase followed by a recent decrease in QMA 1. We infer that the method is at least broadly reliable.

For QMS finfish bycatch species, catch rates for some relatively sedentary species (ling, giant stargazer, gropers) may have decreased as scampi fisheries have developed. None of these is a strong trend (*see* Figures 16 and 18), but they are most evident for ling and giant stargazers in the Chatham Rise fisheries

(QMAs 3 and 4). A decrease in observed catch rates for such species could indicate that fishers have become more selective in their fishing behaviour, that the spread of observer coverage has changed in some way, that the local density of these species has been reduced by scampi fishing, or that there have been large scale changes in the relevant stocks. It is not possible to choose among these alternatives without considerable additional analysis. Conversely, the catch rates of alfonsino in QMA 2 appear to have risen slightly (*see* Figure 18).

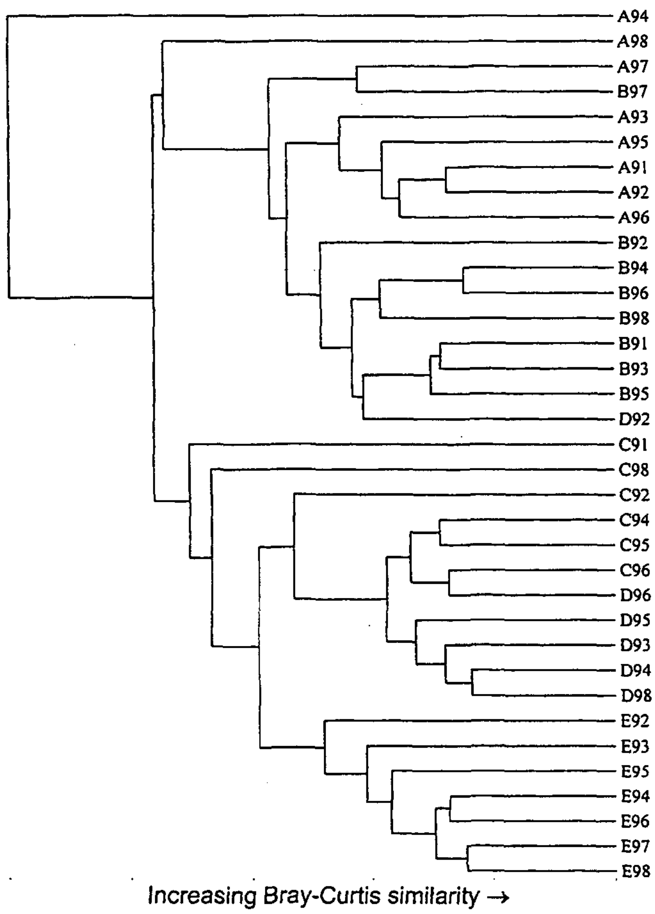

***Figure 15*: Cluster diagram (group average linkage) for pooled observer estimates of finfish bycatch composition. Each "sample" is identified by a letter (QMA 1 = "A", QMA 2 = "B" ... QMA 6 = "E") and a number (1991–92 fishing year = "92", etc.). The tendency for samples to cluster by geographic location rather than by year is reproduced in the nMDS ordination of these samples (*see* Figure 14).**

There are few, if any, trends in catch rates for the non-QMS finfish bycatch selected for this analysis. Large species such as skates and spiny dogfishes, and small species such as rattails, silver roughy, and banded bellowsfish were examined. The two most apparent trends in the data are the prevalence of species indicative of certain depth ranges in some years, and the restriction of some species to the northern or southern QMAs. Sea perches and prawn killers (*Ibacus alticrenatus*, not a finfish bycatch but included because of its "indicator" value) were common in some years (*see* Figure 20) and this suggests that relatively shallow shots were observed in those years. Conversely, the presence of banded bellowsfish and a large proportion of rattails (*see* Figure 19) would tend to suggest that observed fishing was relatively deep in those years. Species such as brown stargazers and mirror dory are largely restricted to QMA 1 (*see* Figures 20 and 21), while ghost sharks are much more common in QMAs 3, 4, and 6 (*see* Figure 21). These patterns almost certainly reflect the distribution and abundance of these groups rather than any differences in the depth distribution or other aspect of observed fishing.

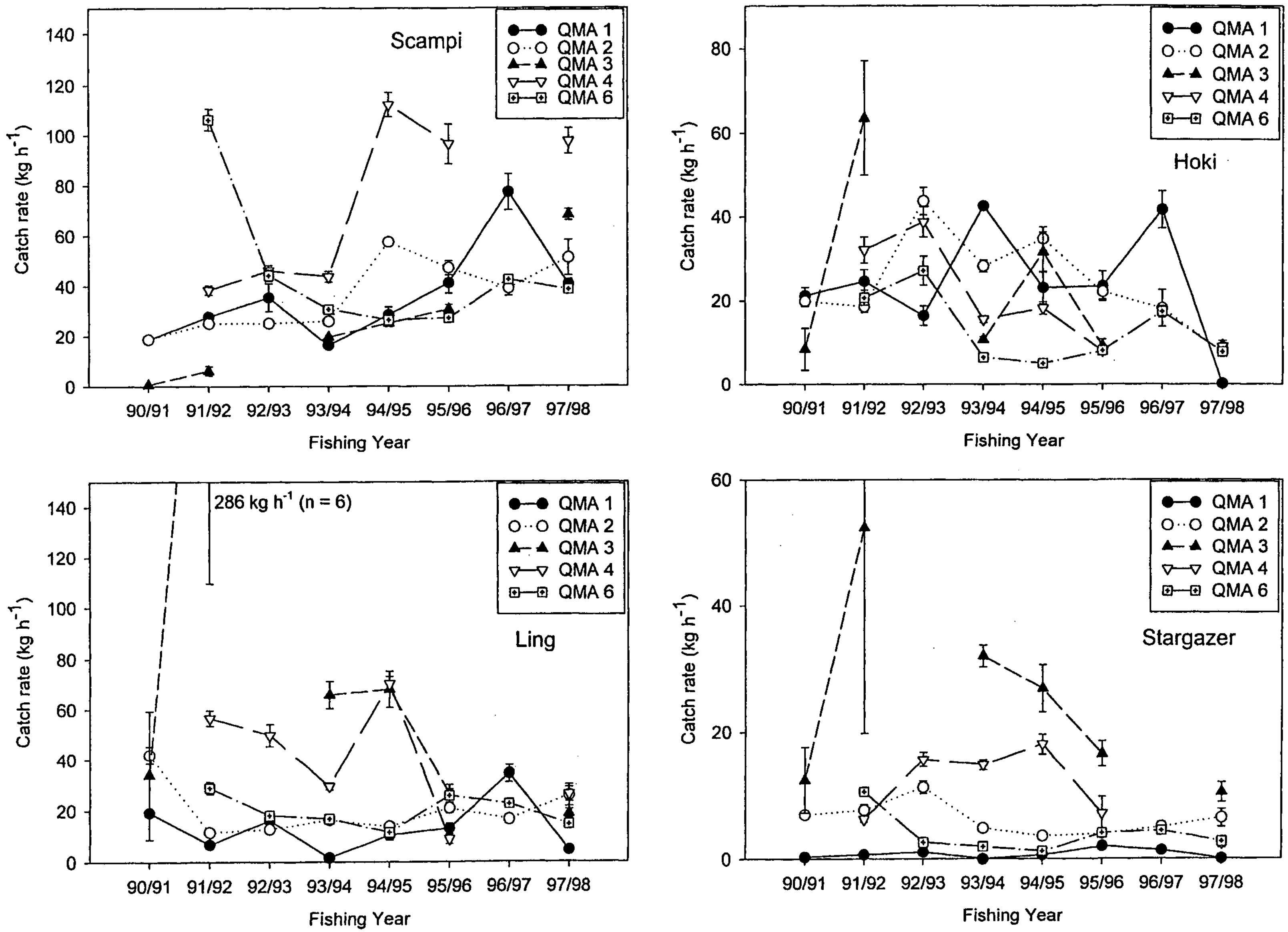

Figure 16: **Unstandardised catch rates (kg h^{-1} ± 1 standard error) of scampi, hoki, ling, and giant stargazer estimated from observer data.**

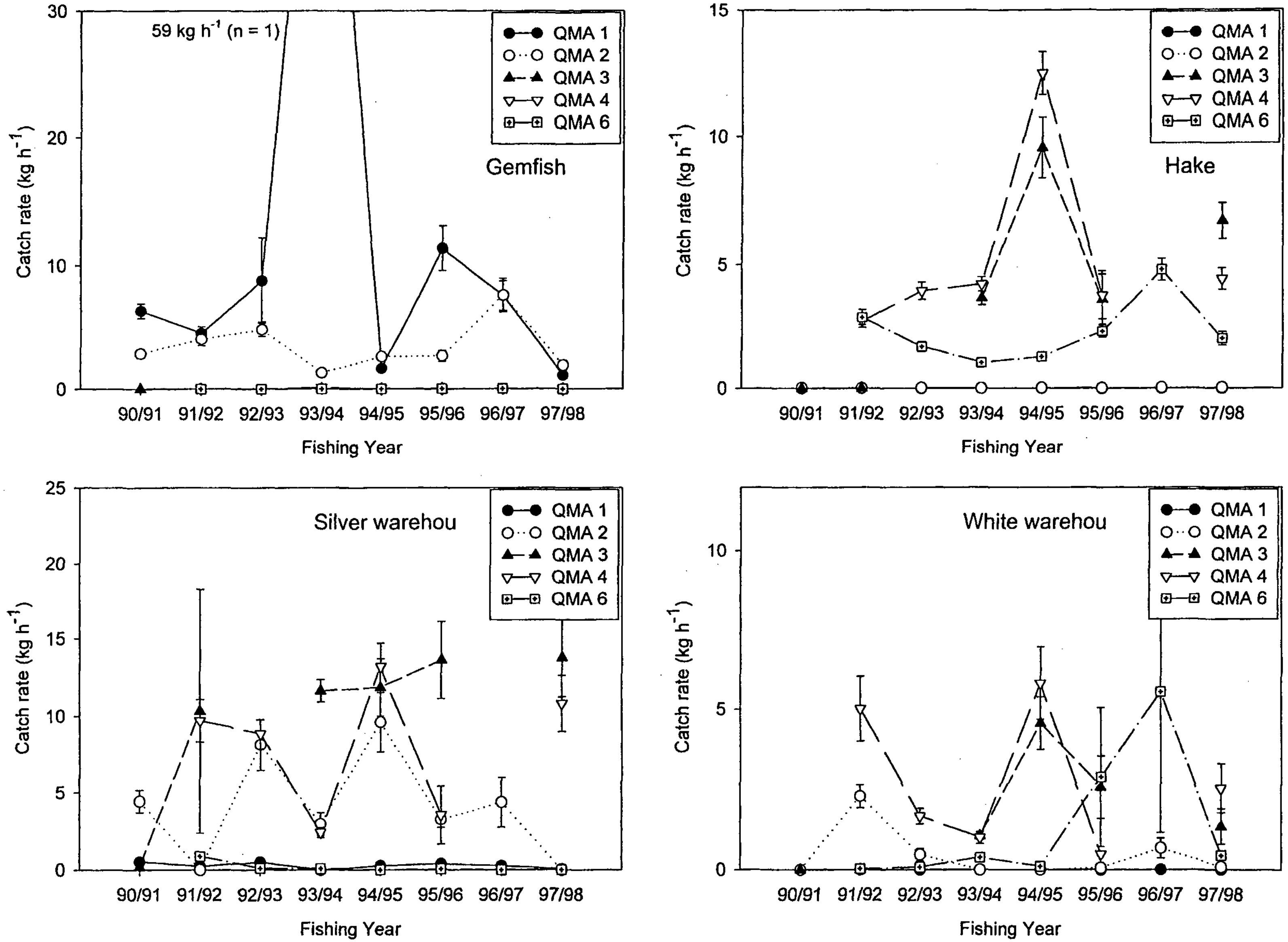

***Figure 17*: Unstandardised catch rates (kg h^{-1} ± 1 standard error) of gemfish, hake, silver warehou, and white warehou estimated from observer data.**

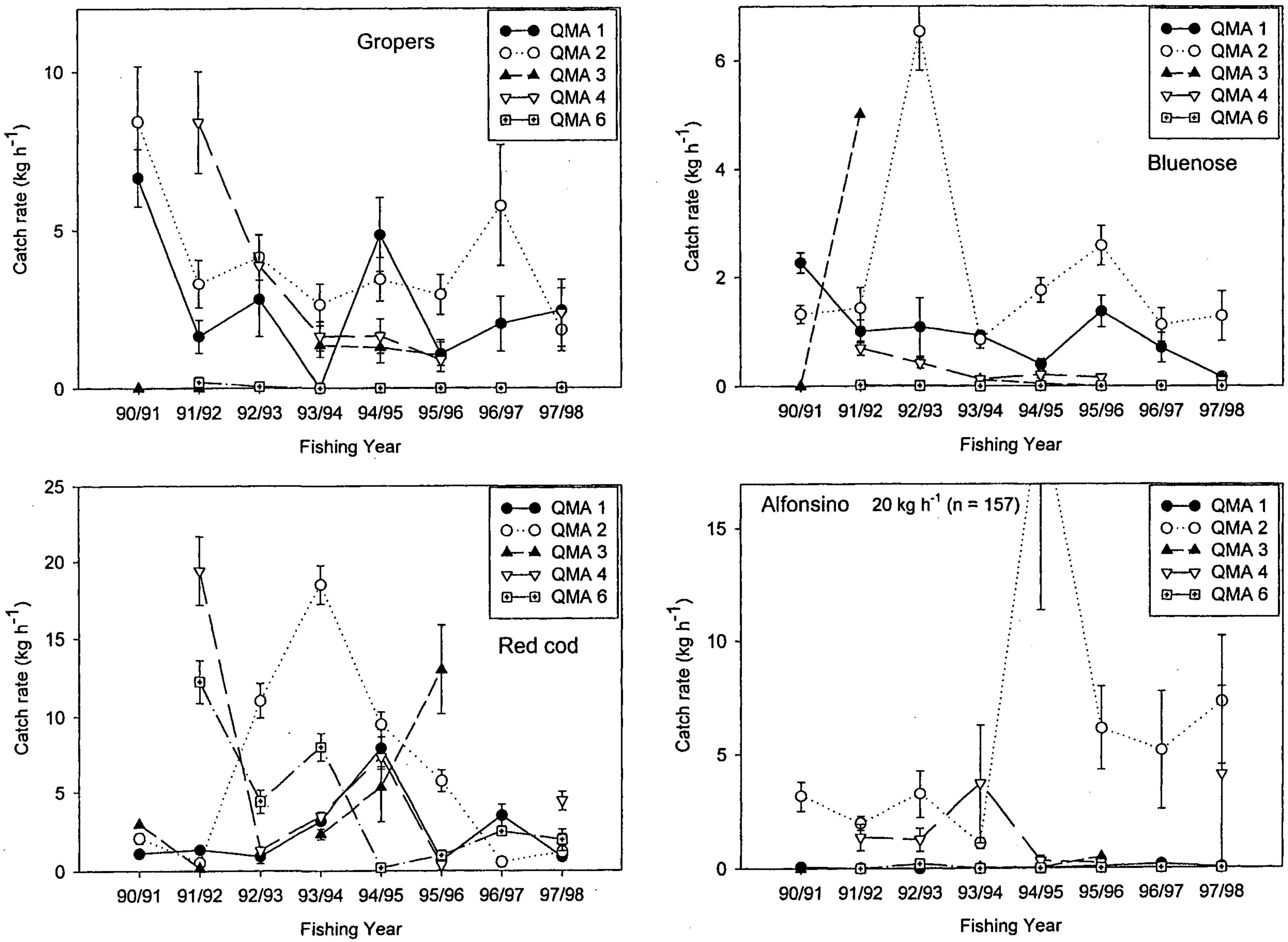

***Figure 18*: Unstandardised catch rates (kg h^{-1} ± 1 standard error) of gropers, bluenose, alfonsino, and red cod estimated from observer data.**

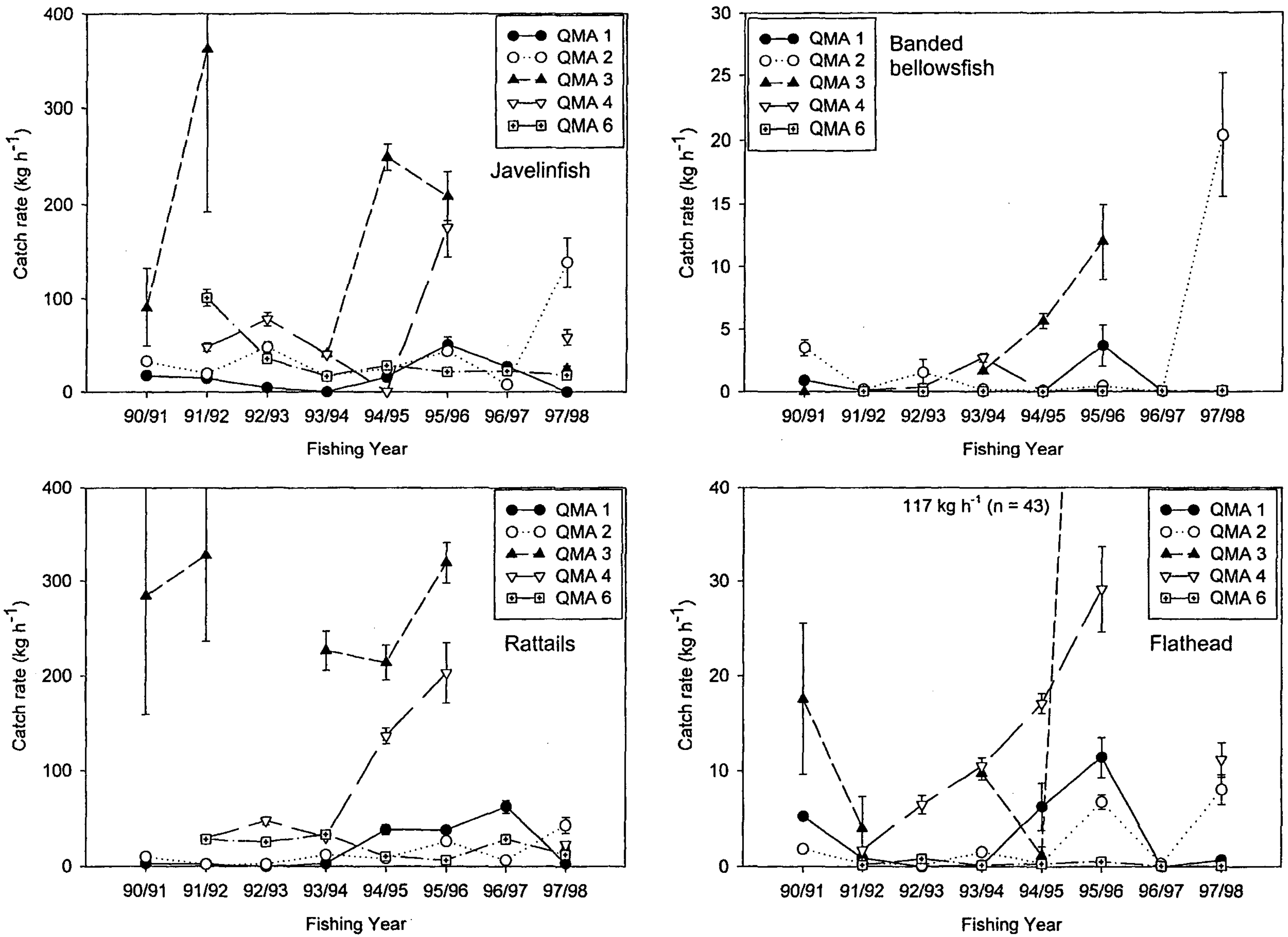

Figure 19: **Unstandardised catch rates (kg h^{-1} ± 1 standard error) of javelinfish, other rattails, banded bellowsfish, and flatheads estimated from observer data.**

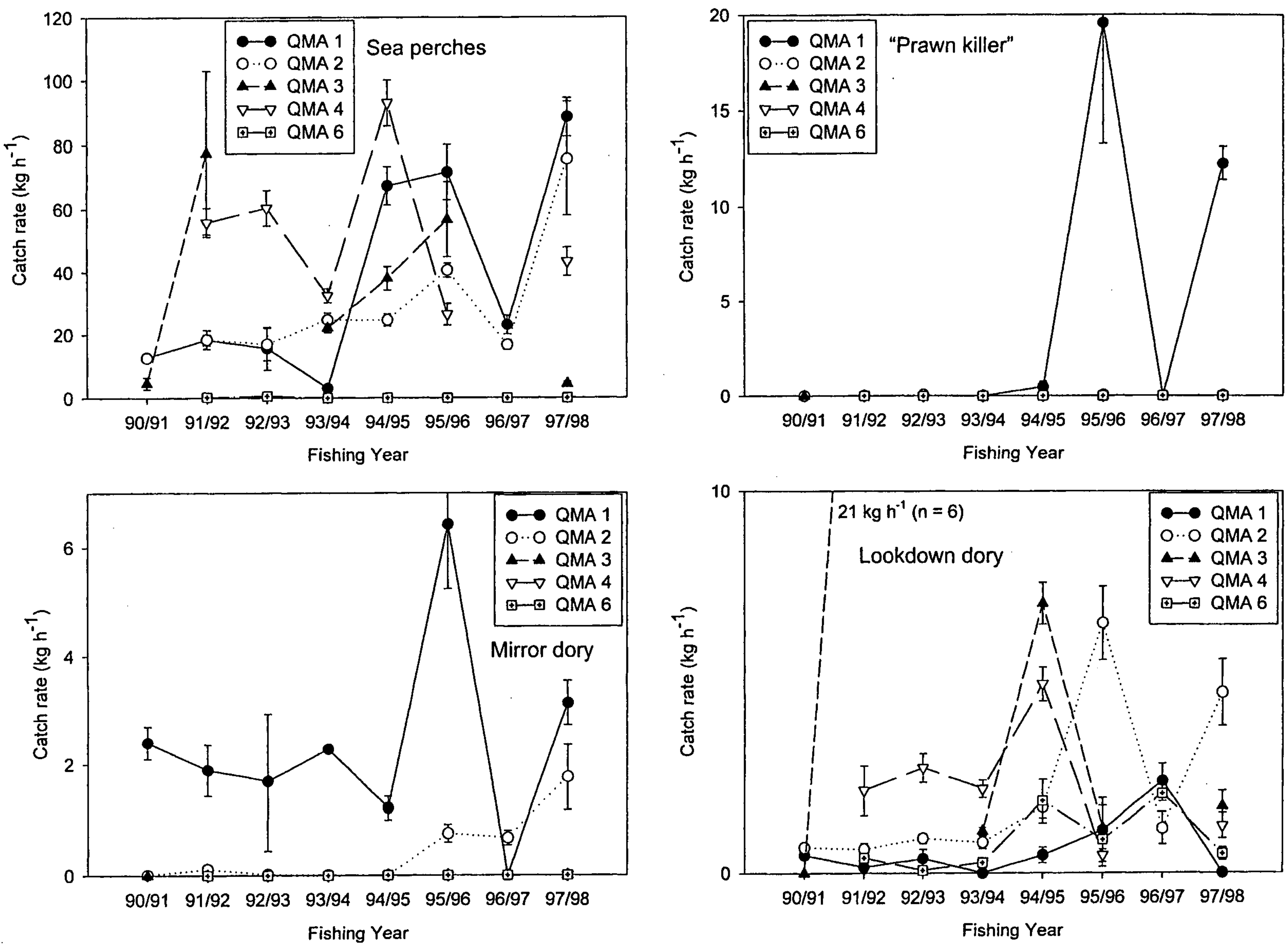

Figure 20: **Unstandardised catch rates (kg h^{-1} ± 1 standard error) of sea perch, "prawn killer", and mirror and lookdown dories estimated from observer data.**

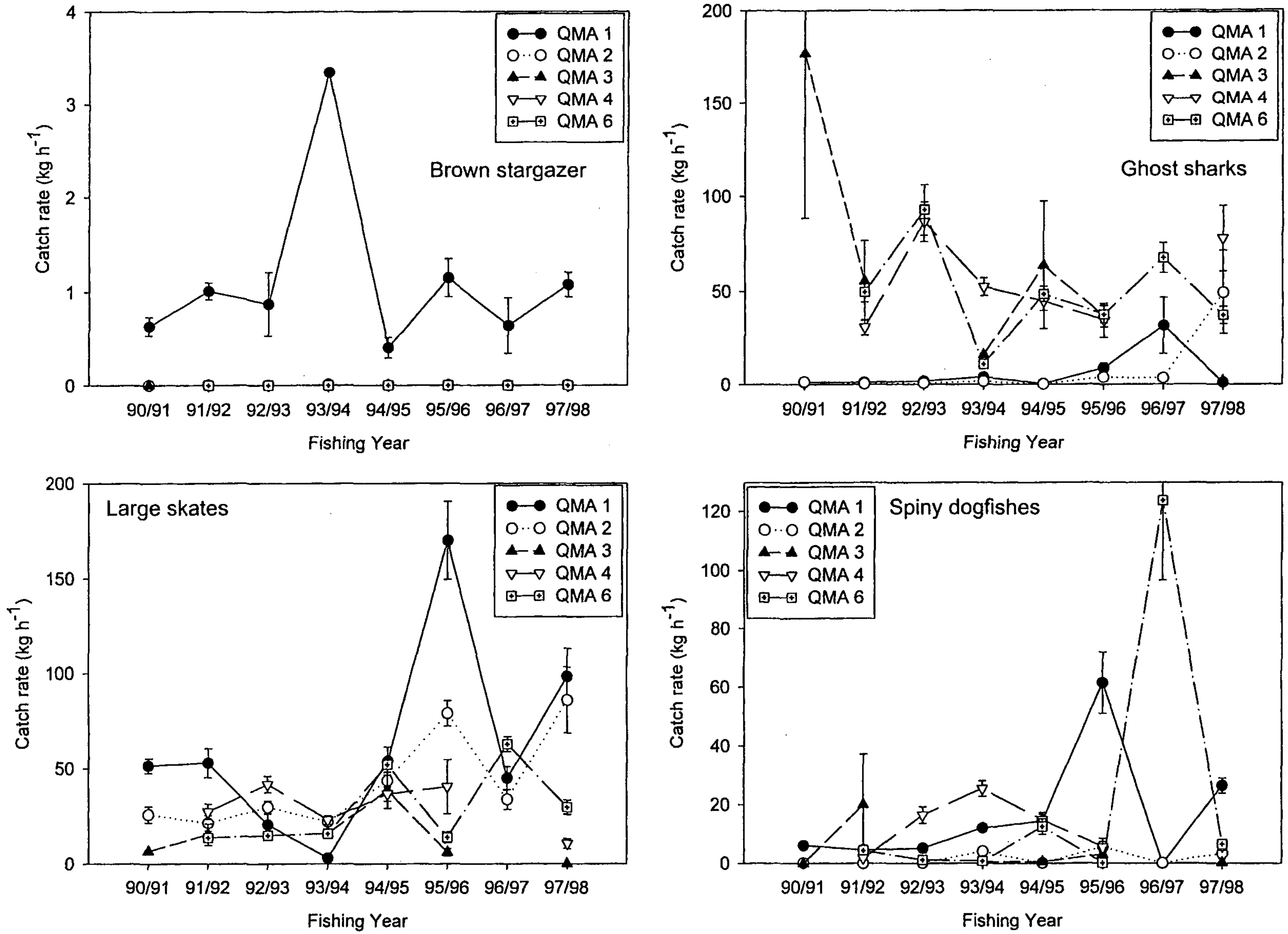

Figure 21: **Unstandardised catch rates (kg h^{-1} ± 1 standard error) of brown stargazers, skates, ghost sharks, and spiny dogfish estimated from observer data.**

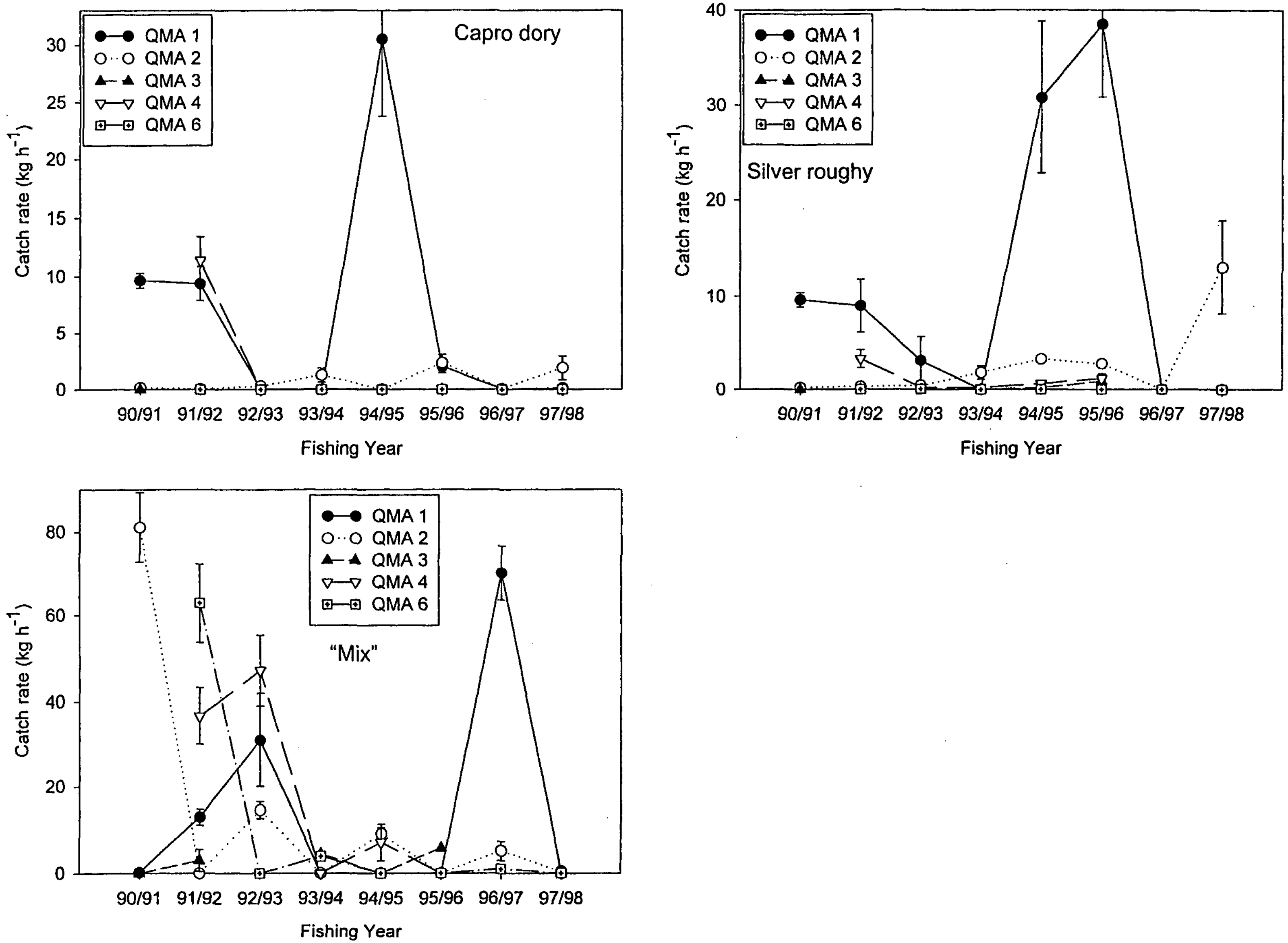

Figure 22: **Unstandardised catch rates (kg h^{-1} ± 1 standard error) of capro dory, silver roughy, and "mixed unspecified small fish" estimated from observer data.**

2.2.3 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 (Cryer *et al.* 1999). 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.

Cryer *et al.* (1999) reported that the length frequency distributions of finfish caught by scampi trawlers were not very different from those caught by target fisheries for the same species in the same area. This comparison can be conducted only for species for which there is an observed target fishery, largely limiting the scope to important QMS species such as hoki and ling. Length frequency distributions for hoki, ling, giant stargazer, and gemfish presented here are not scaled or weighted in any way and represent simple aggregates of all fish measured by observers on board scampi trawlers in each area in each fishing year.

For hoki taken as a bycatch of scampi trawling (Figures 23 and 24), a lower bound to the length frequency distribution at about 50 cm total length is apparent for most areas in most years, although in some years there are additional modes at 35–45 cm which are probably associated with strong recruiting yearclasses. Ballara *et al.* (1998) showed a very similar pattern for the target hoki fisheries.

For ling taken as a bycatch of scampi trawling (Figures 25 and 26), the length frequency distributions are highly variable both by year and by area. Few ling have been measured in QMAs 1 and 2, although small ling (less than 60 cm total length) appear to be more common in the scampi bycatch in the latter area. Observers have measured many more ling in the scampi bycatch from QMAs 3, 4, and 6, and additional ling length frequencies for comparison are available from observers on board hoki trawlers in all three areas, and on board southern blue whiting trawlers in QMA 6. There is a strong indication from observer measurements of ling taken as a bycatch of scampi trawling that many more small ling are taken in QMA 6 than elsewhere in the country (*see* especially Figure 26).

Horn (1999) showed maturity ogives for ling which suggested that males mature at about 75 cm and females at about 85 cm. Comparison of pooled (all years), unscaled, and unweighted ling length frequency distributions from scampi trawling, hoki trawling, and southern blue whiting trawling, and from the target bottom longline fishery (Figure 27) suggest that the proportion of ling likely to be immature was consistently low in the target longline fishery, and about 25% in both scampi and hoki trawl fisheries in QMAs 3 and 4. In the QMA 6 trawl fisheries for hoki and southern blue whiting, the proportion of ling likely to be immature was about 50%, whereas in the scampi fishery, about 75% of the ling bycatch was under 80 cm and likely to be immature.

These comparisons are necessarily coarse because they are based on data pooled over several years and are not weighted by the size of samples and catches. However, unless observer coverage and sampling has been highly unbalanced in one or more of these fisheries, the overall pattern and comparison drawn here should be broadly indicative of the real nature of the ling catch and bycatch. The most striking aspect of the comparison is the high proportion of (probably) juvenile ling taken by the scampi fishery in QMA 6.

Giant stargazers are not frequently taken as a bycatch of scampi trawling in QMA 1, but are commonly taken further south. In QMAs 2, 3, and 4, the modal size is large (50–80 cm) compared with that in QMA 6 (40–60 cm) (Figures 28 and 29). There are few reliable data to allow comparison with other fisheries.

Gemfish are taken as a bycatch of scampi trawling in QMAs 1 and 2. The current target trawl fishery for gemfish is based almost entirely of fish greater than 70 cm fork length (Hurst *et al.* 1999), but the bycatch of scampi trawling includes modest numbers of smaller fish (30–60 cm) in some years (Figure 30), as well as the larger fish seen in the target fishery. Recruitment in gemfish is variable and the gemfish target fishery may include smaller fish in some years.

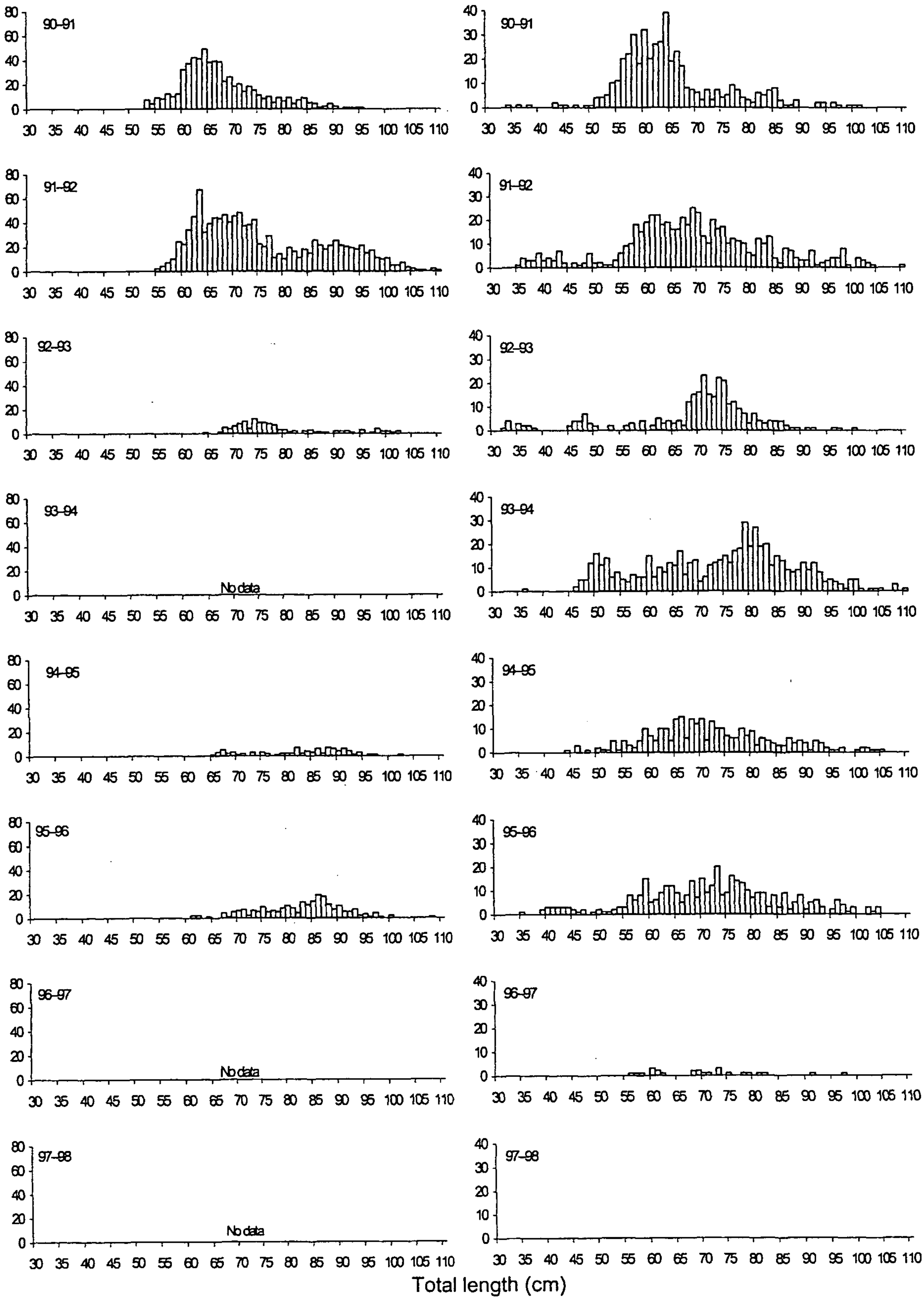

Figure 23: **Length frequency distributions of hoki measured on board scampi trawlers in QMA 1 (left panel) and QMA 2 (right panel) by scientific observers.**

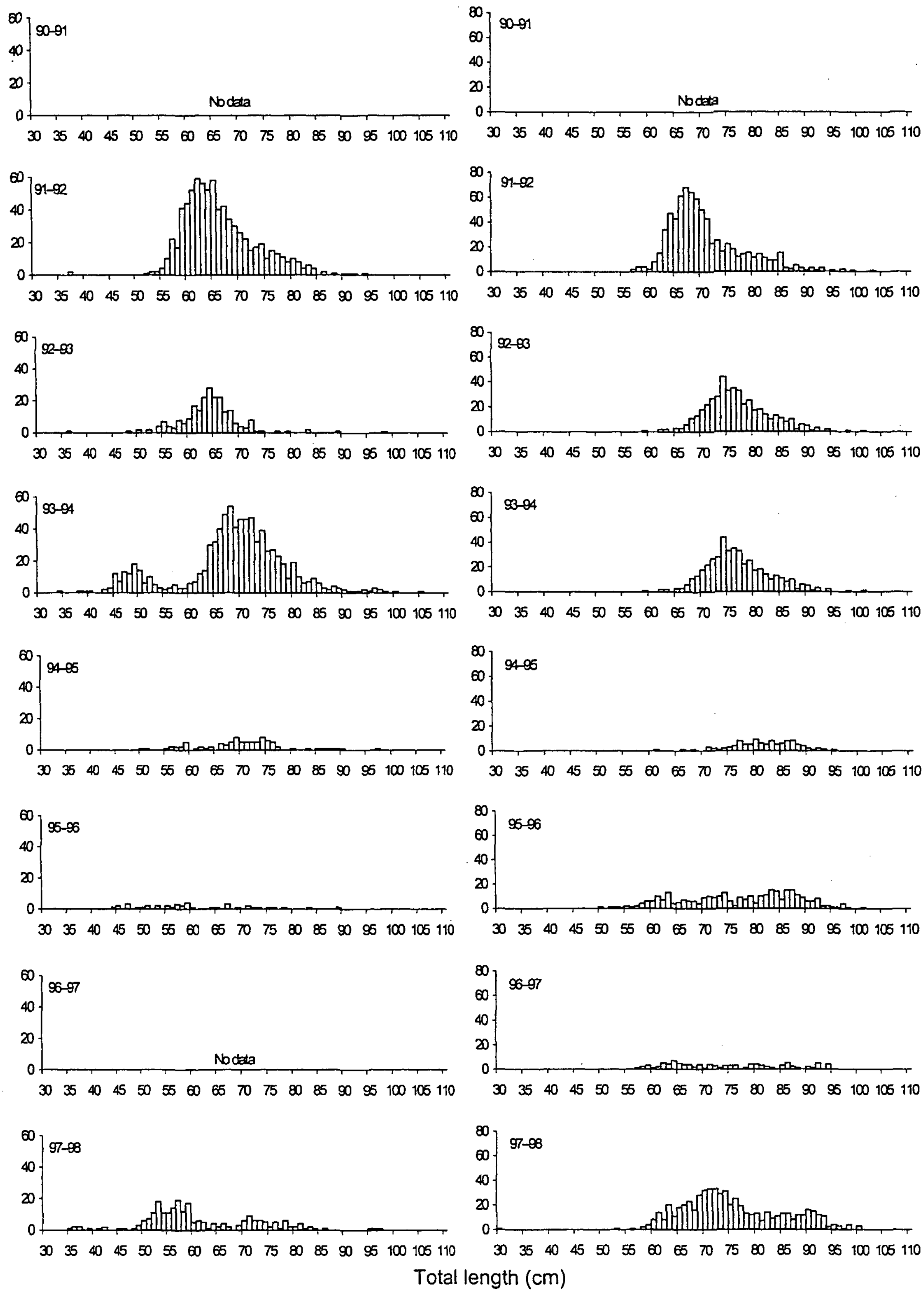

Figure 24: **Length frequency distributions of hoki measured on board scampi trawlers in QMAs 3 & 4 (left panel) and QMA 6 (right panel) by scientific observers.**

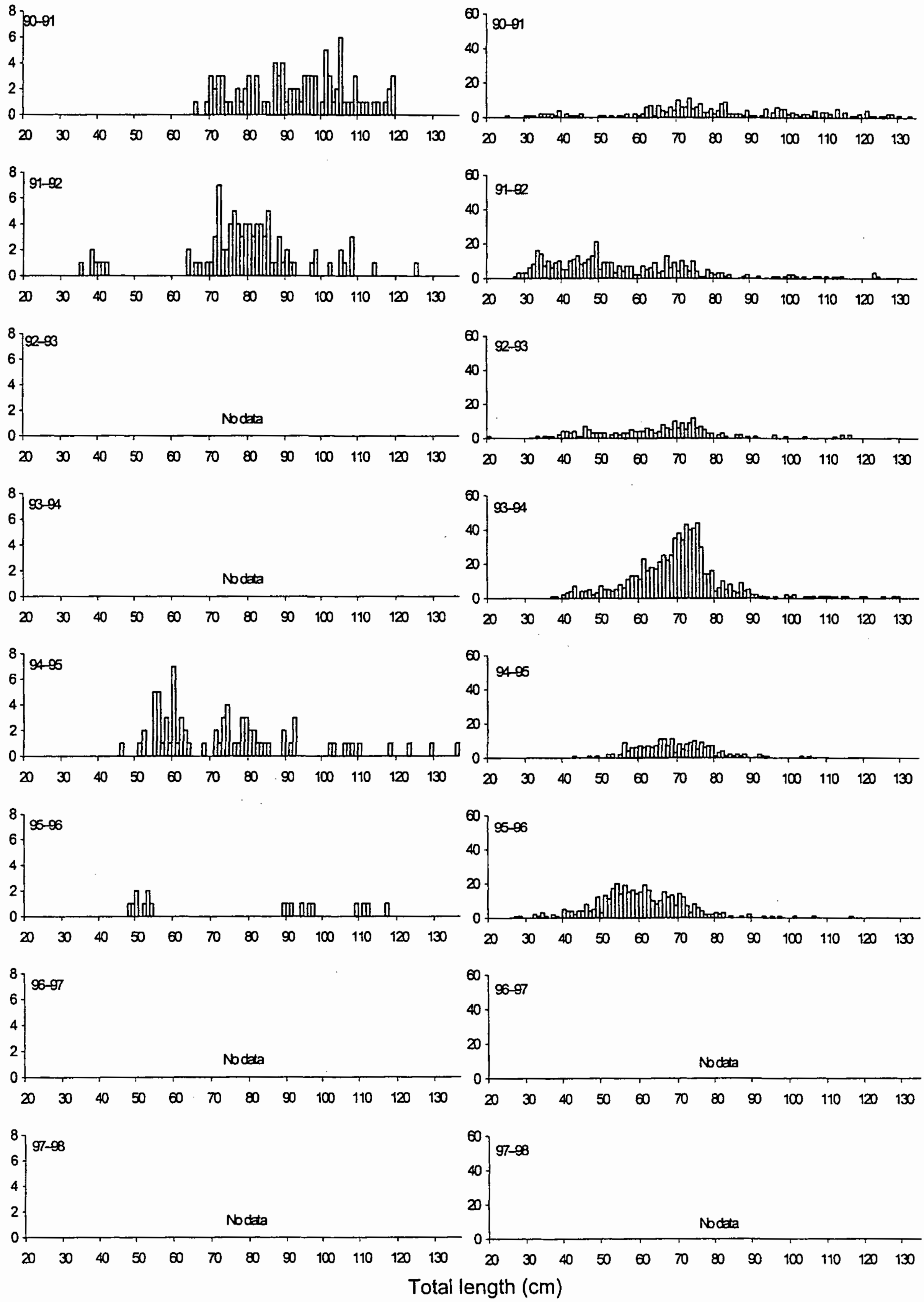

Figure 25: **Length frequency distributions of ling measured on board scampi trawlers in QMA 1 (left panel) and QMA 2 (right panel) by scientific observers.**

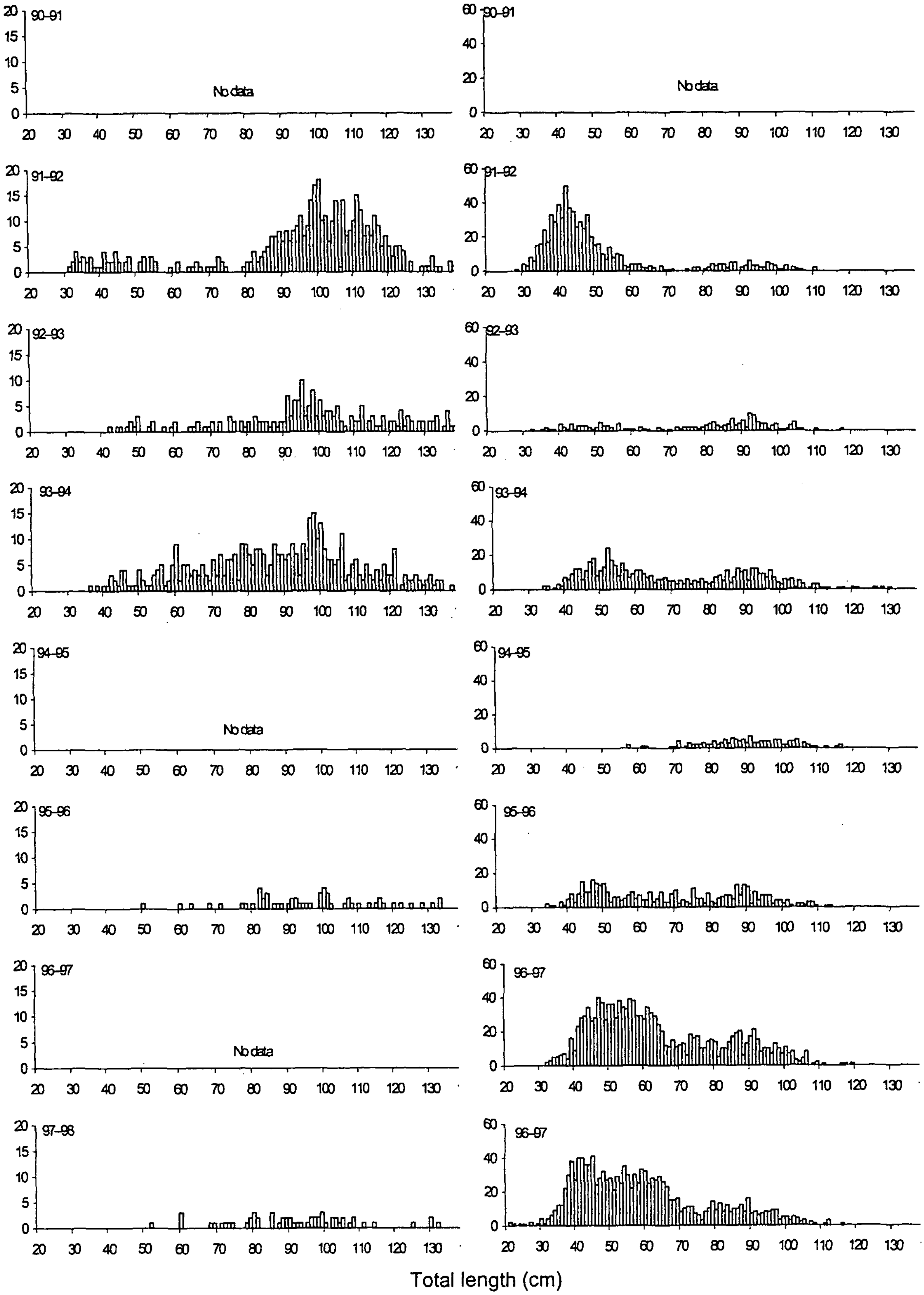

Figure 26: **Length frequency distributions of ling measured on board scampi trawlers in QMAs 3 and 4 (left panel) and QMA 6 (right panel) by scientific observers.**

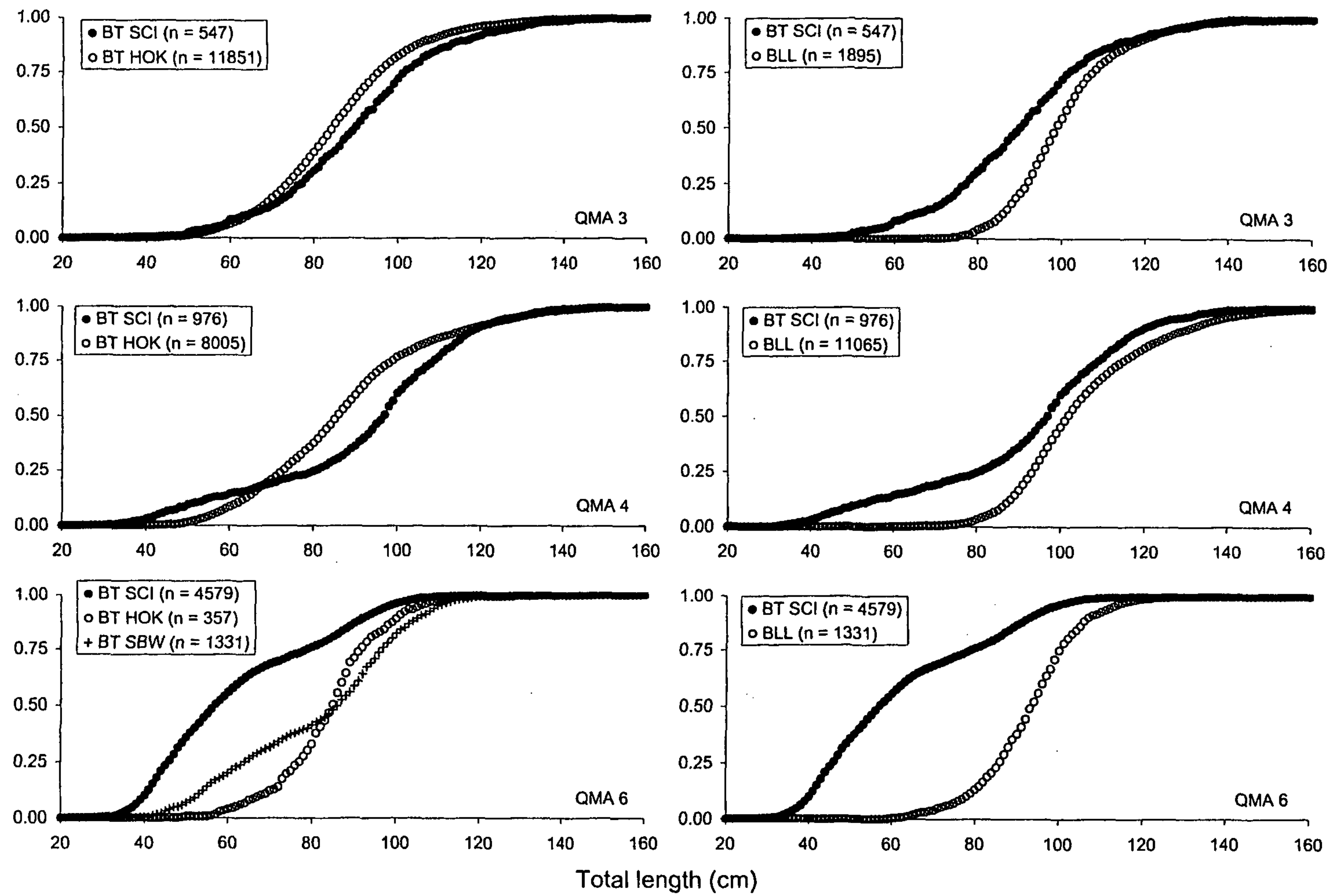

Figure 27: **Cumulative length frequency distributions for ling taken as a bycatch of bottom trawling (left panels) and bottom longlining (right panels) in QMAs 3, 4, and 6 (top to bottom). Data from scientific observers, pooled for all years since 1990–91. Trawl target species and number of ling measured are given for each area. Only target fisheries where more than 300 ling were measured since October 1990 are included.**

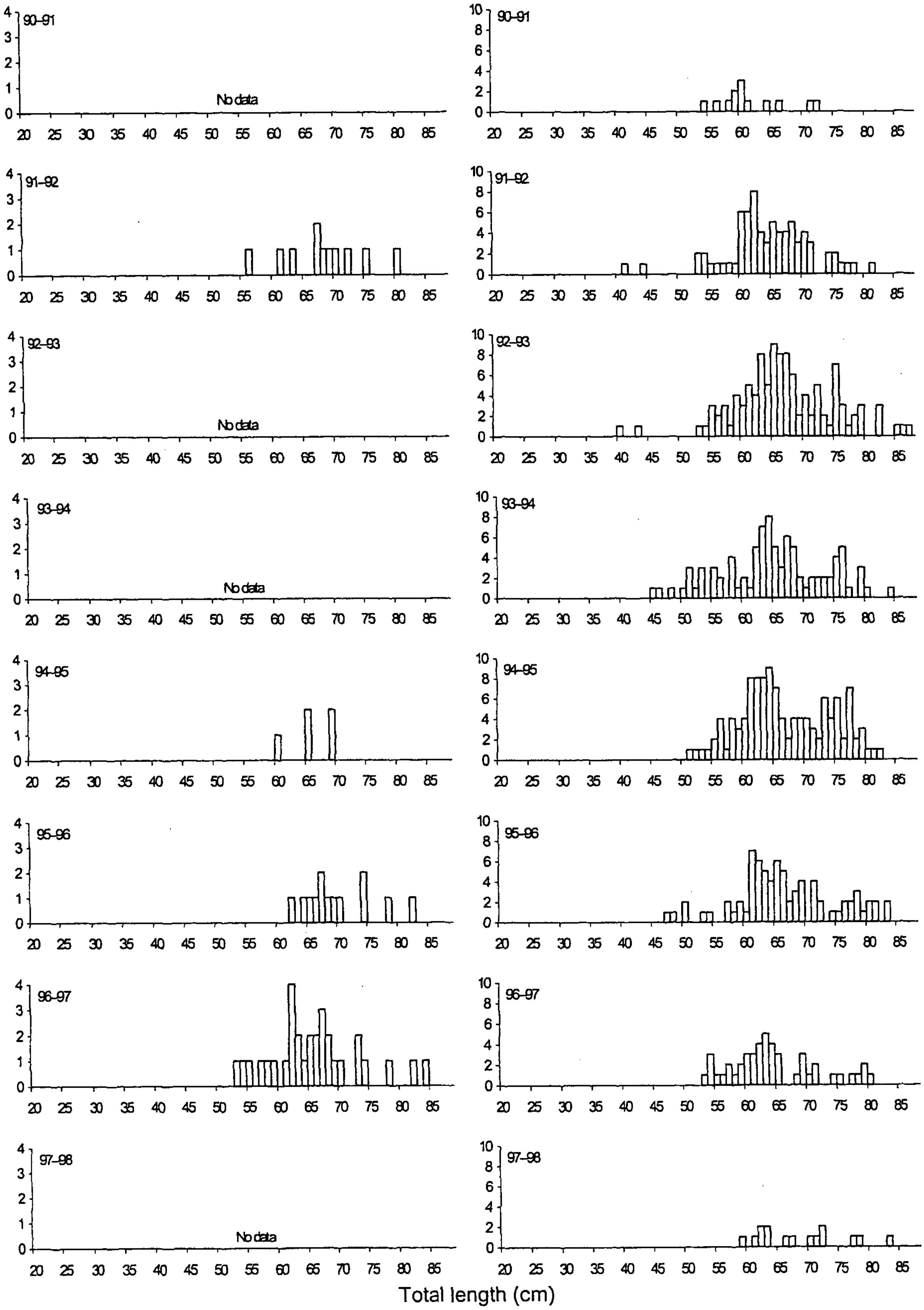

Figure 28: **Length frequency distributions of giant stargazer measured on board scampi trawlers in QMA 1 (left panel) and QMA 2 (right panel) by scientific observers.**

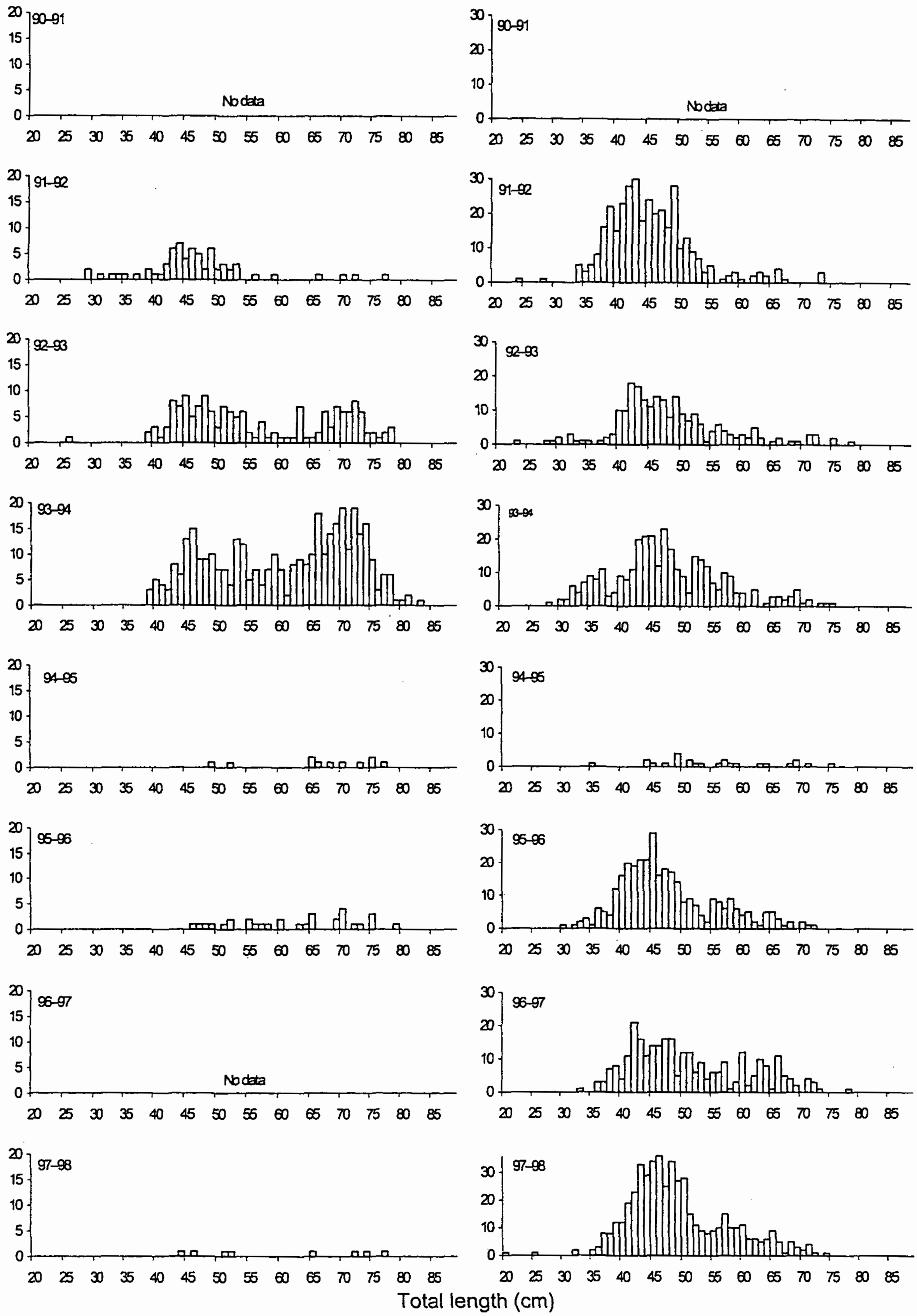

Figure 29: **Length frequency distributions of giant stargazer measured on board scampi trawlers in QMAs 3&4 (left panel) and QMA 6 (right panel) by scientific observers.**

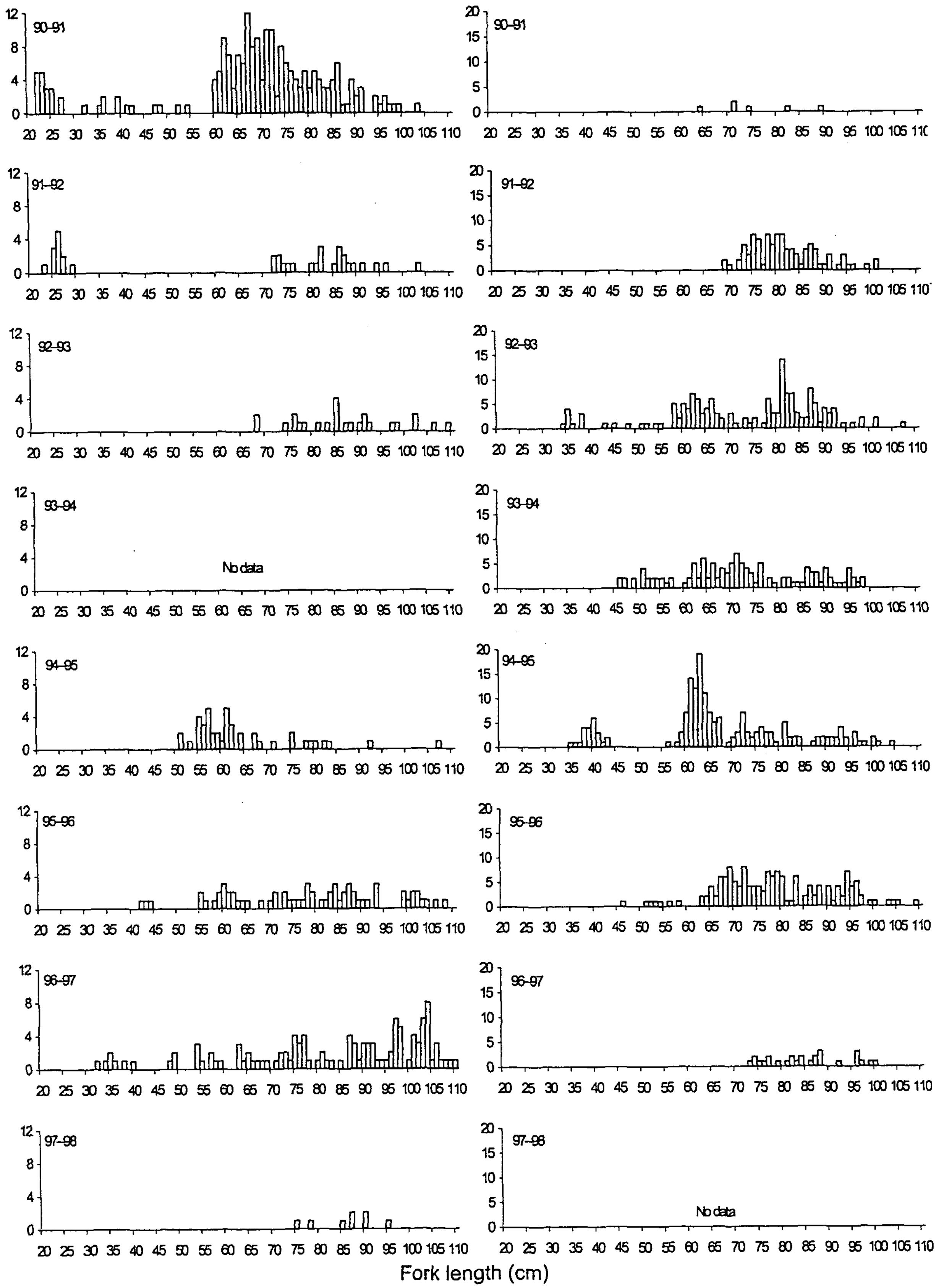

Figure 30: **Length frequency distributions of gemfish measured on board scampi trawlers in QMA 1(left panel) and QMA 2 (right panel) by scientific observers.**

2.2.4 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 recently, by research staff. This complicates any comprehensive temporal analysis of the invertebrate bycatch (Grove & Probert 1998, Cryer *et al.* 1999). However, detailed taxonomic analysis of the invertebrate bycatch of three research voyages in 1996 and 1997 showed a relationship between benthic community structure and fishing history which could be explained by three broad type of hypotheses: benthic community structure had been modified by fishing; or scampi fishing had 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). Information to judge among these general hypotheses was too limited for Cryer *et al.* (1999) to draw further conclusions, but the relationships between fishing pressure and benthic community structure were consistent with the predicted and estimated effects of fishing worldwide (Dayton *et al.* 1995, Thrush *et al.* 1998). No new information on the invertebrate bycatch of scampi trawling has been generated since the 1998 assessment, so the analysis has not been updated.

2.3 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.

2.4 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 experimental estimates of the mortality of trawl-caught scampi taken for scientific purposes. Cryer & Stotter (1997) reported a mortality of 40% over 6 days for lively, undamaged animals (considered suitable for tagging) taken during the summer in QMA 1, whereas more recent work during the winter in QMA 2 suggested that over 90% survival over 6 days was possible. In the commercial fishery, the few discarded scampi are probably badly damaged or very soft, so survival rates of 60–90% would probably be optimistic.

3. RESEARCH

3.1 Stock structure

The stock structure of scampi in New Zealand waters is not well known. Allozyme analyses of animals collected in 1991 and 1994 (Smith 1999) showed a low level of genetic variation (as in *Jasus edwardsii*, Smith *et al.* 1980), but significant heterogeneity in allele frequencies (contrary to the pattern in *Jasus*). There were significant differences at three loci between samples collected from QMA 6A and those from other areas (Smith 1999), but significant differences only at one locus for samples collected from QMAs 1, 2, and 3/4. The abbreviated larval phase (Wear 1976) and lack of large scale migration (Cryer & Stotter 1999) of this species may lead to low rates of gene mixing compared with *Jasus*, which has a long planktonic larval phase and is known to undertake extensive migrations. Size at maturity in *Metanephrops challengeri* also 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.

3.2 Resource surveys

Cryer (1996) presented fully scaled length frequency distributions and sex ratios from trawl surveys in QMAs 1 and 2. Further fully scaled information is available from gear selectivity trials in April 1996, and tagging and its associated trawling activities to estimate growth in September and October 1995 and 1996 (Cryer & Stotter 1997, 1999). Unscaled length frequency distributions are available from commercial voyages where scientific observers were carried. All length frequency distributions generated using trawl methods are likely to be biased by the selectivity characteristics of the gear. During the 1997–98 year, trawling and photographic studies were carried out at 40 stations in the Bay of Plenty (Cryer & Hartill 1998). Density estimates were derived for scampi visible on the surface and for their putative burrows. A length frequency distribution was estimated from the visible animals, although behavioural changes in emergence behaviour with time may mean that even this length frequency distribution is biased.

3.3 Other studies

3.3.1 Estimates of growth rate and natural mortality

3.3.1.1 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 (Cryer & Stotter 1997), and target fishing to recapture these animals was conducted in September and October 1996 (Cryer & Stotter 1999). 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% (Cryer & Stotter 1999).

3.3.1.2 Length frequency analysis

The long-established fisheries in QMAs 1 and 2 have the most comprehensive length frequency data, despite low levels of coverage by scientific observers at times. Simultaneous length frequency analyses using MULTIFAN software (Fournier *et al.* 1990) were conducted 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 (Cryer *et al.* 1999). 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, 1999) was conducted in the same part of QMA 1 as that selected for multiple length frequency analysis, and results from the two methods were compared.

In most MULTIFAN series examined by Cryer *et al.* (1999), the best fitting model had the maximum possible number of age classes and a relatively low von Bertalanffy K (less than 0.10). Few of the von Bertalanffy parameters generated using MULTIFAN were, *prima facie*, consistent with what is known of this species. Most of the estimates of L_∞ were unrealistically large, strongly suggesting that estimates of K were negatively biased (because K and L_∞ are usually very highly negatively correlated in these models, an overestimate of L_∞ usually implies an underestimate of K). This interpretation was 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. This estimate too may be negatively biased because it was derived from returns of 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 MULTIFAN for both sexes in QMA 1 (380–420 m depth) suggest annual increments of the order of 2.0–4.0 mm for large, mature animals, whereas the observed range was -1.0–4.0, with most observations falling below 2.5 mm. However, although this comparison suggested that the MULTIFAN estimates were unrealistic, our overall interpretation of length frequency and tagging studies is that this species grows slowly, has a longevity in the order of 25 years, and has low productivity.

3.3.2 Work for the 1999–2000 fishing year

Work tendered for the 1999–2000 fishing year includes an update of unstandardised CPUE indices, a fuller examination of any changes in fishery characteristics which might explain changes in CPUE, further photographic work, and continuation of the age and growth study started in 1998–99.

3.4 Biomass estimates

3.4.1 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 18, and described in detail by Cryer *et al.* (1998).

Table 18. **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

3.4.2 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.* 1998). Without an index of biomass, modelling and yield assessment will continue to be problematic. Photographic and video methods can give realistic estimates of biomass for *Nephrops norvegicus* (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 Great Mercury and White

Islands, 200–600 m depth. Forty stations were occupied, first by trawl (3 n. 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 were similar to densities observed overseas for *Nephrops norvegicus* (Cryer & Hartill 1998).

Photographic estimates of scampi abundance can be made in several ways, but all are higher than estimates made by trawl (Table 19). 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. Cryer & Hartill (1998) treated these estimates more fully.

***Table 19*: 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

***Table 20*: 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

The results from this camera survey were used by Cryer & Hartill (1998) and Cryer *et al.* (1999) to estimate the minimum absolute abundance of scampi from direct observations of emergent animals

(Table 20). 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.

Given assumed values for the number of entrances per burrow and the average occupancy rate (from Cryer & Hartill 1998), the total absolute abundance of scampi can be estimated from the density of their burrows. 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) (Table 21). 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 21: **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)**

	Mean wt. by trawl (60.45 g)			Mean wt. by photo (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

3.5 Yield estimates

3.5.1 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.

3.5.2 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.

3.5.3 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).

$$\mathrm{MCY} = 0.25 * F_{0.1} * B_0 \text{ or}$$

$$\mathrm{MCY} = 0.50 * F_{0.1} * B_{av}$$

There is no estimate of $F_{0.1}$ for any scampi stock, but Cryer & Stotter (1999) 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 * (0.20–0.25) * 1200 t = 60–75 t or

MCY = 0.50 * (0.20–0.25) * 1200 t = 120–150 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.

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

Again, there is no estimate of F_{ref} for any scampi stock, but Cryer & Stotter (1999) 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 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 Great Mercury 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.

4. MANAGEMENT IMPLICATIONS

There are no reliable estimates of biomass or yield for any QMA, but CPUE analyses developed here and length frequency distributions collected to date (e.g., Cryer 1996, Cryer *et al.* 1998, 1999) 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.

Preliminary 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 (although the 1997–98 standardised indices for many areas are lower than those for 1996–97). 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 3 years to about two-thirds 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 (not mirrored in the 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 world-wide, 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.

5. ACKNOWLEDGMENTS

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Appendix 1: Three letter codes used by scientific observers in reporting the composition of trawl shots for scampi. The interpretation of each code and the number of times each was used between 1991 and 1997 are given, together with the grouping used to separate analyses of bycatch into "fish" and "invertebrate" sections.

Species code	Records	Interpretation	Group
HSL	3	New Zealand (Hooker's) sealion	Mammal
XSH	4	Sooty shearwater	Bird
XXM	1	Unknown — white capped albatross?	Bird
LIN	3670	Ling	Fish
HOK	3475	Hoki	Fish
RAT	2655	Rattail (general)	Fish
STA	2592	Giant stargazer	Fish
JAV	2553	Javelinfish	Fish
RCO	2506	Red cod	Fish
SPE	1959	Sea perch	Fish
GSH	1770	Ghost shark (general)	Fish
LDO	1524	Lookdown dory	Fish
FHD	1463	Deepsea flathead	Fish
HAK	1385	Hake	Fish
SSI	1339	Silverside	Fish
SWA	1251	Silver warehou	Fish
TOA	1217	Toadfish (general)	Fish
MIX	990	Mixed bycatch (probably small)	Fish
SKA	971	Skate (general)	Fish
SSK	952	Smooth skate	Fish
SKI	881	Gemfish	Fish
SRH	781	Silver roughy	Fish
HAG	777	Hagfish	Fish
BNS	776	Bluenose	Fish
WWA	732	White warehou	Fish
SPD	657	Spiny dogfish	Fish
CON	576	Conger eel	Fish
CDO	511	Capro dory	Fish
DSK	507	Deepwater spiny skate	Fish
BBE	470	Banded bellowsfish	Fish
BER	375	Numbfish	Fish
BYX	367	Alfonsino (combined)	Fish
RSK	362	Rough skate	Fish
ERA	329	Electric ray	Fish
CSH	318	Catshark	Fish
MDO	310	Mirror dory	Fish
BEL	292	Unknown — banded bellowsfish?	Fish
SBW	288	Southern blue whiting	Fish
SCH	288	School shark	Fish
RHY	276	Common roughy	Fish
PDG	260	Prickly dogfish	Fish
RIB	241	Ribaldo	Fish
BRZ	214	Brown stargazer	Fish
RBY	214	Rubyfish	Fish
SDO	210	Silver dory	Fish
DCS	205	Dawson's catshark	Fish
BAS	202	Bass	Fish
WIT	199	Witch	Fish
DWD	198	Deepwater dogfish (general)	Fish

Species code	Records	Interpretation	Group
HPB	193	Hapuku & bass (combined)	Fish
PIG	166	Pigfish	Fish
TOP	160	Pale toadfish	Fish
YBO	160	Yellow boarfish	Fish
TAR	156	Tarakihi	Fish
BRC	153	Bastard red cod	Fish
CUC	152	Cucumberfish	Fish
CAR	149	Carpet shark	Fish
FRO	149	Frostfish	Fish
ETL	145	Lucifer's dogfish	Fish
NSD	129	Northern spiny dogfish	Fish
SSH	127	Slender smoothhound	Fish
BSH	120	Seal shark	Fish
JMA	118	Jack mackerel (general)	Fish
API	110	Alert pigfish	Fish
FLA	104	Flatfish (general)	Fish
SCO	102	Swollenhead conger	Fish
SND	100	Shovelnose spiny dogfish	Fish
HCO	96	Hairy conger	Fish
SEE	95	Silver conger	Fish
HAP	92	Hapuku	Fish
OPE	89	Orange perch	Fish
SCG	86	Scaly gurnard	Fish
EEL	82	Unknown — conger eel?	Fish
SBO	82	Southern boarfish	Fish
BTS	80	*Pavoraja* sp. (deepwater skate)	Fish
OSD	80	Other shark or dogfish (general)	Fish
PCO	79	Ahuru	Fish
SBK	78	Spineback	Fish
SBR	75	Southern bastard red cod	Fish
DWE	74	Deepwater eel (??)	Fish
JGU	72	Japanese gurnard	Fish
RAY	70	Rays (general)	Fish
BTH	61	Bluntnose skate (*Pavoraja* sp.?)	Fish
SPO	61	Rig	Fish
SPG	58	Unknown — Southern pigfish?	Fish
BYS	57	*Beryx splendens*	Fish
OFH	56	Oilfish	Fish
LCH	53	Long nosed chimaera	Fish
RUB	53	Rubyfish	Fish
SHA	53	Shark (general)	Fish
LUC	51	*Luciosudus* sp. (waryfish)	Fish
LSK	50	Long tailed skate	Fish
CBE	49	Crested bellowsfish	Fish
SNI	48	Snipefish	Fish
SYN	47	Synaphobranchidae (eel)	Fish
RUD	45	Rudderfish	Fish
BOA	44	Sowfish	Fish
CHX	44	Pink frogmouth	Fish
HEX	41	Sixgilled shark	Fish
LSO	41	Lemon sole	Fish
PLZ	41	Scaly stargazer	Fish
NOT	41	*Paranotothenia* sp.	Fish

Species code	Records	Interpretation	Group
BCD	38	Black cod	Fish
PSY	37	*Psychrolutes* sp. (sculpin)	Fish
STR	34	Stingray (general)	Fish
CHI	33	Chimaera (general)	Fish
GSP	33	Pale ghostshark	Fish
ETM	30	*Etmopterus* sp. (shark)	Fish
HEP	22	Sharpnose sevengill shark	Fish
CBO	19	Bollons' rattail	Fish
GFL	18	Greenback flounder	Fish
JMM	15	Murphy's mackerel	Fish
GON	15	*Gonorynchus gonorynchus*	Fish
PLS	14	Plunket's shark	Fish
SLR	14	Slender roughy	Fish
SPZ	14	Spotted stargazer	Fish
EPO	13	Limp eel pout	Fish
JGH	13	Unknown — Japanese gurnard?	Fish
RAG	12	Ragfish	Fish
YCO	12	Yellow cod	Fish
CDL	11	Cardinalfish	Fish
EMO	11	Blackbelly lantern shark	Fish
MAN	11	Finless flounder	Fish
BYD	10	*Beryx decadactylus*	Fish
RDO	10	Rosy dory	Fish
BCR	9	Blue cusk eel	Fish
EUC	9	Eucla cod	Fish
TOD	9	Dark toadfish	Fish
BAR	8	Baracoutta	Fish
MOK	8	Blue moki	Fish
OPA	8	Opalfish	Fish
ZDO	8	Zenion dory	Fish
ELE	7	Elephantfish	Fish
BCO	6	Blue cod	Fish
MOD	6	Morid cod (general)	Fish
RBM	6	Ray's bream	Fish
STN	6	Southern bluefin tuna	Fish
BWH	5	Bronze whaler shark	Fish
EMA	5	English mackerel	Fish
SEV	5	Broadnose sevengill shark	Fish
ETB	4	Baxter's lantern dogfish	Fish
PSK	4	Longnose deepsea skate (*Pavoraja* sp.?)	Fish
RBT	4	Redbait	Fish
SNA	4	Snapper	Fish
CSQ	4	*Centrophorus squamosus* (shark)	Fish
RPE	3	Red perch	Fish
RSN	3	Red snapper	Fish
SDF	3	Spotted flounder	Fish
APR	2	Catshark	Fish
BEE	2	Basketwork eel	Fish
BPE	2	Butterfly perch	Fish
FLO	2	Flounder (general)	Fish
JAK	2	Unknown — javelinfish?	Fish
OPL	2	Unknown — orange perch?	Fish

Species code	Records	Interpretation	Group
ORH	2	Orange roughy	Fish
ALB	1	Albacore tuna	Fish
BOE	1	Black oreo	Fish
BSK	1	Basking shark	Fish
BSP	1	Bigscale pomphret	Fish
BWS	1	Blue shark	Fish
DEA	1	Dealfish	Fish
DSP	1	Deepsea pigfish	Fish
ECO	1	Prickly shark	Fish
EPL	1	Bigeye cardinalfish	Fish
FHS	1	Unknown — deepsea flathead?	Fish
GUR	1	Red gurnard	Fish
KIN	1	Kingfish	Fish
LFE	1	Longfinned eel	Fish
ODO	1	Sand shark	Fish
PDF	1	Unknown — prickly dogfish?	Fish
PIL	1	Pilchard	Fish
SLK	1	Slickhead (black slickhead?)	Fish
SOL	1	Sole (general)	Fish
SOR	1	Spiky oreo	Fish
TAO	1	Unknown — dark toadfish?	Fish
UEE	1	Umbrella conger	Fish
VNI	1	Blackspot rattail	Fish
YBF	1	Yellowbelly flounder	Fish
TUB	1	*Tubbia tasmanica (stromateoid)*	Fish
SCI	3947	Scampi	Invertebrate
SQU	1505	Arrow squid	Invertebrate
CRB	872	Crab (general)	Invertebrate
WSQ	430	Warty squid	Invertebrate
OCT	426	Octopus	Invertebrate
ANT	350	Anemones (general)	Invertebrate
SFI	340	Starfish (general)	Invertebrate
SPI	318	Spider crab (general)	Invertebrate
MOL	185	Molluscs (general)	Invertebrate
HSI	184	Jackknife prawn	Invertebrate
SCC	178	Sea cucumber	Invertebrate
MIQ	163	Warty squid	Invertebrate
NOS	154	*Nototodarus sloanii*	Invertebrate
PRA	149	Prawn (general)	Invertebrate
ASQ	140	Unknown — arrow squid?	Invertebrate
ASR	114	Starfish (general)	Invertebrate
VOL	113	Volute (general)	Invertebrate
SQX	93	Squid (general)	Invertebrate
GSC	88	Giant spider crab	Invertebrate
CRU	74	Crustacea (general)	Invertebrate
SHL	69	Shovelnosed lobster (*Scyllarus* sp)	Invertebrate
JFI	58	Jellyfish (general)	Invertebrate
SAL	57	Salps (general)	Invertebrate
SUR	47	Kina	Invertebrate
NOG	47	*Nototodarus gouldi*	Invertebrate
SLG	41	Sea slug (general)	Invertebrate
PED	39	Scarlet prawn	Invertebrate
PRK	37	Prawn killer (*Ibacus*)	Invertebrate

Species code	Records	Interpretation	Group
AFO	35	Royal red prawn	Invertebrate
KIC	28	King crab (general)	Invertebrate
SSC	28	Giant masking crab	Invertebrate
ECH	24	Echinoderm (general)	Invertebrate
WHE	24	Whelks (general)	Invertebrate
DWO	21	Deepwater octopus (*Graneledone* sp.)	Invertebrate
CAM	17	Sabre prawn	Invertebrate
NMA	16	*Notopandalus magnoculus*	Invertebrate
ONG	15	Sponge (general)	Invertebrate
OPI	8	Umbrella octopus (*Opisthoteuthis*)	Invertebrate
PLM	8	*Plesionika martia* (prawn)	Invertebrate
OCP	5	Octopus (general)	Invertebrate
ECN	3	Echinoid (general)	Invertebrate
BSQ	2	Broad squid	Invertebrate
CRH	2	Unknown — cephalopod general?	Invertebrate
CRO	2	Unknown — crustacean general?	Invertebrate
SCZ	2	Unknown — scampi?	Invertebrate
SEO	2	Seaweed (general)	Invertebrate
RSQ	2	*Ommastrephes bartrami* (squid)	Invertebrate
COU	1	Coral (general)	Invertebrate
CRA	1	*Jasus edwardsii*	Invertebrate
SLO	1	Spanish lobster	Invertebrate
URO	1	Sea urchin (general)	Invertebrate
VSQ	1	Violet squid	Invertebrate
SER	1	*Sergestes* sp. (shrimp)	Invertebrate
UNI	51	Unidentified (general)	Unusable
POO	49	Unknown — no ideas	Unusable
BLB	20	Unknown — no ideas	Unusable
CAW	9	Unknown — no ideas	Unusable
DSR	6	Unknown — no ideas	Unusable
EGG	6	Fish eggs?	Unusable
SAN	6	Unknown — no ideas	Unusable
ELR	1	Unknown — no ideas	Unusable
SAF	1	Unknown — no ideas	Unusable
SMP	1	Unknown — no ideas	Unusable
ZFO	1	Trash (general)	Unusable
ZOM	1	Trash (metal)	Unusable