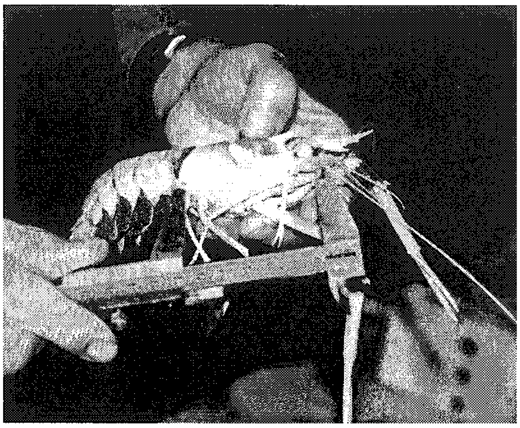
Movement and growth rates of scampi inferred from tagging, Aldermen Islands, western Bay of Plenty

Martin Cryer
Dean R. Stotter



NIWA Technical Report 49
ISSN 1174-2631
1999

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Published by NIWA
Wellington
1999

Inquiries to:
Publication Services, NIWA,
PO Box 14-901, Wellington, New Zealand

ISSN 1174-2631
ISBN 0-478-08470-6

Citation: Cryer, M. & Stotter, D. R. 1999:
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Aldermen Islands, western Bay of Plenty.
NIWA Technical Report 49. 35 p.

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Contents

Abstract

Cryer, M. & Stotter, D. R. 1999: Movement and growth rates of scampi inferred from tagging, Aldermen Islands, western Bay of Plenty. ***NIWA Technical Report 49.*** **35 p.**

Almost 8000 scampi were tagged and released from RV *Kaharoa* in September 1995, and 72 were recaptured between the release voyage and February 1997. None has been returned since. Female scampi were much more likely to be recovered than males, and large animals were more likely to be recovered than small animals. Small males were least likely to be recaptured. Scampi tagged and released during the night were more likely to be recaptured than those tagged during daylight, a pattern consistent with sunlight-induced damage to eyesight demonstrated overseas. An apparent net movement of tagged scampi down the continental slope of about 20 m depth (about 500 m horizontally) was observed, but the extent of net movement along depth contours cannot be determined because of the coarse sampling scale of the trawl recovery method. Estimation of the parameters of a von Bertalanffy growth curve was possible only for female scampi, and classical and modern likelihood methods yielded similar results ($K = 0.11$–0.14). The limitations of these estimates are discussed in relation to the possible effects on growth of trawling and tagging, and the lack of any very small tagged animals. A similar analysis for males was not possible because of the lack of small animals. A published relationship between K and M, the instantaneous rate of natural mortality, suggests that $M = 0.20$–0.25 for female scampi, with a *c.v.* of over 30%.

Introduction

The New Zealand scampi (*Metanephrops challengeri* Balss) is a deepwater clawed lobster in the family Nephropidae. It is widely distributed around the New Zealand coast, principally in depths of between 200 and 600 m on the continental slope (Figure 1). Fisheries for scampi developed in the late 1980s in Quota Management Areas (QMAs) 1 and 2, and subsequently in QMAs 3, 4, and 6 (Cryer 1996). Notwithstanding the size and value of the fishery, few data are available to assess stocks. Assessments between 1995 and 1997 using commercial CPUE and fishery-independent trawl survey indices were not able to generate reliable estimates of current or reference biomass for any scampi stock (Cryer *et al.* 1998). The 1995 Fishery Assessment Plenary agreed that an estimate of stock productivity would probably be more useful than another trawl survey index in early 1996 (Annala 1995). A medium-scale tagging programme aimed at estimating growth rates was considered to be one of the simpler methods of generating such an estimate.

A mark-release-recapture project was devised to provide an estimate of growth rate for scampi in QMA 1. Estimates of growth rate can be used to estimate longevity and mortality rates using published relationships (e.g., Charnov *et al.* 1993) between the K parameter of the von Bertalanffy growth equation and the instantaneous rate of natural mortality, M.

This work was carried out under contract to the Ministry of Fisheries under project SHSP08. Tagging was conducted during 20–30 September 1995 on board RV *Kaharoa* (voyage KAH9511) where M. Cryer was voyage leader and A. Muir was skipper (Cryer & Stotter 1997). Target trawling to recover tags was conducted during 23–27 September and 18–22 October 1996 on board MFV *Drysdale* (voyages DRY9601 and DRY9602) where M. Cryer was voyage leader and W. Steele was skipper. D. Stotter carried out all database maintenance and editing. M. Cryer was the project leader and J. Booth the project director.

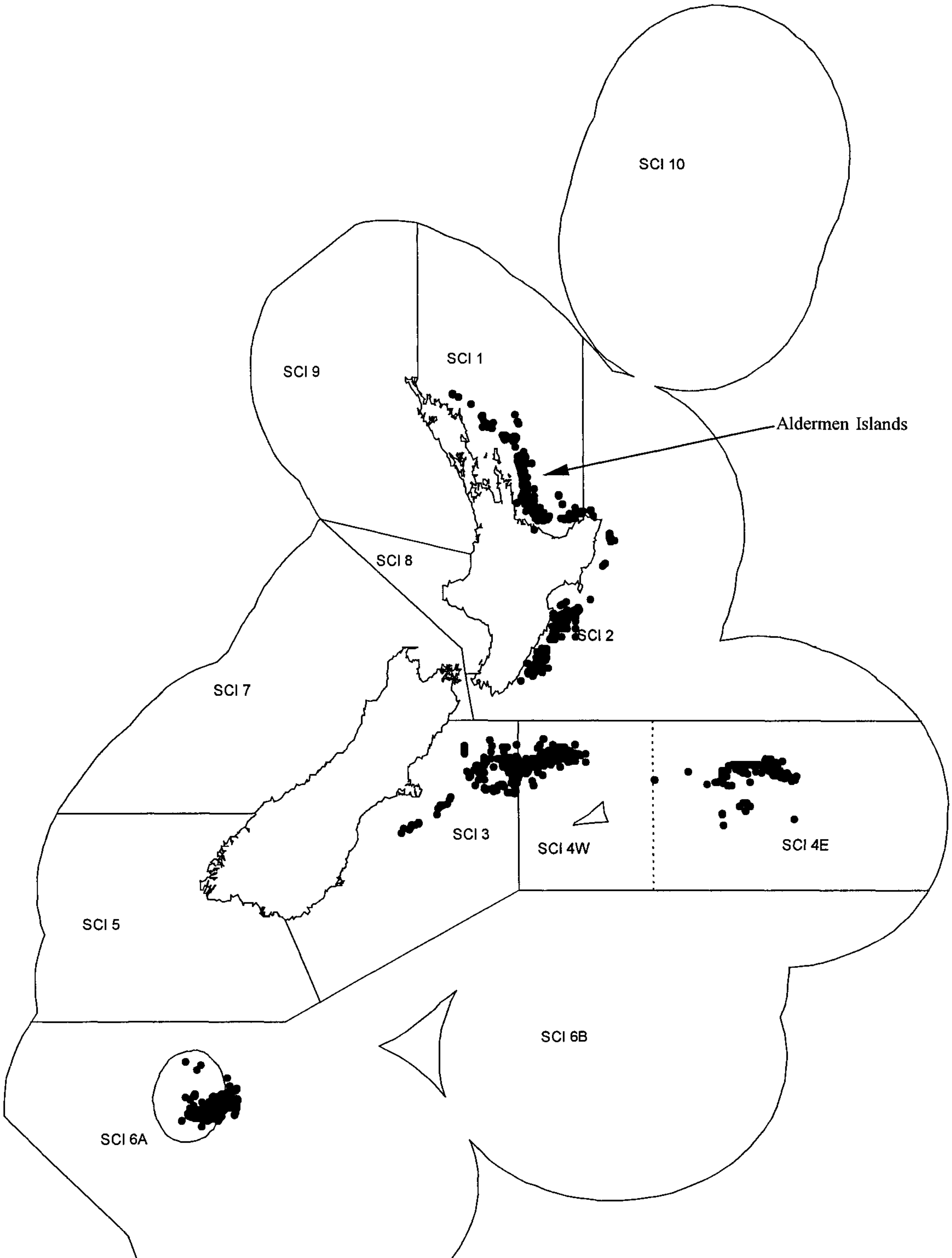

Figure 1: **Fishery management areas and the location of the main fishing areas for scampi, *Metanephrops challengeri*, in New Zealand waters. The approximate location of the Aldermen Islands tagging site (in the middle of the main QMA 1 fishery area) is shown by the arrow.**

Objectives

Project objectives

1. To estimate the growth rate of scampi in QMA 1 (Bay of Plenty) and/or QMA 2 (Napier – Wairarapa).

2. To estimate length and weight at age, maximum age, and natural mortality of scampi for inclusion in production models for estimating yield.

Methods

Vessel and gear specifications

RV *Kaharoa*, the vessel used for the release phase, is a stern trawler with an overall length of 28 m, a displacement of 302 t, and main engine power of 552 kW. The gear used was a single standard "Florida Flyer" net with 80 mm meshes in the body and 35 mm meshes in the codend. Bison doors were used. A net plan was given by Cryer & Stotter (1997).

MFV *Drysdale*, the vessel used for the recapture phase, is a stern trawler with a registered length of 24.9 m, a registered tonnage of 143 t, and main engine power of 578 kW. The gear used on recovery voyages was NIWA's "Florida Flyer" net and NIWA's Bison doors.

A netsonde with pressure-sensitive activator was attached in the middle of the headline for all shots on release and recovery voyages. The netsonde was critical in establishing actual bottom contact time as the sinking rate of this gear can vary dramatically among shots. Trawling was conducted at a target speed of 2.8–3.0 kn.

Capture of scampi for tagging

Trawling to catch scampi for tagging was undertaken at randomly selected depths within a box off the Aldermen Islands bounded by parallels 36° 56.0' and 36° 59.0' S and depth contours 360 and 430 m (Figure 2). Depth contours run at a bearing of about 10° T and are approximately straight in this area. Tows were 20 or 30 min long, depending on the likely catch of scampi (catches were considerably smaller before dawn), and the target towing speed was 3.0 kn.

The first trawl for each day was shot away at or before 0400 h NZDT, the last at or before 1500 h NZDT. Up to seven shots per day were possible. A total of 61 shots was completed (Appendix 1a).

Tagging and release of scampi

The selection of scampi for tagging was based on four criteria: they were lively and responsive when removed from the gear; they were not punctured or crushed in any way; they had not lost more than two appendages, and they were not soft-shelled (recently moulted). As the voyage progressed, smaller animals and more females were selected to ensure that a good spread of sizes of both sexes was tagged. Animals were not tagged in proportion to abundance by size, sex, egg, or moult stage.

Scampi selected for tagging were transferred as soon as possible from the catch to darkened non-draining fish bins of well-aerated seawater chilled slightly with seawater ice. Scampi were tagged using sequentially numbered blue streamer tags (Hallprint type 4S). These were inserted ventrally between the carapace and cuticle of the first abdominal segment through the musculature of the abdomen. For each scampi tagged, a record was made of the sex, the stage of any external eggs, and any damaged or broken appendages or antennae.

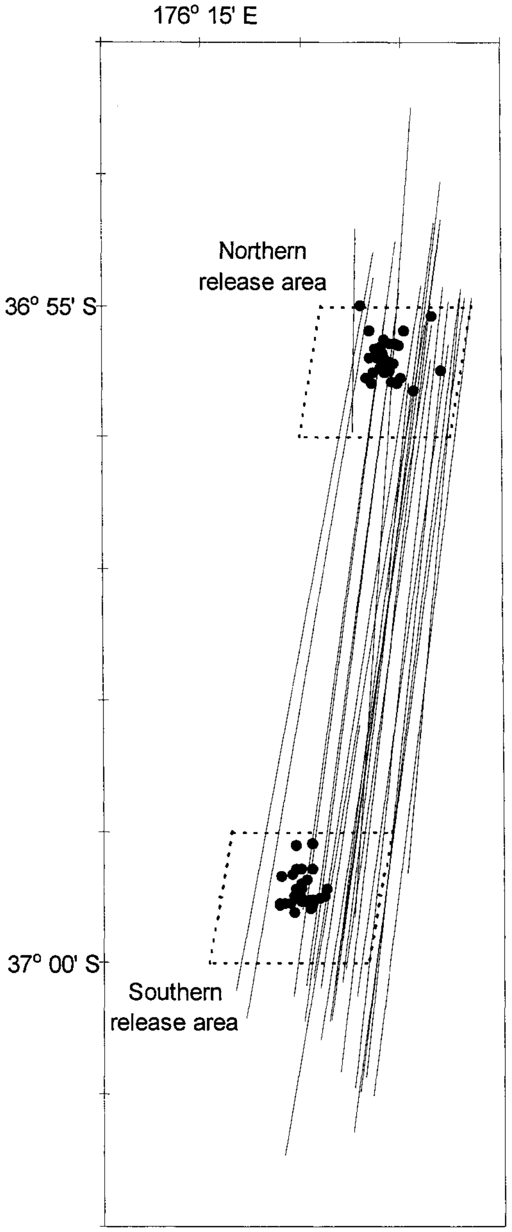

***Figure 2*: Location of tag release boxes (KAH9511, dotted lines), actual release sites (solid dots, location recorded using non-differential GPS at the surface), and recapture shots on DRY9601 (solid lines) and DRY9602 (dashed lines).**

Tagged scampi were returned after a minimum of handling to further darkened non-draining fish bins of well-aerated seawater chilled slightly with seawater ice. To minimise the predation of tagged scampi in mid water and hasten their descent to the seabed, batches of tagged scampi were returned to the sea in brown paper tubes weighted with stones and tied top and bottom with elastic bands and water soluble release clips (made from "Lifesaver" mints). Up to about 100 scampi were returned in each release bag. Prior trials indicated that release clips dissolved in less than 1 h allowing the tubes to open and the scampi to escape. The brown paper tubes took several days to disintegrate.

Tag releases were made in two boxes about 1 mile square each off the Aldermen Islands. The release boxes were immediately north and south of the capture box, and were bounded by parallels 36° 55.0' and 37° 00.0' S and depth contours of 360 and 430 m (Cryer & Stotter 1997). To test the proposition that damage to the retina caused by light is detrimental to scampi survival (Shelton *et al.* 1985), the first, and sometimes the second, batch of tagged scampi each day was returned to the sea before sunrise. Twelve batches of scampi were tagged without exposure to any direct sunlight (1370 individuals or 17% of the total), the remaining 49 batches (6581 individuals or 83% of the total) being exposed to various levels of exposure depending on the time of day and the amount of cloud cover. All tagged scampi were measured (orbital carapace length, OCL, being the linear distance from the rear of the eye orbit to the notch in the trailing edge of the carapace) to the next whole millimetre down using vernier callipers. Release data were stored in the Empress database *tag*.

Tag recaptures

The tagging programme was publicised in *Seafood New Zealand*, requesting that tagged scampi taken by commercial fishers be sent (frozen) to NIWA for analysis, together with the date, location, and depth of capture.

Directed (research) trawling to recapture tagged scampi was undertaken on two voyages scheduled about 12 months after tagging. During the first of these voyages (DRY9601), trawling was conducted at randomly selected depths between 360 and 400 m along tracks designed to cross both release locations between parallels 36° 55.0' and 37° 00.0' S (*see* Figure 2). Shooting and hauling positions were determined so that the gear would be on the bottom throughout both of the release boxes. A warp to depth ratio of 3.0 was maintained, and simple trigonometry was used to estimate that the gear was about 0.6 n.m. behind the vessel during trawling at this depth. Tows were for about 100 min. It appeared from the depth of recaptures during DRY9601 and from discussions with commercial vessels operating in the vicinity that the likelihood of catching tagged scampi was greater in deeper water. Trawl shots during DRY9602 were therefore made in 400–430 m depth. A total of 12 shots was completed during voyage DRY9601 and 14 during DRY9602 (Appendix 1b).

All recaptured scampi were measured with a precision of 0.1 mm (OCL, to the next 0.1 mm down) using vernier callipers. This measurement precision is greater than that used during the release phase. This has implications for subsequent analysis. Recapture data were stored in the Empress database *tag*.

Estimation of variability of measurements

A sample of 61 relatively undamaged tagged scampi was selected from the pool of 72 recoveries. In a quiet laboratory, each of three readers measured OCL for each of the scampi twice on the left-hand side of the animal to the next 0.1 mm down using vernier callipers. The repeat measurements were separated by at least 2 hours. In addition, one of the readers measured each of the animals a third time, but on the right side of each animal.

Estimation of growth rate

General approach

Scampi, in common with other crustaceans, can only increase in size following a moult, resulting in a "stepped" growth curve which cannot be summarised in a single two or three parameter curve. However, as the necessary data on the (length- or age-specific) frequency of moulting and increment at moult for the construction of a stepped curve are not available, it is assumed that the von Bertalanffy equation is a reasonable description of average growth in scampi, at least for the larger size classes susceptible to capture by trawl:

$$L_t = L_\infty.(1 - e^{-K(t-t_0)}) \tag{1}$$

where L_∞ is the asymptotic length and K is a constant known as Brody's growth coefficient (describing the rapidity with which annual increments in length decrease with age). The term t_0 defines the hypothetical age at which an individual would have been zero length had it always grown in the manner described by this equation. Often this equation describes growth well only for larger individuals (Ricker 1975).

Two methods were used to estimate the overall growth rate of scampi from tag return data: the classical method of Ricker (1975) and the likelihood-based method of Francis (1988). The former method requires time at liberty to be close to 1 year, whereas the latter approach has no such requirement.

For both methods of estimating growth, the higher precision of measurement at recapture compared with release leads to a problem of estimating the growth increment between release and recapture. If release measurements (to the next whole millimetre down) are used unmodified, then a positive bias averaging 0.5 mm will be introduced when the increment is calculated using recapture measurements made to the 0.1 mm down. This was addressed by adding 0.5 mm to the release measurement for each animal:

$$\Delta L = L_{recapture} - (L_{release} + 0.5) \tag{2}$$

where ΔL is the increment and the L_{sub} are the lengths (OCL) at release and recapture.

Ricker's method

The starting point for this method is a plot of L_{t+1} against L_t, the lengths of individuals or age classes at two points in time about 1 year apart. Walford (1946) showed that:

$$L_{t+1} = L_\infty(1-k) + k.L_t \tag{3}$$

where k is a constant known as Ford's growth coefficient, related to the von Bertalanffy K by:

$$k = e^{-K} \tag{4}$$

From (2), the slope of a regression of L_{t+1} against L_t is equal to k, from which K can be estimated using (3). In addition, L_∞ can be estimated from the Y intercept at $L_\infty(1\text{-}k)$. As the absolute age is not known for any of the individuals released, it is not possible to estimate t_0, and it is assumed to be zero.

This method assumes that the tags are all recovered after exactly 1 year (or, with slight modifications, after some other time period). As the scampi tag returns were not so conveniently distributed in time, a censored data set was selected from the pool of available data by excluding all recaptures with a time at liberty of less than 90 d or more than 370 d. It was considered *a priori* that moulting (and increase in size) was quite likely to occur quite soon after the release voyage (probably in the summer, e.g., Nichols *et al.* (1987), Howard (1989) for *Nephrops norvegicus*) and that moulting, at least for reasonably large animals, is an annual event. The short-term recaptures were excluded to minimise the probability of including in the analysis scampi which had not moulted, and the long-term recaptures were excluded to minimise the probability of including scampi which had moulted twice.

Francis's method

Francis (1988) described a likelihood method of estimating the average annual increment in size for two arbitrary initial sizes selected by the user to cover the spread of the available data. This method does not require that the time at liberty be close to 1 year and indeed can be used to explore patterns in length increment with time at liberty to derive seasonal growth functions. This method was used with the whole, uncensored data set of 43 females.

Francis cautioned that length-based tag return data are not directly compatible with age-based growth functions such as that of von Bertalanffy. However, the two expected annual increments at arbitrary size can be used to estimate the most likely values of the von Bertalanffy parameters K and L_∞ as follows:

$$K = -\log_e\left(1 + \frac{\Delta L_1 - \Delta L_2}{L_1 - L_2}\right) \qquad (5)$$

$$L_\infty = \frac{L_2.\Delta L_1 - L_1.\Delta L_2}{\Delta L_1 - \Delta L_2} \qquad (6)$$

where L_1 and L_2 are the two arbitrary sizes, and ΔL_1 and ΔL_2 are the respective estimated average annual increments.

Estimation of uncertainty by bootstrapping

For both Ricker and Francis methods, the standard errors of the parameter estimates were estimated by bootstrapping. Random selections of the original sample size were drawn, with replacement, from the censored or uncensored data set, respectively. For each of 200 bootstrap replicates, K and L_∞ were estimated using Equations 3–6 and the results stored. The standard deviations of the bootstrap replicate estimates of K and L_∞ were considered estimates of the standard errors of these parameters, from which their *c.v.*s can be estimated.

Other data collection

Standard station and catch records were completed for all shots on all three voyages. Start and finish latitudes and longitudes and stratum codes defined the ship's position for each shot, and all environmental variables on the forms were recorded. The exact start and finish locations of the gear during trawling can be calculated from the ship's location, together with warp lengths, depth of water, and an observation that the gear did not lift from the seabed until about 400 m of wire had been retrieved.

The weight of scampi caught on each tow was estimated by direct weighing using motion-compensating scales. Length-frequency distributions of 10–25 kg of scampi (depending on the available time and the catch of scampi), and egg and gonad stages for all females from within such samples, were collected for all tows. Catch weights of all bycatch species were collected from each tow. For Quota Management System (QMS) species and large non-QMS species, estimation was by direct weighing, whereas for smaller QMS species estimation was by sorting and weighing of sub-samples. Length frequency data were collected for all QMS species and dories.

The average bottom temperature was recorded for almost all tows. The temperature readout from the netsonde was calibrated accurately on deck during the voyage by immersing the transponder in a large bin of water constantly refreshed from the deck hose (about 15 °C) together with the receiver and a mercury in glass thermometer accurate to 0.1 °C. Both records were within 0.1 °C of one another.

All data other than the details of released and recaptured tagged scampi were stored on the Empress database *trawl*.

Results

Tag releases

An overall average of 24% of scampi by weight was selected for tagging, ranging from about 80% in small catches to about 10% in large catches (Figure 3). The maximum weight of scampi tagged from any given shot was about 9 kg, this being an operational limit rather than a restriction caused by shortage of suitable animals. Only during pre-dawn shots, when catches of scampi were lower, was tagging restricted by the availability of suitable animals.

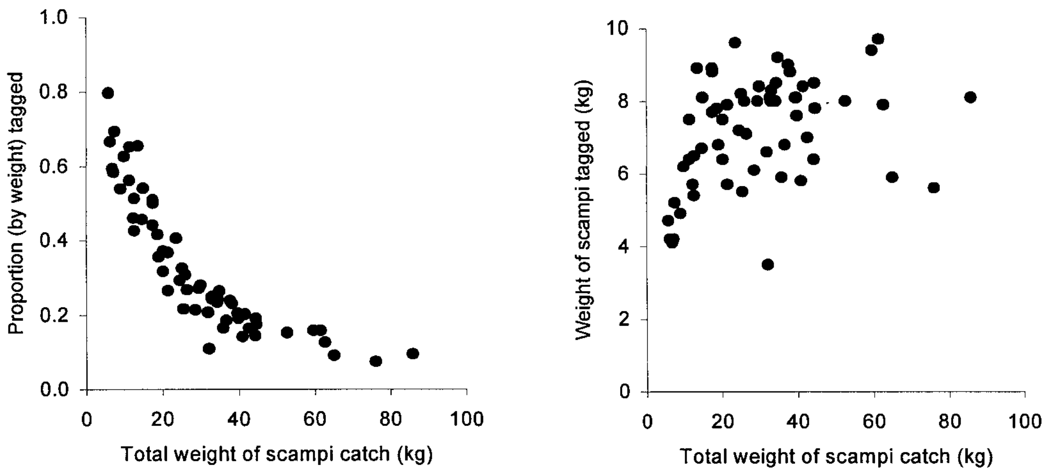

***Figure 3*: The proportion of the total catch of scampi (left) and the total weight of scampi (right) accepted for tagging from each shot during the release voyage.**

A total of 8001 animals was tagged, 50 of which were used in a mortality experiment (Cryer & Stotter 1997) and the remaining 7951 (4605 males and 3346 females) were released. The locations of the release areas to the north and south of the capture box are shown in Figure 2 and the locations of particular release sites are summarised in Appendix 2. The length frequency distributions of tagged scampi and those rejected for tagging without any exposure to sunlight are shown in Figure 4. Comparable length frequency distributions for scampi exposed to sunlight are shown in Figure 5.

Tag recaptures

During the release voyage (KAH9511), eight tagged scampi were recaptured alive. Five of these were caught during trawling operations to capture scampi, although capture and release sites did not theoretically overlap (Cryer & Stotter 1997), indicating some drift during descent to the seabed, or movement by tagged animals. The other three were caught on the last shot of the voyage which was deliberately located through the northern release site. All live recaptured animals appeared lively and in good condition. One further tagged scampi was recovered dead from the stomach of a ling caught on the northern release site on the last shot. Subsequent recaptures were made throughout the year following release, although there was some concentration of recaptures after about 4 months and again after about 12 months from release (the latter from both research and commercial fishing).

Target trawling for tagged scampi through the release sites during voyages DRY9601 and DRY9602 yielded only three and six tagged animals respectively. Commercial fishers returned the remaining 55 tag recoveries (Appendix 3).

Probability of recapture

Sex, size, time of day (especially with regard to exposure to sunlight), and depth at release were examined to assess the extent to which they might affect the probability of recapture of tagged scampi (Table 1).

Of the 72 recaptures, 27 were males and 45 were females. Of these, seven males and five females were caught within about 30 days of release. If the short term recaptures are excluded, then it appears that males are significantly less likely to be recaptured than females (contingency table, $\chi^2_1 = 14.98$; $p < 0.001$, Table 1). This contingency appeared to be stronger for small animals (less than 48 mm carapace length: $\chi^2_1 = 31.06$, $p < 0.001$) than for large animals (greater than 48 mm carapace length: $\chi^2_1 = 0.02$, $p = 0.90$). Animals not exposed to sun (i.e., trawled, tagged and released before dawn) were also more likely to be recaptured than those exposed to sunlight ($\chi^2_1 = 7.38$, $p = 0.007$), although the exact timing of release (morning *vs* afternoon) did not seem to affect the likelihood of recapture ($\chi^2_1 = 0.001$, $p = 0.98$). The two sexes appeared equally likely to be recaptured if released before dawn ($\chi^2_1 = 0.04$, $p = 0.84$), but males released after dawn were less likely to be recaptured than females ($\chi^2_1 = 19.38$, $p < 0.001$).

The mean depth at release of tagged scampi that were eventually recaptured (after a time at liberty of 90 d or more) was almost identical to the mean release depth of all tagged scampi (378 m for both males and females). From this, it is inferred that the probability of recapture was not contingent on depth of release.

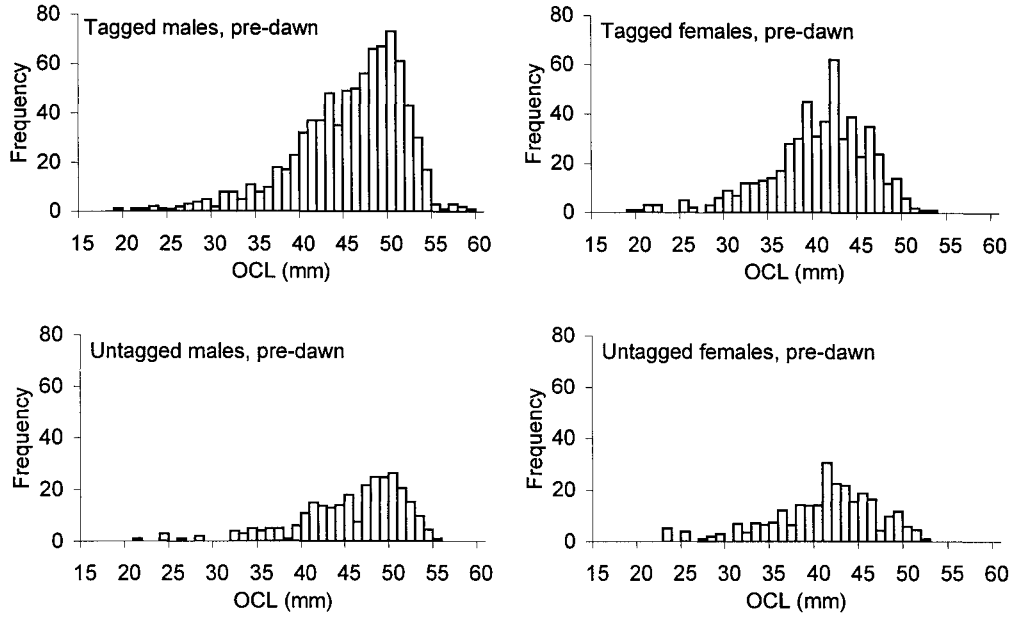

Figure 4: Length frequency distributions (OCL = orbital carapace length), scaled to total numbers caught, of male and female scampi tagged and rejected for tagging from shots completed before dawn on voyage KAH9511.

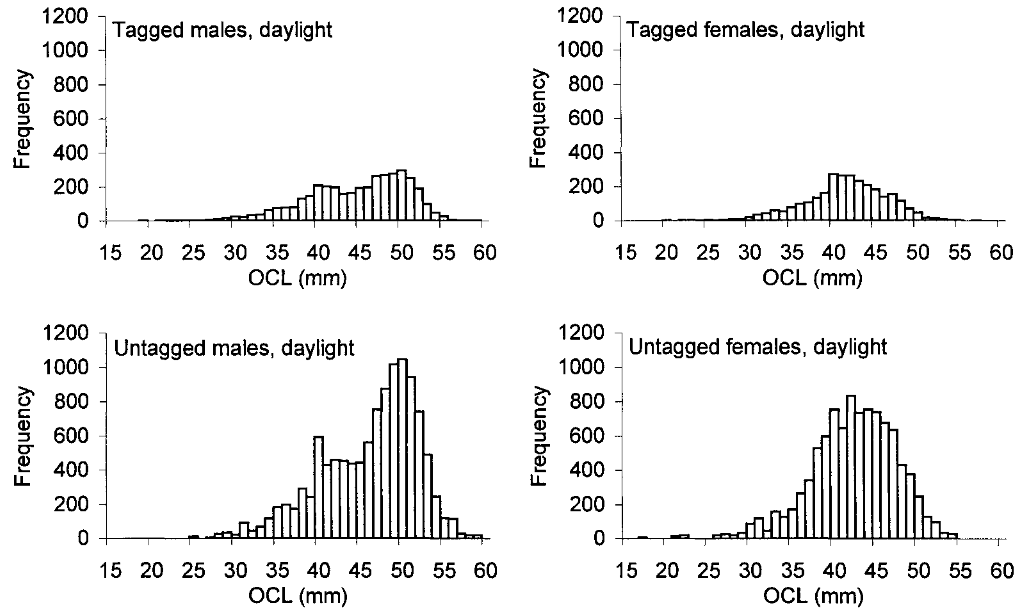

Figure 5: Length frequency distributions, scaled to total numbers caught, of male and female scampi tagged and rejected for tagging from shots completed after dawn on voyage KAH9511.

***Table 1*: Contingency table tests to assess the relationship between given characteristics of tagged scampi and their relative likelihood of recapture**

Test for contingency of likelihood of recapture on sex (all sizes)

	Male	Female	Totals	χ^2	p
Recovered	20	40	60		
Unrecovered	4 586	3 307	7 893		
Totals	4 606	3 347	7 953	14.99	0.0001

Test for contingency of likelihood of recapture on sex (OCL < 48 mm)

	Male	Female	Totals	χ^2	p
Recovered	2	37	39		
Unrecovered	3 108	3 122	6 230		
Totals	3 110	3 159	6 269	31.06	0.0000

Test for contingency of likelihood of recapture on sex (OCL > 48 mm)

	Male	Female	Totals	χ^2	p
Recovered	19	3	22		
Unrecovered	1 830	313	2 143		
Totals	1 849	316	2 165	0.02	0.8981

Test for contingency of likelihood of recapture on exposure to sunlight

	Pre-dawn	Daylight	Totals	χ^2	p
Recovered	17	42	59		
Unrecovered	1 249	6 645	7 894		
Totals	1 266	6 687	7 953	7.38	0.0066

Test for contingency of likelihood of recapture on time of day (after dawn)

	Morning	Afternoon	Totals	χ^2	p
Recovered	21	21	42		
Unrecovered	3 335	3 310	6 645		
Totals	3 356	3 331	6 687	0.00	0.9806

Test for contingency of likelihood of recapture on sex (no exposure to sunlight)

	Male	Female	Totals	χ^2	p
Recovered	10	7	17		
Unrecovered	764	485	1 249		
Totals	774	492	1 266	0.04	0.8438

Test for contingency of likelihood of recapture on sex (exposed to sunlight)

	Male	Female	Totals	χ^2	p
Recovered	10	32	42		
Unrecovered	3 822	2 823	6 645		
Totals	3 832	2 855	6 687	19.38	0.0000

Location of recaptures and migration

For recaptured animals at liberty for more than 90 d, the mean depth at recapture was considerably greater than the mean depth at release for both males (398 *vs* 378 m) and females (397 *vs* 378 m) (paired t-tests, $t_{17} = 11.60$ and $t_{38} = 9.72$, respectively; $p << 0.001$, Figure 6). In contrast, the mean depth at recapture of the 12 animals recaptured after a time at liberty of less than 90 d (mean 10 d, both sexes pooled) was almost identical to the mean release depth of these animals (375.5 *vs* 375.0 m; paired t-test, $t_{11} = 0.06$; $p \gg 0.10$). This combination of observations strongly suggests that the tagged animals had migrated some distance down the slope during their time at liberty, and that the difference in mean depths at release and recapture was not due to drift of the tagged animals during their descent to the seabed.

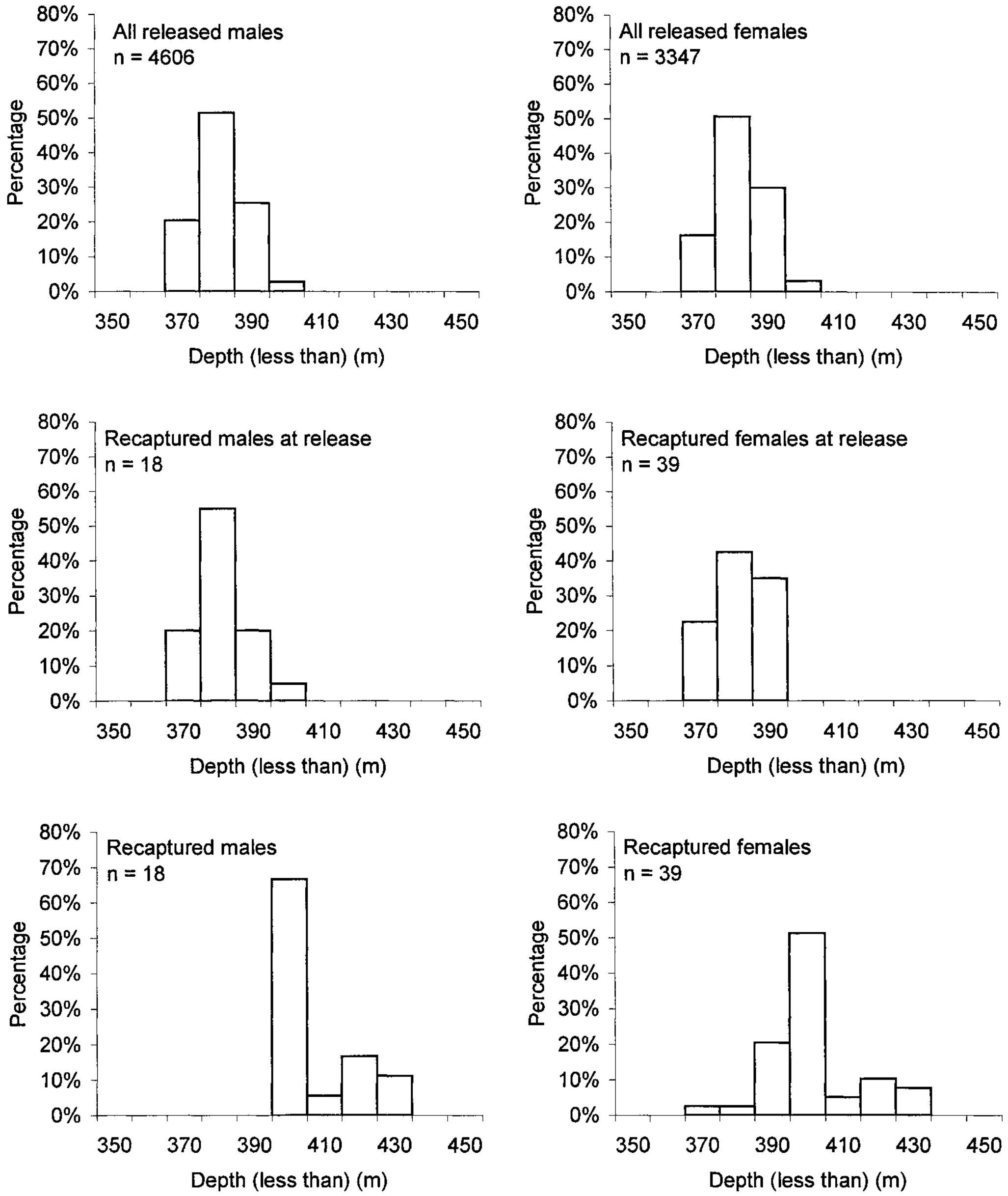

***Figure 6*: Frequency distributions of release depths for all male and female tagged scampi and of depth at release and depth at recapture for those scampi that were recaptured after more than 90 d at liberty.**

Given that the slope of the seabed in this location is about 3.8% (approximate measurements from nautical charts), an increase in depth of about 20 m probably entails a horizontal movement of about 500 m over the 12 months at liberty. As most trawl shots for scampi are made at roughly constant depth (and therefore have a very restricted sampling scale in this dimension), the movement of tagged scampi down the slope is considered real.

The frequency distribution of the distance between the release and estimated recapture locations is shown in Figure 7. About 80% of recovered tagged scampi were recaptured within 5 n. miles of their release location, and the largest reliable estimated distance between release and recapture sites was about 11 n. miles. The distance travelled during a research trawl for scampi is usually 3–5 n. miles, and a commercial shot is usually 5–12 n. miles (Cryer *et al.* 1998), so the sampling scale of trawl shots is too coarse to detect movements of scampi on a smaller scale. Movements along depth contours of similar magnitude to the probable movement down the slope (500 m, or about 0.25 n. miles) would not be detectable by trawling. The two records of tagged scampi being recovered more than 12 n. miles from their site of release are probably unreliable as the specified recapture locations are in less than 200 m depth of water where scampi are almost never recorded. The latitude of one of these records (tag number 7159) was probably mis-recorded as 36° S instead of 37° S, at which the distance travelled would have been less than 5 n. miles. Given the uncertainties involved in the exact location of recapture and the sampling scale of trawl shots along depth contours, the extent of movement of tagged scampi along depth contours while at liberty cannot be determined, but is probably less than the sampling scale of the trawl method.

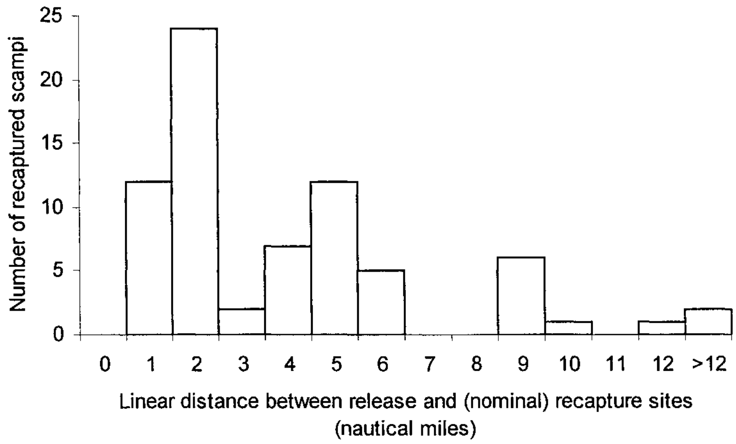

***Figure** 7:* **Frequency distribution of distance between release and recapture sites for tagged scampi. For comparison, research trawls are usually 3–5 n. miles, and commercial shots 5–12 n. miles long.**

Estimation of variability of measurements

Two of the three readers made measurements on the left side of tagged scampi that were not significantly different from one another (median difference = 0.1 mm, sign test $p = 0.215$). However, the third reader recorded significantly smaller measurements (median difference from both other readers = 0.4 mm, sign test $p < 0.001$). In addition, the measurements taken on the right side of the animals were significantly greater than those taken on the left side (median difference = 0.3 mm, sign test $p < 0.001$). Both observations suggest that bias in estimated length increment can be introduced by the use of different readers to measure release and recapture lengths, or by the use of different measurement sites.

Of the 183 replicate measurements, 3 were clear "transcription" errors (they were so different from the other 5 measurements for a given animal that it is highly unlikely that they represent measurement error *per se*, more likely they stem from mistakes made in reading the callipers or in recording the data). This is a contamination rate of about 1.6%.

Taking into account measurement error and contamination of 1.6% (with essentially random lengths), it was estimated by simulation that the standard deviation of length increments where start and finish lengths are recorded by the same person is about 0.42 mm (Figure 8). When different people make the two measurements (as occurs for most tagged scampi), this error increases to 0.65 mm (e.g., Figure 9).

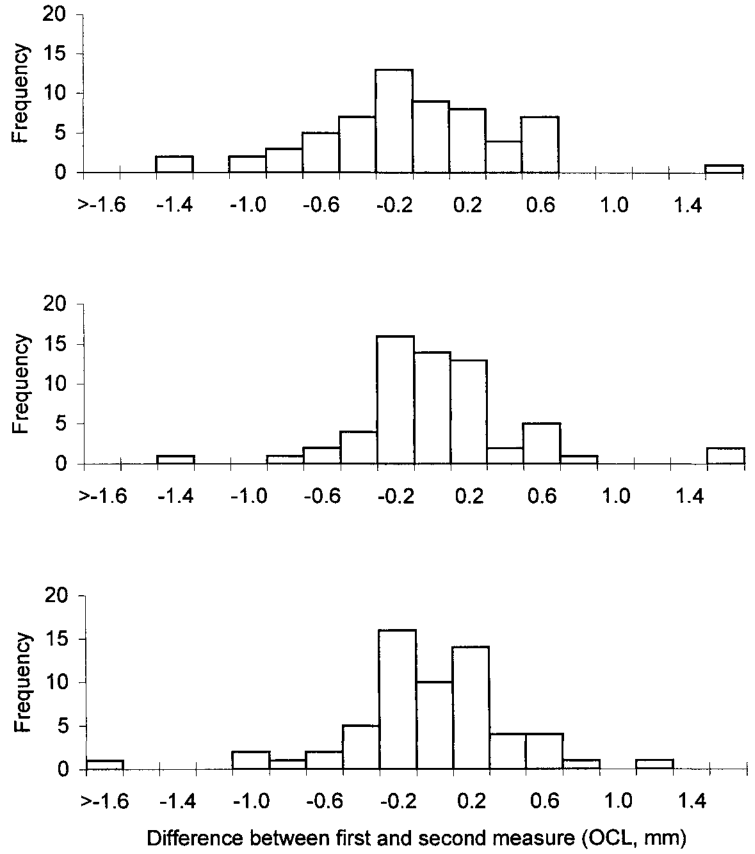

Figure 8: **Difference between measurements (OCL) of the same scampi by each of the three readers. Negative values indicate the second measurement was smaller than the first, and positive values that it was larger.**

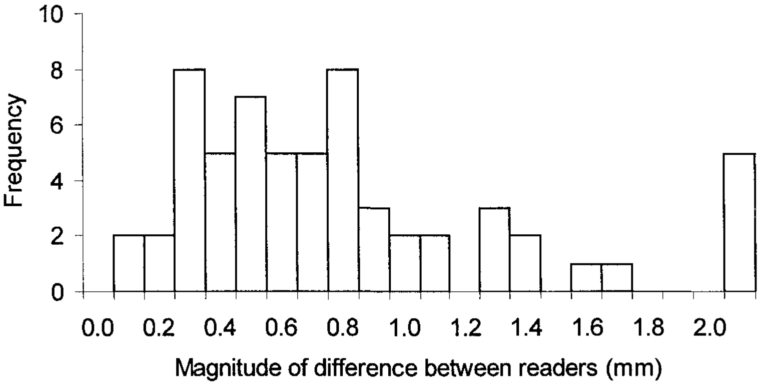

Figure 9: **Frequency distribution of the greatest between-reader average measurements of scampi OCL (mm) made on 61 animals by three experienced readers.**

Estimation of growth rate and length-at-age

Ricker's method (*see* Figure 6) generated estimates for the parameters of the von Bertalanffy equation (assuming $t_0 = 0$) of $K = 0.14$ y^{-1} and $L_\infty = 48.9$ mm (*see* Figure 7) with estimated *c.v.*s (by bootstrapping) of 33.4% and 20.9%, respectively. The return data for males cannot be used for an analysis using Ricker's method because the plot of L_{t+1} against L_t has a slope greater than 1.0 (Figure 10). Francis's method generated estimated annual increments of 1.34 and -0.19 mm for female scampi of 35 and 50 mm OCL, respectively. The pooled standard deviation of the residuals was 0.94. If the estimates for females are translated to the parameters of the von Bertalanffy equation (assuming $t_0 = 0$) then $K = 0.11$ y^{-1} and $L_\infty = 48.1$ mm with estimated *c.v.*s (by bootstrapping) of 47.9% and 13.5%, respectively. Again, the data for males are too poor make realistic estimates of an average growth function, but the estimates of average annual increment are 2.85 and 1.31 mm at 35 and 50 mm OCL, respectively.

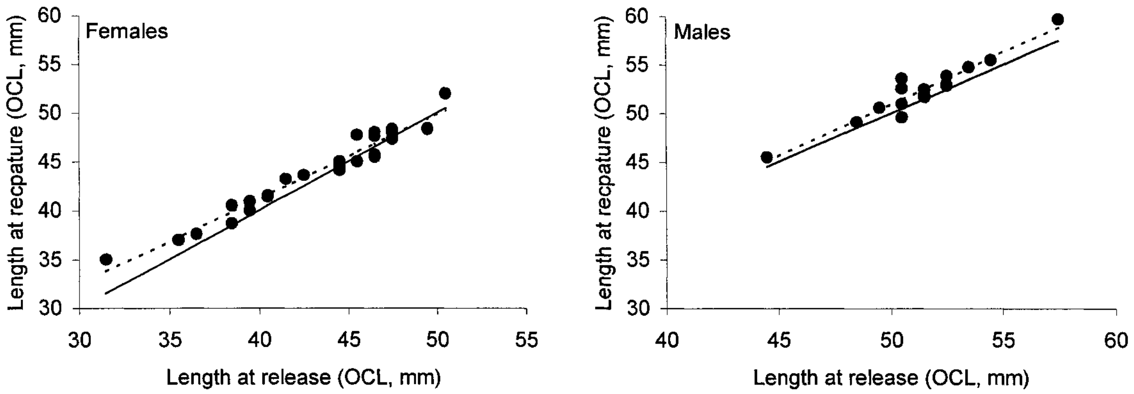

***Figure 10*: Walford line (dashed) for female (left) and male (right) scampi at liberty for 90–370 d. Zero growth is denoted by the solid line, and each recaptured scampi by a solid dot. Estimated parameters for females by Ricker's method are K = 0.14 y^{-1}; L_∞ = 48.9 mm. t_0 assumed = 0.0 y. This analysis is not possible for males as the slope of the Walford line is >1.0.**

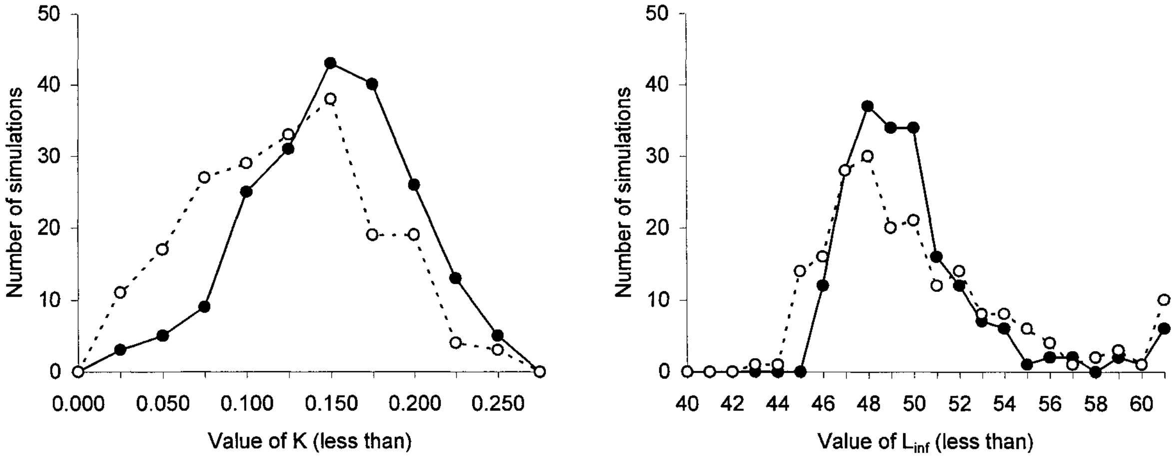

***Figure 11*: Frequency distributions, from 200 bootstrap replicates, of the von Bertalanffy growth model parameters *K* and L_∞. Solid lines with solid circles represent the analysis using censored data and Ricker's (1975) method, while dashed lines and open circles indicate the analysis using all data and Francis's (1988) method.**

The two methods give broadly similar results and, for both parameters, the modal class of bootstrap estimates is the same for the two methods (0.125–0.150 y^{-1} for K and 47–48 mm for L_∞). The main difference in the results is that the point estimates of K and L_∞ made using Francis's method are smaller than those made using Ricker's method (although not significantly). This difference is mirrored in the statistical distribution of the parameters, none of which is estimated precisely (Figure 11).

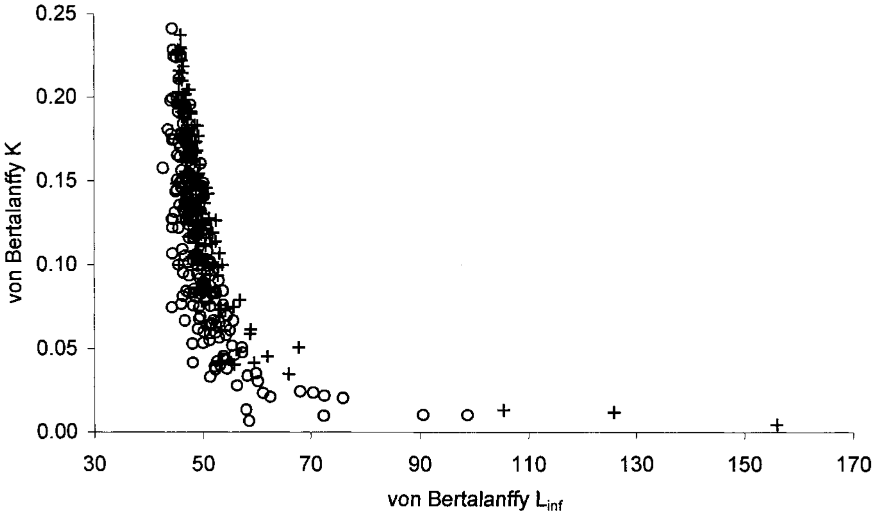

***Figure 12*: Correlation between the von Bertalanffy growth model parameters K and L_∞ from 200 bootstrap replicates generated using censored data and Ricker's (1975) method (crosses) and all data and Francis's (1988) method (open circles).**

As is usual for the estimated parameters of growth curves (e.g., Fournier *et al.* 1990), the K and L_∞ parameters are highly correlated (Figure 12). There is an approximately linear relationship between the two parameters for K of 0.05–0.25 y^{-1}, but as K decreases below about 0.05 y^{-1}, the association becomes increasingly curvilinear and L_∞ estimates becomes increasingly unrealistic (compared with the maximum observed size of about 55–60 mm for females of this species).

The growth curves generated by the two methods are very similar, and both show the very wide variability associated with the poor parameter estimation (Figure 13). The 95% confidence limits of the curves were generated by estimating, for each age class, the 95% confidence limits of length-at-age from the bootstrap replicates (Table 2). The mean of the bootstrap length-at-age estimates is consistently lower than the mean length-at-age predicted by the estimated curves. This is because the distribution of length-at-age is not symmetrical.

Examination of the residuals from Francis's method (which uses more of the data) allows an exploration of factors that might influence growth rate. With only 43 data points and a relatively large measurement error compared with the expected annual increment, this is of necessity an indicative analysis only. However, there are apparent trends in the residuals which, while tenuous in terms of statistical significance, can be interpreted in biologically sensible ways (Figure 14).

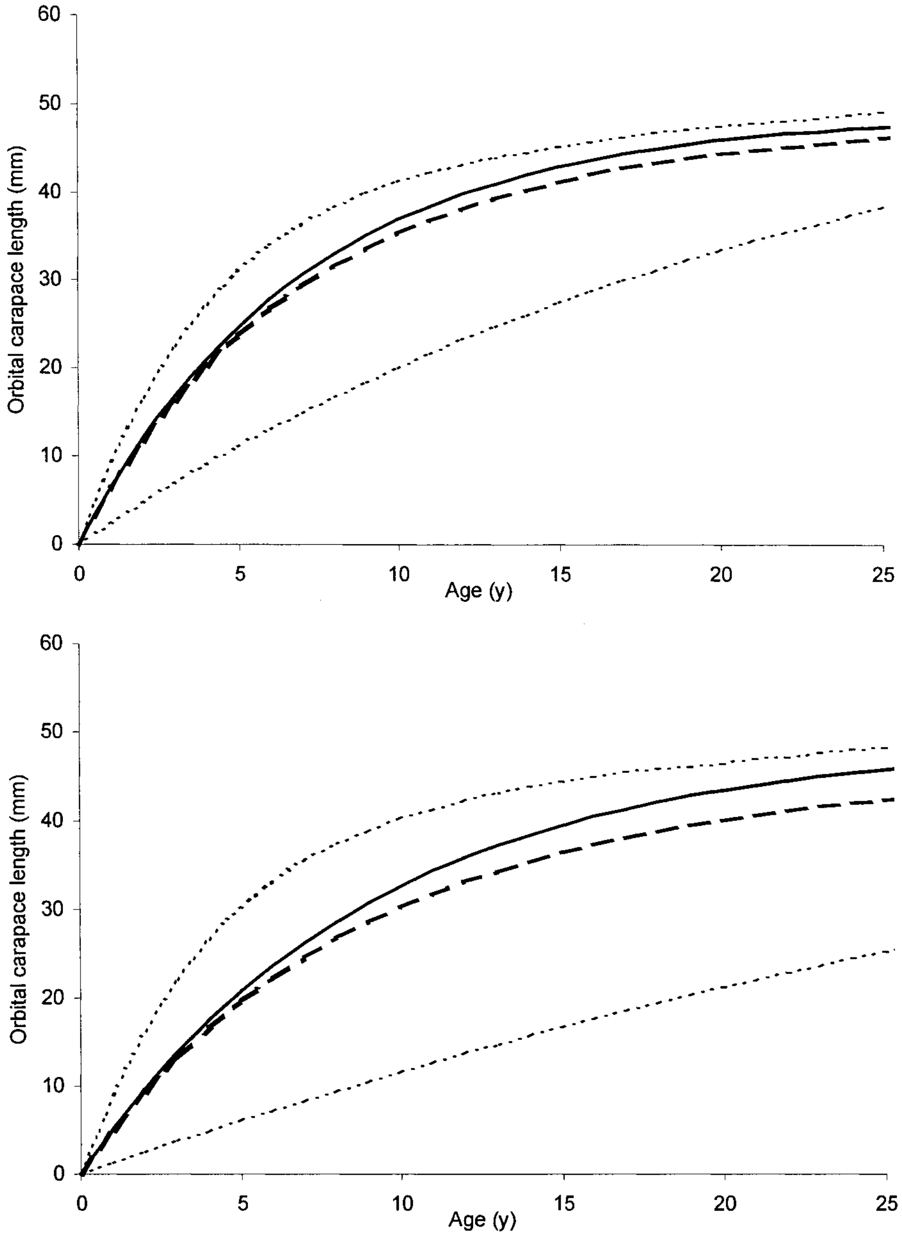

***Figure 13*: Estimated von Bertalanffy growth curves for female scampi in the Bay of Plenty by Ricker's method (top) and Francis's method (bottom). The heavy solid line denotes the estimated growth curve, the heavy dashed line denotes the mean length at age from the 200 bootstrap estimates, and the dotted lines the upper and lower limits of a 95% confidence distribution from the bootstraps. The real curve for scampi would be "stepped" because growth can only occur following each moult.**

First, there may be a relationship between the time at release and residuals with respect to expected growth. Animals captured, tagged, and released late in the day when temperatures were relatively high and when the exposure to u.v. light can be expected to be maximal, seemed to have lower growth rates than animals tagged before dawn or during the early morning (one way ANOVA, $F_{2,40} = 2.218$, $p = 0.122$). Smaller average increments for these animals would be consistent with the additional stress and damage during the tagging process, and is reflected also in their lower probability of recapture.

***Table 2*: Estimates of length (OCL, mm) and weight (greenweight, g) at age for female scampi in the Bay of Plenty according to von Bertalanffy models generated using Ricker's (1975) and Francis's (1988) method. Regression parameters were 0.00046 and 3.083 were used in a length-weight regression of the form $W = aL^b$. Upper and lower 95% limits were estimated using bootstrap procedures**

	Length						Weight					
	Ricker			Francis			Ricker			Francis		
Age (y)	Point	Upper	Lower	Point	Upper	Lower	Point	Upper	Lower	Point	Upper	Lower
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	6.4	9.2	2.4	5.1	9.0	1.3	0.1	0.4	0.0	0.1	0.4	0.0
2	11.9	16.6	4.7	9.7	16.2	2.5	1.0	2.6	0.1	0.5	2.5	0.0
3	16.8	22.4	6.9	13.7	21.9	3.8	2.7	6.7	0.2	1.5	6.3	0.0
4	21.0	27.1	9.0	17.4	26.5	5.0	5.5	12.1	0.4	3.1	11.3	0.1
5	24.6	30.9	11.1	20.7	30.2	6.1	9.0	18.1	0.8	5.2	16.8	0.1
6	27.8	34.0	13.0	23.6	33.1	7.3	13.0	24.2	1.3	7.9	22.3	0.2
7	30.5	36.3	14.9	26.3	35.6	8.4	17.4	29.8	1.9	10.9	27.9	0.3
8	32.9	38.3	16.7	28.6	37.4	9.5	22.0	35.0	2.7	14.2	32.6	0.5
9	35.0	40.0	18.4	30.7	38.9	10.6	26.6	39.9	3.7	17.7	36.7	0.7
10	36.8	41.2	20.1	32.6	40.3	11.7	31.0	43.9	4.8	21.3	40.9	0.9
11	38.4	42.3	21.7	34.3	41.3	12.7	35.3	47.5	6.1	24.9	44.3	1.2
12	39.8	43.2	23.2	35.8	42.4	13.8	39.3	50.6	7.5	28.5	47.9	1.5
13	41.0	43.9	24.7	37.2	43.2	14.8	43.1	53.3	9.0	32.0	50.8	1.8
14	42.0	44.6	26.1	38.4	43.9	15.7	46.5	55.8	10.7	35.3	53.4	2.3
15	42.9	45.2	27.4	39.5	44.5	16.7	49.7	58.2	12.5	38.5	55.5	2.7
16	43.7	45.8	28.7	40.5	45.0	17.6	52.5	60.6	14.4	41.5	57.7	3.2
17	44.4	46.4	30.0	41.4	45.6	18.6	55.1	63.1	16.4	44.3	59.8	3.7
18	45.0	46.8	31.2	42.1	45.9	19.5	57.4	65.0	18.5	47.0	61.3	4.3
19	45.5	47.2	32.3	42.9	46.2	20.4	59.4	66.6	20.7	49.4	62.5	5.0
20	45.9	47.6	33.4	43.5	46.6	21.2	61.2	68.4	23.0	51.7	64.0	5.7
21	46.3	48.0	34.5	44.0	47.0	22.1	62.8	70.0	25.3	53.8	65.8	6.4
22	46.7	48.2	35.5	44.6	47.3	22.9	64.3	71.0	27.6	55.7	67.3	7.2
23	46.9	48.5	36.5	45.0	47.8	23.7	65.5	72.6	30.0	57.5	69.0	8.0
24	47.2	48.9	37.4	45.4	48.1	24.5	66.6	74.2	32.5	59.1	70.6	8.8
25	47.4	49.2	38.4	45.8	48.4	25.3	67.6	75.9	35.1	60.6	72.1	9.7
26	47.6	49.7	39.3	46.1	48.7	26.1	68.4	77.9	37.9	61.9	73.4	10.7
27	47.8	50.0	40.2	46.4	49.0	26.8	69.2	79.4	40.6	63.2	74.5	11.6
28	47.9	50.2	41.1	46.7	49.1	27.5	69.8	80.6	43.4	64.3	75.3	12.7
29	48.1	50.4	41.9	46.9	49.2	28.3	70.4	81.8	46.3	65.3	75.8	13.7
30	48.2	50.7	42.7	47.1	49.5	29.0	70.9	82.8	48.8	66.2	77.1	14.8

Second, there may be a relationship between the time at liberty and residuals with respect to expected growth. Animals recaptured after 3–7 months at liberty appear more likely to have positive residuals than animals recaptured after 10–13 months (these two ranges represent most of the data). If there is a seasonal component to average growth, then this type of pattern can be used to examine the nature of seasonal variation. Unfortunately, the fact that recoveries were unevenly spread in time, combined with the relatively high measurement error, will mean that any seasonal trend will not be well determined. However (ignoring those recaptures made within the first month after release), 9 of 11 recaptures made 3–7 months after release showed positive residuals compared with 13 of 27 recaptures made 10–13 months after release ($\chi^2_1 = 3.64$, $p = 0.057$). This suggests that most females recaptured after 3–7 months (January to April) had already increased in size, consistent with a spring or early summer moulting period (as in *Nephrops norvegicus*, Nichols *et al.* (1987), Farmer (1989)).

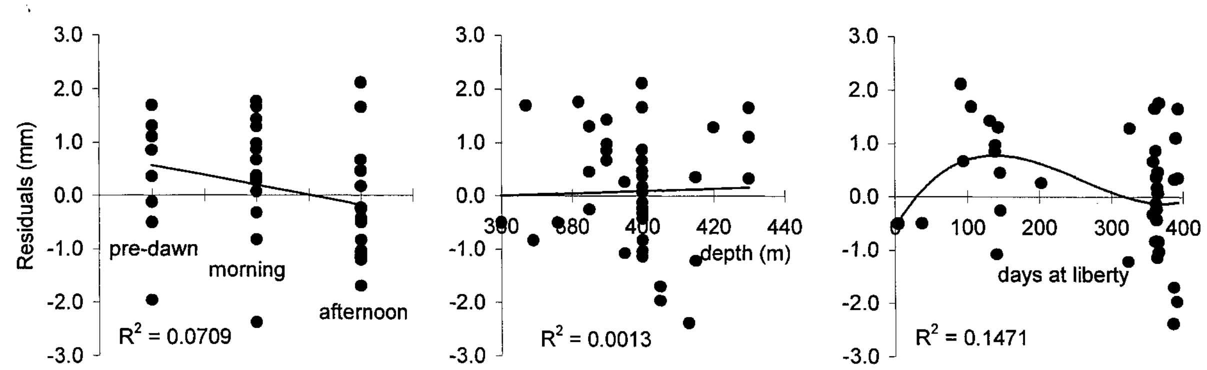

***Figure 14*: Plots of residuals (observed increment minus expected increment) from the Francis analysis of growth rate for female scampi with (from left to right) time of day at release, depth, and time at liberty. For illustrative purposes only, linear regressions are plotted through the first two, and a third order polynomial through the last. Near significant relationships are apparent for the time of day at release and for time at liberty.**

Estimation of the rate of natural mortality and longevity

The instantaneous rate of natural mortality, *M*, for female scampi can be estimated using the *K* parameter from a fitted von Bertalanffy curve as these are known to be related across a wide variety of poikilotherms. Charnov *et al.* (1993) (but *see* also Pauly 1980) gave a predictive equation of:

$$\log_e M = 0.95 \log_e K + 0.50 \qquad (7)$$

The estimates of *K* made using the Ricker method ($K = 0.14$) and Francis's method ($K = 0.11$) lead to estimates of $M = 0.25$ and $M = 0.20$, respectively. This ignores any error in the estimates of K and in the predictive regression. Incorporating error in the estimate of *K* and in the prediction of *M* from *K* (using the bootstrapped values of *K* and sampling from the distributions of the intercept and slope of Charnov *et al.*'s 1993 regression) leads to a 95% confidence range for the rate of natural mortality in female scampi of $M = 0.08$–0.42 and $M = 0.04$–0.39 for the Ricker and Francis methods, respectively (equivalent to *c.v.*s of about 34% and 46%, Figure 15).

Annala & Sullivan (1997) gave an approximate equation for predicting *M* from the maximum observed age in a population:

$$M = -\frac{\log_e(p)}{A} \qquad (8)$$

where *p* is the proportion of individuals reaching an observed age of *A* (or older) in a stock. For an unexploited (or lightly exploited) stock, the proportion is frequently assumed to be $p = 0.01$. By rearrangement, longevity can be estimated from:

$$A = -\frac{\log_e(p)}{M} \qquad (9)$$

Ricker's and Francis's methods of estimating *K* and, hence, *M* generate longevity estimates (for unexploited stocks) of 18 years (95% confidence range 11–58 years) and 23 years (12–128 years), respectively.

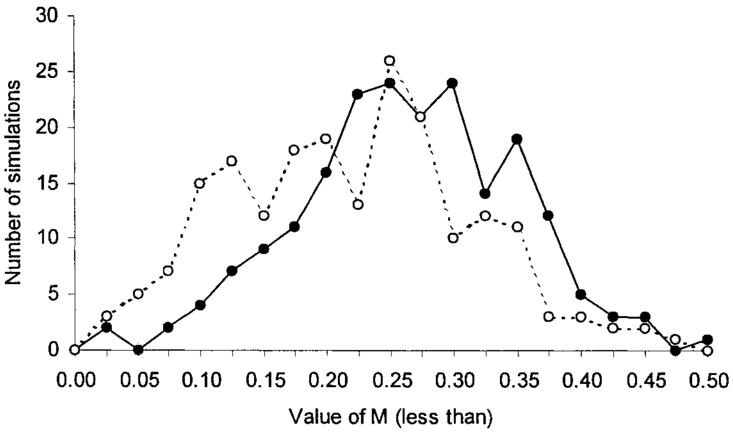

***Figure 15*: Frequency distributions, from 200 bootstrap replicates, of the estimated rate of natural mortality, *M*, based on Charnov *et al.*'s (1993) regression of *M* on the von Bertalanffy *K*. Variation associated with uncertainty in *K* was incorporated using non-parametric bootstrap procedures, and that associated with the regression was incorporated using a parametric bootstrap using the published means and variances for the regression slope and intercept. Solid lines with solid circles represent the analysis using Ricker's (1975) method, while dashed lines and open circles indicate the analysis using Francis's (1988) method.**

Discussion

The greater average depth from which tagged scampi were recovered (compared with the average depth at which these animals were released) strongly suggests that there was some migration down the slope in the time between release and recapture. The estimated average minimum movement down the slope was about 500 m horizontally and, given the sampling scale of trawl shots in this dimension, this is considered real. If movement along the slope was of a similar magnitude, then it would not be detectable using trawl recoveries as most trawl shots cover several miles. Thus, it is not possible to say much about the longshore movement of scampi from this work, other than that its annual extent is probably less than the scale of the trawl sampling method.

The probability of recapture in scampi was found to depend on sex, size, and whether or not the animal was exposed to sunlight during the tagging process. Small animals, especially males, were much less likely to be recaptured, and this may be the result of gear selectivity in the commercial fleet, or of differential mortality. The commercial fleet uses gear quite similar to that used to catch and release scampi, so it is considered unlikely that this is the cause of the difference. Considerable damage to the eyesight of *N. norvegicus* was observed by Shelton *et al.* (1985) and Chapman *et al.* (1989), and near or complete blindness was observed in most recaptured *M. challengeri* (eyes black and non-reflective compared with bright orange and highly reflective in undamaged individuals). For nearly all recaptures, it is not possible to say whether blinding occurred during release or recapture. Gaten (1988) developed a technique whereby retinal damage could be assessed for *N. norvegicus* exposed to sunlight, but such detailed assessment of damage is not required for the purpose of this analysis (of growth rate). Shelton *et al.* (1985) and Chapman *et al.* (1989) showed that although retinal damage was often serious, it did not seem to affect the likelihood of recapture for tagged animals. Indeed, in their study, *N. norvegicus* with retinal damage were slightly more likely to be recovered than those with no damage. The findings of our study are directly contrary to this finding, with animals not exposed to sunlight being considerably more likely to be recaptured than those tagged during daylight. Consistent with this pattern is the suggestion in the data that scampi exposed to the maximum light and heat-related stress (those tagged in the afternoon) showed smaller average length increments than animals tagged before dawn or in the early morning.

It appears that there are interactions among sex, size, and light-exposure factors, with small males exposed to sunlight having the lowest likelihood of recapture and, by inference, the highest rate of mortality following tagging. We speculate that social interactions and fighting among males may be responsible for this pattern, as small males could be seriously disadvantaged in fights by blindness following exposure to sunlight. Maynou & Sarda (1997) documented competition among males for territory and for females in a population of *N. norvegicus*, which is closely related functionally as well as taxonomically. An alternative explanation involving differential vulnerability to predation is also possible, but it is not clear why only small males (and, especially, not small females) would become more vulnerable to predators unless they had markedly different emergence patterns from females.

Tagging has been suggested as a means of estimating absolute stock biomass in *M. challengeri*, given the difficulties associated with other techniques and the lack of any current biomass estimates. However, the inferred patterns of differential mortality between the sexes and with size suggest that tagging (at least during daylight) is not a suitable method for estimating absolute biomass without considerable extra preparatory work. Information on probable mortality rates of tagged scampi by sex and size would be required to make realistic estimates of biomass.

Repeat measurements of scampi by three readers who had previously participated in scampi research voyages showed that there were some consistent differences among readers (although a sample of three readers is not a very big sample in comparison with the total number of staff involved). The differences were not large (less than 0.5 mm), but could be significant in the context of estimating growth increments of 0–3 mm for tagged animals. The names of staff measuring tagged scampi were not recorded at the time of release and, given the uncertainties involved in measuring OCL using callipers, incorporating the recording of staff names into all scampi studies might be worthwhile.

The variability of measurements of OCL was not very large, but there was almost 2% contamination by aberrant records, even when the measurements were taken in a quiet laboratory by experienced staff recording their own readings in their own time. This contamination could be expected to be worse, possibly much worse, in the field where conditions can be noisy and uncomfortable and there is pressure to complete tasks quickly. There was a consistent difference for one reader in measurements of OCL made on the right and left sides of each animal. It is not known whether this is due to problems with the measurement or some aspect of the morphology of scampi. Measurements of OCL should be standardised to the left side of the animal to maintain consistency. Some further replicate measurements would be useful in characterising the uncertainty in individual measurements made in the field.

The few recaptures made during the release voyage did not allow any analysis of growth rate because the time at liberty was short compared with the likely intermoult period. In addition, few of the animals had increased in size: the maximum increment was only 1 mm OCL, which is close to the margin of error of such measurements. Subsequent recaptures made by target trawling and by commercial fishers were clustered around the ideal (for Ricker's method) of 12 months at liberty, and the data for females were adequate to estimate the parameters of a von Bertalanffy curve. Ricker's (1975) and Francis's (1988) methods give similar results on these data, with estimates of K being 0.14 and 0.11 respectively, and L_∞ being close to 48 mm in both. Error bounds estimated by bootstrapping suggest that these estimates both have considerable uncertainty and should be treated with caution.

It is possible that trawling and/or tagging have a detrimental impact on the growth of scampi. Cryer & Stotter (1997) documented a mortality of about 50% over 2 weeks for scampi held in temperature controlled aquariums after capture by trawl and marking with streamer tags. The mortality of control animals subjected to trawl capture but not to tagging was similar, suggesting that the rigours of trawling are more detrimental to scampi than the tagging process. Overseas studies on scampi and other crustaceans suggest that streamer tags do not have marked effects on mortality or growth (e.g., Montgomery & Gray 1991, Montgomery *et al.* 1995). Further, scampi tagged during the hottest and brightest period of the day appear, from analysis of the residuals generated by Francis's technique, to have a slightly smaller average increment than scampi tagged during darkness or during the early morning. This suggests that the rigours of trawling (and/or tagging), especially during the day, may have relatively long-term effects on scampi growth.

The major problems associated with the estimates of growth rate and longevity presented here are first, a general paucity of small (young) animals, second, small sample sizes, and third, a lack of males. These problems have restricted our analyses to females, and have forced the extrapolation of growth rates estimated for mature animals to immature life stages. It is widely accepted (e.g., Anon. 1995, 1998) that growth of the related species *Nephrops norvegicus* is better described using separate curves for the two sexes and for mature and immature individuals, with curves for immature individuals being considerably steeper than those for mature individuals. If growth slows markedly at maturity, then estimation of growth curves describing all life stages using data only from mature animals is highly likely to lead to poor estimates of average growth rates during immature stages, average age at maturity, longevity, and productivity. The parameter estimates and growth curves presented here may well be affected by such problems, most likely resulting in a growth curve which is too shallow for the younger age classes, negative bias in the estimates of K and M, and positive bias in the estimate of longevity. The magnitude of such bias cannot be determined without knowledge of the growth rate of smaller animals.

This study has generated a useful first estimate of the likely productivity of scampi stocks in northern New Zealand. The instantaneous rate of natural mortality, M, is probably close to 0.20–0.25, although the *c.v.* for this estimate is wide (about 35–45%). This rather uncertain estimate of M can be used as a surrogate for a target fishing mortality in subsequent assessments where biomass can be deduced, or to set bounds on productivity parameters in fitted production curves.

Acknowledgments

Thanks are due to Wayne Steele, skipper of the *Drysdale*, and his crew for their flexibility, patience, and outstanding cuisine. Steve O'Shea, Paul Grimes, and Mark Morrison assisted ably in the field. A high proportion of tag returns came from commercial fishers, most notably from Simunovich Fisheries Ltd, and we extend our gratitude to the companies, skippers, and other staff involved for their assistance and support. John Booth reviewed an early draft, suggesting some major improvements, and Mike Beardsell did his usual thorough job on our vernacular. This work was funded by the Ministry of Fisheries, project number SHSP08, in the 1995–96 and 1996–97 fishing years.

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Appendix 1a: **Station details (including start latitude and longitude) and greenweight of scampi caught for trawling conducted during KAH9511 (scampi tagging release phase)**

		Time		Lat		Long		Depth		Dist.	Temp		Scampi
Stn no.	Date	In	Out	°	` S	°	` E	Min.	Max.	(n m)	Bott.	Surf.	(kg)
1	21/9/95	4:38	5:08	36	57.9	176	17.0	407	409	1.54	10.1	14.6	5.9
2	21/9/95	7:28	7:58	36	56.2	176	16.8	384	386	1.57	10.6	14.6	65.1
3	21/9/95	9:58	10:28	36	58.6	176	16.0	365	366	1.60	11.1	14.9	39.8
4	21/9/95	12:36	13:06	36	56.9	176	16.9	395	397	1.60	10.5	16.4	76.1
5	21/9/95	14:22	14:34	36	58.7	176	16.1	370	371	0.52	10.6	15.7	17.5
6	22/9/95	4:28	4:48	36	58.6	176	15.9	361	363	1.04	10.7	15.1	9.1
7	22/9/95	6:34	6:55	36	57.3	176	16.6	380	384	1.18	10.6	15.1	44.5
8	22/9/95	8:07	8:28	36	57.9	176	16.5	386	386	1.15	10.5	15.2	41.0
9	22/9/95	9:35	9:55	36	57.0	176	16.3	360	362	1.15	10.9	15.0	28.6
10	22/9/95	10:55	11:25	36	58.0	176	16.4	376	378	1.63	10.4	15.2	21.5
11	22/9/95	12:28	12:48	36	57.4	176	17.0	407	407	1.12	10.1	15.4	61.5
12	22/9/95	13:55	14:15	36	58.5	176	16.4	384	384	1.03	10.1	15.3	26.5
13	23/9/95	4:33	4:53	36	57.8	176	17.3	427	427	1.01	-	15.3	18.8
14	23/9/95	6:29	6:50	36	57.1	176	16.4	365	365	1.03	10.6	15.3	34.3
15	23/9/95	7:54	8:15	36	58.1	176	16.5	388	388	1.11	10.4	15.3	39.6
16	23/9/95	9:23	9:43	36	57.2	176	16.3	360	362	1.03	10.9	15.5	6.3
17	23/9/95	10:45	11:04	36	58.0	176	17.0	415	415	1.07	10.2	15.6	42.7
18	23/9/95	12:11	12:31	36	57.5	176	16.5	376	378	1.11	10.5	15.7	17.6
19	23/9/95	13:26	13:46	36	58.3	176	17.0	418	419	1.12	-	15.9	35.9
20	24/9/95	4:24	4:44	36	56.6	176	16.7	376	379	1.03	10.5	15.1	9.9
21	24/9/95	6:28	6:48	36	57.4	176	17.2	418	420	1.09	9.8	15.5	85.9
22	24/9/95	7:55	8:16	36	56.1	176	17.3	412	413	1.06	10.4	15.4	59.7
23	24/9/95	9:33	9:47	36	57.3	176	17.2	415	416	0.77	10.1	15.4	24.6
24	24/9/95	11:03	11:33	36	57.7	176	17.3	430	430	1.59	10.2	15.5	62.7
25	24/9/95	12:46	13:01	36	57.1	176	17.2	420	421	0.77	9.6	14.8	23.7
26	24/9/95	14:07	14:22	36	58.1	176	16.9	410	410	0.74	10.1	16.0	44.3
27	25/9/95	3:04	3:24	36	57.1	176	17.0	407	408	1.01	9.7	15.1	13.6
28	25/9/95	4:25	4:45	36	57.5	176	16.7	391	393	1.09	10.4	15.4	17.5
29	25/9/95	6:24	6:46	36	57.0	176	17.4	424	426	1.11	10.0	15.0	38.2
30	25/9/95	7:53	8:08	36	57.7	176	16.5	391	393	0.74	10.2	15.4	37.7
31	25/9/95	9:06	9:26	36	57.1	176	16.8	392	395	1.03	10.1	15.2	32.2
32	26/9/95	4:19	4:39	36	58.6	176	16.6	397	398	1.07	10.2	15.7	11.4
33	26/9/95	6:27	6:47	36	57.0	176	17.3	424	425	1.04	10.2	15.3	33.2
34	26/9/95	7:47	8:07	36	57.9	176	17.0	411	412	1.03	10.2	15.4	44.7
35	26/9/95	9:08	9:23	36	57.3	176	17.0	405	405	0.81	10.1	15.5	29.5
36	26/9/95	10:50	11:10	36	57.8	176	17.1	421	421	1.02	10.0	15.8	31.9
37	26/9/95	12:10	12:25	36	57.2	176	16.9	400	402	0.78	10.4	16.0	52.7
38	26/9/95	13:34	13:49	36	58.2	176	17.0	417	418	0.90	9.9	16.1	20.2
39	27/9/95	4:19	4:39	36	56.6	176	16.6	374	375	1.02	10.4	15.2	7.5
40	27/9/95	6:58	7:14	36	58.0	176	16.1	362	363	0.87	10.5	15.7	30.0
41	27/9/95	8:20	8:37	36	57.6	176	17.1	415	416	0.88	10.1	15.7	32.8

Appendix 1a contd.: **Station details (including start latitude and longitude) and greenweight of scampi caught for trawling conducted during KAH9511 (scampi tagging release phase)**

		Time		Lat		Long		Depth		Dist.	Temp		Scampi
Stn.	Date	In	Out	°	` S	°	` E	Min.	Max.	(n m)	Bott.	Surf.	(kg)
42	27/9/95	9:40	9:55	36	57.1	176	17.1	411	412	0.77	10.3	15.7	41.6
43	27/9/95	11:21	11:38	36	58.2	176	16.7	398	399	0.78	10.3	15.8	26.0
44	27/9/95	12:40	12:55	36	57.4	176	17.2	421	424	0.80	10.1	15.4	25.5
45	27/9/95	13:52	14:08	36	58.2	176	16.3	372	373	0.90	10.5	16.0	12.4
46	28/9/95	4:28	4:48	36	58.8	176	16.1	372	374	1.05	10.4	15.7	11.5
47	28/9/95	6:32	6:52	36	56.2	176	16.7	374	376	1.08	10.5	15.3	20.2
48	28/9/95	7:48	8:04	36	56.7	176	16.7	383	383	0.78	10.5	15.6	14.7
49	28/9/95	9:12	9:27	36	57.0	176	17.1	406	409	0.77	–	15.2	36.7
50	28/9/95	10:54	11:11	36	58.2	176	16.0	358	360	0.92	10.8	15.7	6.9
51	28/9/95	12:14	12:29	36	56.4	176	17.3	415	415	0.75	10.0	15.6	19.1
52	28/9/95	13:23	13:38	36	58.1	176	16.1	363	364	0.78	10.9	15.8	15.0
53	29/9/95	4:27	4:47	36	58.2	176	16.5	388	389	1.03	10.4	15.7	7.2
54	29/9/95	6:18	6:38	36	56.5	176	16.7	376	378	0.99	10.6	15.1	21.5
55	29/9/95	7:44	8:04	36	56.3	176	17.0	401	401	0.97	10.5	15.6	39.9
56	29/9/95	8:57	9:12	36	58.5	176	16.6	397	397	0.73	10.4	15.7	34.9
57	29/9/95	11:03	11:23	36	56.5	176	17.2	413	414	0.91	10.0	15.3	25.2
58	29/9/95	12:20	12:42	36	57.9	176	17.0	415	415	1.07	10.2	15.7	34.5
59	30/9/95	3:33	3:53	36	58.2	176	17.0	414	417	1.11	10.1	15.8	12.7
60	30/9/95	4:47	5:07	36	56.3	176	17.5	427	429	1.03	9.8	15.8	12.7
61	30/9/95	6:27	6:46	36	55.4	176	17.3	360	430	0.97	10.1	15.8	33.0

Appendix 1b: **Station details (including start latitude and longitude) and greenweight of scampi caught for trawling conducted during DRY9601 and DRY9602 (scampi tagging recapture phase)**

		Time		Lat		Long		Depth		Dist.	Temp		Scampi
Stn.	Date	In	Out	°	` S	°	` E	Min.	Max.	(n m)	Bott.	Surf.	(kg)
	DRY9601												
1	24/9/96	8:30	10:15	36	55.4	176	17.21	395	400	5.35	–	–	113
2	24/9/96	12:10	13:42	36	59.0	176	16.00	379	382	5.15	–	–	133
3	24/9/96	15:21	15:50	36	55.0	176	16.56	356	364	1.56	–	–	39
4	25/9/96	6:30	8:16	36	59.9	176	16.01	382	387	5.60	10.7	-	159
5	25/9/96	9:21	11:15	36	55.2	176	16.74	363	370	5.73	10.9	-	162
6	25/9/96	13:23	15:04	36	59.6	176	16.03	–	–	5.10	10.9	-	86
7	25/9/96	16:12	16:43	36	56.2	176	17.08	400	402	1.59	10.9	-	18
8	26/9/96	6:03	7:42	36	59.7	176	15.91	375	375	5.20	10.8	-	112
9	26/9/96	8:52	10:44	36	55.4	176	16.73	369	372	5.73	11.1	-	185
10	26/9/96	12:23	13:49	36	58.7	176	17.04	420	422	4.47	10.5	-	156
11	26/9/96	15:19	17:06	36	55.7	176	17.32	410	413	5.52	10.7	-	145
12	26/9/96	18:10	18:46	36	59.6	176	16.17	386	388	2.03	10.9	-	25
	DRY9602												
1	18/10/96	10:50	12:50	36	59.1	176	16.5	395	395	6.17	10.4	-	137
2	18/10/96	13:57	16:03	36	55.7	176	17.2	404	405	6.43	10.4	-	217
3	19/10/96	5:27	7:26	37	00.3	176	16.6	415	417	5.95	10.4	-	116
4	19/10/96	8:32	10:10	36	55.9	176	17.5	421	421	5.01	10.4	-	193
5	19/10/96	11:30	13:40	37	00.7	176	16.5	417	423	6.41	10.5	-	163
6	19/10/96	14:52	16:51	36	55.0	176	17.3	408	410	6.13	10.4	-	63
7	20/10/96	5:24	7:24	37	00.2	176	16.4	403	406	5.90	10.4	-	127
8	20/10/96	8:28	10:00	36	56.0	176	17.3	412	413	4.70	10.4	-	150
9	20/10/96	11:15	13:21	37	00.4	176	16.6	417	422	6.09	10.1	-	210
10	20/10/96	14:49	16:49	36	54.9	176	17.4	411	416	6.16	10.2	-	89
11	21/10/96	5:22	7:28	37	00.4	176	16.5	411	415	6.15	10.4	-	62
12	21/10/96	8:37	10:30	36	55.1	176	17.4	408	412	5.77	9.8	-	41
13	21/10/96	11:31	13:38	37	0.41	176	16.7	424	429	6.13	9.8	-	112
14	21/10/96	14:50	16:50	36	54.7	176	17.4	411	413	6.14	10.4	-	113

Appendix 2: **Position and depth of release stations for tagged scampi**

		Latitude		Longitude		Releases		
Station	Depth (m)	°	` S	°	` E	Male	Female	All
1	379	36	55.50	176	16.90	44	31	75
3	380	36	59.45	176	16.25	73	27	100
4	380	36	55.65	176	17.14	72	27	99
5	380	36	59.53	176	16.00	39	11	50
6	380	36	59.51	176	16.00	55	45	100
7	379	36	55.37	176	16.82	93	42	135
8	370	36	55.55	176	16.66	66	38	104
9	367	36	55.20	176	16.70	96	97	193
10	374	36	59.44	176	15.94	58	57	115
11	369	36	55.40	176	16.70	92	33	125
12	367	36	59.55	176	15.77	76	21	97
13	370	36	59.57	176	15.78	99	76	175
14	387	36	59.34	176	15.90	77	48	125
15	389	36	55.30	176	16.95	47	53	100
16	380	36	59.40	176	16.00	27	23	50
17	376	36	55.40	176	16.77	99	76	175
18	370	36	59.56	176	15.83	85	65	150
19	378	36	56.60	176	16.97	65	10	75
20	380	36	59.54	176	16.00	62	63	125
21	370	36	55.00	176	16.60	113	37	150
22	362	36	55.50	176	17.40	44	56	100
23	367	36	59.35	176	15.80	70	30	100
24	380	36	55.59	176	16.91	41	131	172
25	383	36	59.53	176	16.10	87	113	200
26	393	36	55.55	176	17.00	71	53	124
27	376	36	59.63	176	15.92	70	79	149
28	382	36	55.43	176	16.89	82	93	175
29	372	36	55.60	176	16.71	57	67	124
30	380	36	55.36	176	16.81	97	71	168
31	394	36	55.20	176	17.04	56	51	107
32	379	36	59.45	176	16.00	29	12	41
33	380	36	55.30	176	16.90	74	84	158
34	382	36	59.37	176	16.05	87	63	150
35	384	36	59.60	176	16.08	28	22	50
36	390	36	55.09	176	17.31	74	31	105
37	370	36	55.52	176	16.74	80	58	138
38	390	36	59.50	176	16.22	55	99	154
39	386	36	55.44	176	16.93	75	66	141
40	380	36	59.55	176	16.10	58	51	109

Appendix 2 contd.: **Position and depth of release stations for tagged scampi**

		Latitude		Longitude		Releases		
Station	Depth (m)	°	' S	°	' E	Male	Female	All
41	375	36	55.34	176	16.75	86	64	150
42	381	36	55.51	176	16.85	56	44	100
43	373	36	59.30	176	15.94	70	30	100
44	380	36	55.49	176	16.82	126	47	173
45	373	36	59.55	176	15.89	77	73	150
46	382	36	55.50	176	16.84	81	69	150
47	381	36	59.54	176	16.03	90	35	125
48	382	36	59.53	176	16.08	53	47	100
49	373	36	59.50	176	15.92	73	27	100
50	379	36	55.47	176	16.81	102	23	125
51	382	36	55.32	176	16.81	94	56	150
52	389	36	59.51	176	16.18	74	51	125
53	378	36	55.35	176	16.80	70	55	125
54	374	36	59.30	176	15.99	60	15	75
55	374	36	59.30	176	15.99	67	58	125
56	367	36	59.12	176	15.93	119	31	150
57	378	36	55.27	176	16.84	43	32	75
58	380	36	59.30	176	16.10	86	53	139
59	380	36	59.30	176	16.10	78	57	135
60	380	36	55.50	176	17.40	85	63	148
61	380	36	59.40	176	16.00	81	69	150
62	378	36	59.10	176	16.10	90	54	144
63	380	36	55.41	176	16.84	63	67	130
64	384	36	55.49	176	16.87	41	34	75
65	386	36	55.31	176	16.98	13	2	15
66	386	36	55.31	176	16.98	54	80	134

Appendix 3: **Release and recapture details for all recaptured tagged scampi**

	Release data									Recapture data						
			Dpth	Lat.		Long			OCL		Dpth	Lat.		Long.		OCL
Tag	Date	Time	(m)	°	` S	°	` E	Sex	(mm)	Date	(m)	°	` S	°	` E	(mm)
52	21/9/95	6:50	379	36	55.5	176	16.9	M	51	21/9/96	400	36	56.0	176	15.0	52.0
72	21/9/95	6:50	379	36	55.5	176	16.9	M	53	21/9/96	400	36	56.0	176	15.0	54.8
292	21/9/95	12:00	380	36	55.7	176	17.1	F	46	21/9/96	400	36	56.0	176	15.0	45.7
510	21/9/95	16:00	379	36	55.4	176	16.8	M	49	8/1/96	–	37	4.0	176	16.0	50.6
644	22/9/95	9:05	367	36	55.2	176	16.7	M	47	25/9/95	425	36	57.0	176	17.4	47.0
764	22/9/95	9:05	367	36	55.2	176	16.7	F	40	21/9/96	400	36	56.0	176	15.0	41.4
904	22/9/95	10:25	374	36	59.4	176	15.9	M	48	21/9/96	400	36	56.0	176	15.0	49.1
908	22/9/95	10:25	374	36	59.4	176	15.9	F	41	27/11/96	380	37	35.0	176	39.0	–
1039	22/9/95	12:00	369	36	55.4	176	16.7	F	39	21/9/96	400	36	56.0	176	15.0	40.9
1202	22/9/95	13:30	367	36	59.6	176	15.8	F	48	29/10/95	360	37	1.0	176	15.0	48.0
1231	22/9/95	14:55	370	36	59.6	176	15.8	F	47	19/10/96	430	37	4.0	176	16.0	49.3
1455	22/9/95	15:40	387	36	59.3	176	15.9	F	47	15/2/96	385	36	51.0	176	16.0	48.0
1543	23/9/95	6:00	389	36	55.3	176	17.0	F	39	17/10/96	430	37	4.0	176	16.0	41.6
1607	23/9/95	6:00	389	36	55.3	176	17.0	F	47	20/10/96	415	36	55.0	176	17.4	48.0
2135	23/9/95	13:00	380	36	59.5	176	16.0	F	47	27/12/95	390	36	55.0	176	17.0	48.2
2208	23/9/95	14:30	370	36	55.0	176	16.6	F	49	21/9/96	400	36	56.0	176	15.0	48.3
2280	23/9/95	14:30	370	36	55.0	176	16.6	F	46	12/8/96	415	37	6.0	176	16.0	45.5
2345	23/9/95	14:30	370	36	55.0	176	16.6	F	40	21/9/96	400	36	56.0	176	15.0	41.5
2359	23/9/95	15:00	362	36	55.5	176	17.4	F	49	11/2/96	395	37	4.0	176	14.0	48.4
2386	23/9/95	15:00	362	36	55.5	176	17.4	F	44	28/9/95	376	36	56.2	176	16.7	44.0
2389	23/9/95	15:00	362	36	55.5	176	17.4	F	47	16/2/96	385	36	51.0	176	14.0	47.3
2395	23/9/95	15:00	362	36	55.5	176	17.4	M	50	21/9/96	400	36	56.0	176	15.0	52.6
2494	24/9/95	5:45	367	36	59.4	176	15.8	F	38	8/1/96	–	37	4.0	176	16.0	40.5
2500	24/9/95	5:45	367	36	59.4	176	15.8	M	57	8/1/96	–	37	4.0	176	16.0	59.8
2549	24/9/95	5:45	367	36	59.4	176	15.8	M	50	8/1/96	400	37	4.0	176	16.0	49.6
2563	24/9/95	9:00	380	36	55.6	176	16.9	F	47	21/9/96	400	36	56.0	176	15.0	48.0
2631	24/9/95	9:00	380	36	55.6	176	16.9	F	31	25/9/96	382	36	59.9	176	16.0	35.0
2840	24/9/95	10:30	383	36	59.5	176	16.1	F	38	21/9/96	400	36	56.0	176	15.0	38.7
3154	24/9/95	13:40	376	36	59.6	176	15.9	F	47	21/9/96	400	36	56.0	176	15.0	47.4
3408	24/9/95	15:45	372	36	55.6	176	16.7	F	41	28/9/95	376	36	56.2	176	16.7	41.0
3419	24/9/95	15:45	372	36	55.6	176	16.7	F	44	21/9/96	400	36	56.0	176	15.0	44.7
3435	24/9/95	15:45	372	36	55.6	176	16.7	F	41	28/9/95	376	36	56.2	176	16.7	41.0
3436	24/9/95	15:45	372	36	55.6	176	16.7	M	52	10/4/96	391	36	57.9	176	16.6	53.0
3491	24/9/95	15:45	372	36	55.6	176	16.7	F	39	21/9/96	400	36	56.0	176	15.0	40.0
3578	25/9/95	5:25	380	36	55.4	176	16.8	F	44	20/10/96	405	37	0.2	176	16.4	43.0
3591	25/9/95	5:25	380	36	55.4	176	16.8	F	36	21/9/96	400	36	56.0	176	15.0	37.6
3656	25/9/95	5:25	380	36	55.4	176	16.8	M	44	6/2/96	400	36	51.0	176	16.0	45.5
3670	25/9/95	5:53	394	36	55.2	176	17.0	F	44	30/9/95	360	36	55.4	176	17.3	44.0
3768	25/9/95	5:53	394	36	55.2	176	17.0	M	50	26/9/96	411	36	55.7	176	17.3	51.0
3895	25/9/95	8:41	380	36	55.3	176	16.9	M	51	21/9/96	400	36	56.0	176	15.0	51.7
4056	25/9/95	10:10	382	36	59.4	176	16.1	F	46	21/9/96	400	36	56.0	176	15.0	47.6
4117	25/9/95	10:10	382	36	59.4	176	16.1	F	41	17/10/96	430	37	4.0	176	16.0	42.6

Appendix 3 contd.: **Release and recapture details for all recaptured tagged scampi**

	Release data									Recapture data						
			Dpth	Lat.		Long			OCL		Dpth	Lat.		Long.		OCL
Tag	Date	Time	(m)	°	' S	°	' E	Sex	(mm)	Date	(m)	°	' S	°	' E	(mm)
4226	26/9/95	5:58	390	36	55.1	176	17.3	F	46	16/2/96	385	36	51.0	176	14.0	47.9
4259	26/9/95	5:58	390	36	55.1	176	17.3	M	50	19/10/96	418	37	0.7	176	16.5	53.0
4307	26/9/95	5:58	390	36	55.1	176	17.3	M	52	21/9/96	400	36	56.0	176	15.0	53.9
4330	26/9/95	5:58	390	36	55.1	176	17.3	M	54	20/10/96	417	37	0.4	176	16.6	55.0
4334	26/9/95	7:20	370	36	55.5	176	16.7	M	50	21/9/96	400	36	56.0	176	15.0	53.6
4712	26/9/95	11:45	386	36	55.4	176	16.9	F	50	21/9/96	400	36	56.0	176	15.0	52.0
5036	26/9/95	15:06	381	36	55.5	176	16.9	F	44	21/9/96	400	36	56.0	176	15.0	44.1
5559	27/9/95	12:09	382	36	55.5	176	16.8	M	45	30/9/95	427	36	56.3	176	17.5	45.0
5588	27/9/95	12:09	382	36	55.5	176	16.8	F	37	18/10/96	405	36	55.7	176	17.2	37.0
5962	27/9/95	15:26	373	36	59.5	176	15.9	F	45	26/9/96	369	36	55.4	176	16.7	45.0
6042	28/9/95	5:58	379	36	55.5	176	16.8	F	42	14/2/96	390	36	52.0	176	15.0	43.6
6102	28/9/95	5:58	379	36	55.5	176	16.8	M	51	21/9/96	400	36	56.0	176	15.0	52.5
6128	28/9/95	5:58	379	36	55.5	176	16.8	M	49	30/9/95	360	36	55.4	176	17.3	49.0
6179	28/9/95	8:43	382	36	55.3	176	16.8	F	35	14/2/96	390	36	52.0	176	15.0	37.0
6255	28/9/95	8:43	382	36	55.3	176	16.8	F	47	21/9/96	400	36	56.0	176	15.0	48.3
6506	28/9/95	11:45	378	36	55.4	176	16.8	M	42	30/9/95	360	36	55.4	176	17.3	42.0
6677	28/9/95	14:10	374	36	59.3	176	16.0	F	45	29/12/95	400	37	5.0	176	15.0	47.7
6766	28/9/95	14:55	367	36	59.1	176	15.9	M	46	29/10/95	360	37	1.0	176	15.0	46.0
7009	29/9/95	9:43	380	36	59.3	176	16.1	M	41	30/9/95	360	36	55.4	176	17.3	41.0
7028	29/9/95	9:43	380	36	59.3	176	16.1	F	44	21/9/96	400	36	56.0	176	15.0	44.6
7105	29/9/95	9:43	380	36	59.3	176	16.1	F	46	20/8/96	420	36	59.0	176	17.0	48.0
7159	29/9/95	9:44	380	36	59.3	176	16.1	F	41	8/2/96	390	36	4.0	176	14.0	43.2
7296	29/9/95	10:35	380	36	55.5	176	17.4	M	53	19/10/96	430	37	4.0	176	16.0	54.3
7326	29/9/95	10:35	380	36	55.5	176	17.4	M	54	21/9/96	400	36	56.0	176	15.0	55.5
7366	29/9/95	10:35	380	36	55.5	176	17.4	F	47	21/9/96	400	36	56.0	176	15.0	47.2
7620	29/9/95	14:15	378	36	59.1	176	16.1	M	52	30/12/95	410	36	50.0	176	16.0	52.9
7924	30/9/95	8:02	386	36	55.3	176	17.0	F	44	20/4/96	395	36	56.6	176	17.0	45.0
7952	30/9/95	8:02	386	36	55.3	176	17.0	F	40	20/10/96	413	36	56.0	176	17.3	39.0
7967	30/9/95	8:02	386	36	55.3	176	17.0	M	54	20/10/96	425	37	4.0	176	16.0	55.2
7975	30/9/95	8:02	386	36	55.3	176	17.0	M	50	29/10/95	360	37	1.0	176	15.0	50.0