



The status of *Trachurus murphyi* in New Zealand waters as of 2008

New Zealand Fisheries Assessment Report 2013/15

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EXECUTIVE SUMMARY

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Three analyses are presented that summarise the presence of *T. murphyi* in research trawl and MFish data, the distribution of aerial sightings of jack mackerel, and the standardised stock indices from the deepwater trawl fishery. All suggest a peak in presence/abundance of this species in about 1993 or 1994, followed by a decline to a markedly lower level from about 1998.

Scaled length frequency and age distribution estimates were produced for *T. murphyi* from various sources within three periods: 1991; selected years between 1992–93 and 2000–01; and 2005. Otoliths were prepared and read for 1991 and 2005, and age-length keys applied to scaled length frequency data in JMA 3 and/or JMA 7. For 1992–93 to 2000–01, existing annual age-length keys from JMA 7 were applied to scaled length frequency data from JMA 3 and 7. Length distributions and age estimates were scaled to annual commercial landings, after adjustment for the proportion of *T. murphyi* in the three-species jack mackerel reported catch. For 1991 and 2005, respective totals of 279 and 338 otolith thin sections were read, which was difficult because of a large variation in the number of zones for a given length. A linear regression model explained between 54 and 82% of the variance between readers, reflecting this difficulty. Although an age-estimation technique for New Zealand *T. murphyi* has recently been developed, validation is still required and the results of catch at age analyses should be viewed in this context.

Length frequency distributions remained unchanged from 1991 to 2005, usually exhibiting a single mode at about 50 cm with most sizes ranging from about 40 to 60 cm. There were no major differences in length distributions from JMA 3 and 7, with the exception of a mode of small fish (26–35 cm) in 1995–96 from JMA 7. These findings are consistent with those of earlier studies on long-term length frequency distributions and suggest ongoing recruitment into the fishery for the last 14 years or so. Estimated age distributions were similar between 1991 and 2005, with most ages between about 10 and 35 yr. In the early 1990s, few fish were older than 25 yr, with maximum age increasing to 31 yr by 2000–01, and 35 yr in 2005, consistent with an ageing population. Young fish continued to recruit to the fishery, possibly indicating ongoing invasions into New Zealand waters. Although year classes cannot be tracked continuously from 1991 to 2005, there is evidence of modal progression for several years between 1992–93 and 1997–98.

In 1991 and from 1992–93 to 2001–01, males dominated samples, but in 2005 female numbers were greater. The high proportion of males has been attributed to females experiencing greater mortality from the combined physiological stress of spawning and the uncertainty of an oceanic habitat. Growth models (von Bertalanffy) were fitted to the 2005 length-age data supplemented with several juvenile otoliths sourced from Chile. The results of the analysis suggest that the sexes have distinct growth curves and the growth parameters were as follows: L_{∞} of 52.9 and 49.3 and K of 0.17 and 0.24, for males and females respectively.

This study has highlighted three major features of the *T. murphyi* invasion. The abundance of this species has now declined considerably since its peak in the 1990s, but this decline is not necessarily indicative of *T. murphyi*'s impending disappearance from New Zealand. Maximum age has increased, consistent with an ageing population, but minimum age has not changed over time, consistent with a population that is self sustaining, although there is little information to identify the source of recruits. Thus, the age structure suggests that the population will persist. A gradual change in sex ratios over time is evident in JMA 7, from a high representation of males to a more balanced male-female population recently, although this is not repeated in JMA 3. There is evidence at the scale of statistical area for tow catches to be dominated by one of the two sexes.

1 INTRODUCTION

Until the mid 1980s, only the two “New Zealand species” of jack mackerel (*Trachurus declivis* and *T. novaezelandiae*) were found in New Zealand waters. The Chilean jack mackerel, *T. murphyi*, (also known as Murphy’s mackerel or slender jack mackerel) invaded New Zealand waters in the mid 1980s and was first positively identified by Kawahara et al. (1988) in 1986. By the late 1990s, this species was distributed all around New Zealand and was the dominant jack mackerel in some areas (Taylor 1999). It is unknown whether it has become permanently established here, although evidence presented by Taylor (2002) has suggested that there has been successful spawning in New Zealand waters. Taylor (Taylor 1999) concluded that the population is made up of two fractions — the larger comprises those immigrating as invaders, the smaller those produced by successful spawning.

1.1 Catches

The three species of jack mackerel are managed within the QMS as a single species in four stock management areas (Figure 1), although there is no catch from JMA 10. They support substantial, though somewhat variable, commercial trawl and purse-seine fisheries. Landings increased steadily from 1983–84 (Figure 2). Between 1991–92 and 1998–99, total landings were relatively stable around 40 000 t with the highest recorded catch of almost 48 000 t in 1992–93. Landings almost halved to about 21 000 t in 1999–00 and then increased steadily each year to the second highest catch on record (46 600 t) in 2004–05. The high catches in recent years have been from JMA 7. Catches in JMA 3 declined from the peak catch of 20 000 t in 1995–96 to only about 700 t in 2003–04 and 2004–05 and, although there was an increase to 5000 t in 2005–06, the total dropped to less than 2000 t in 2006–07.

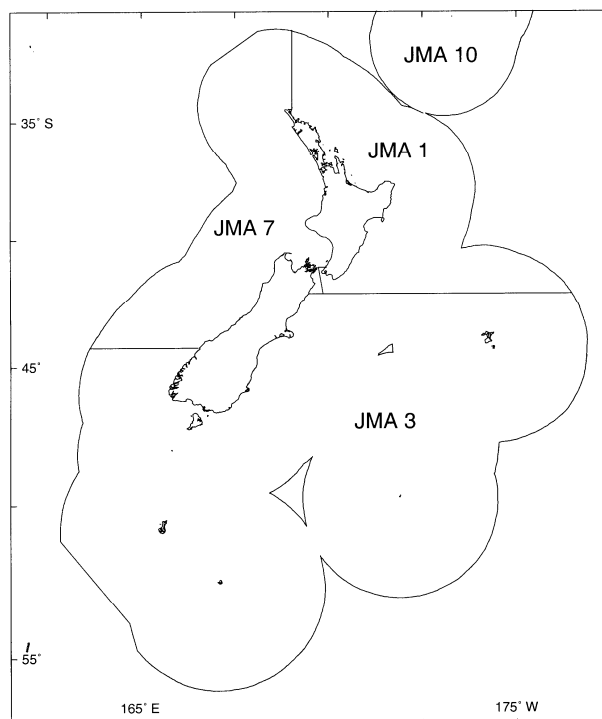


Figure 1: Jack mackerel Fishstocks.

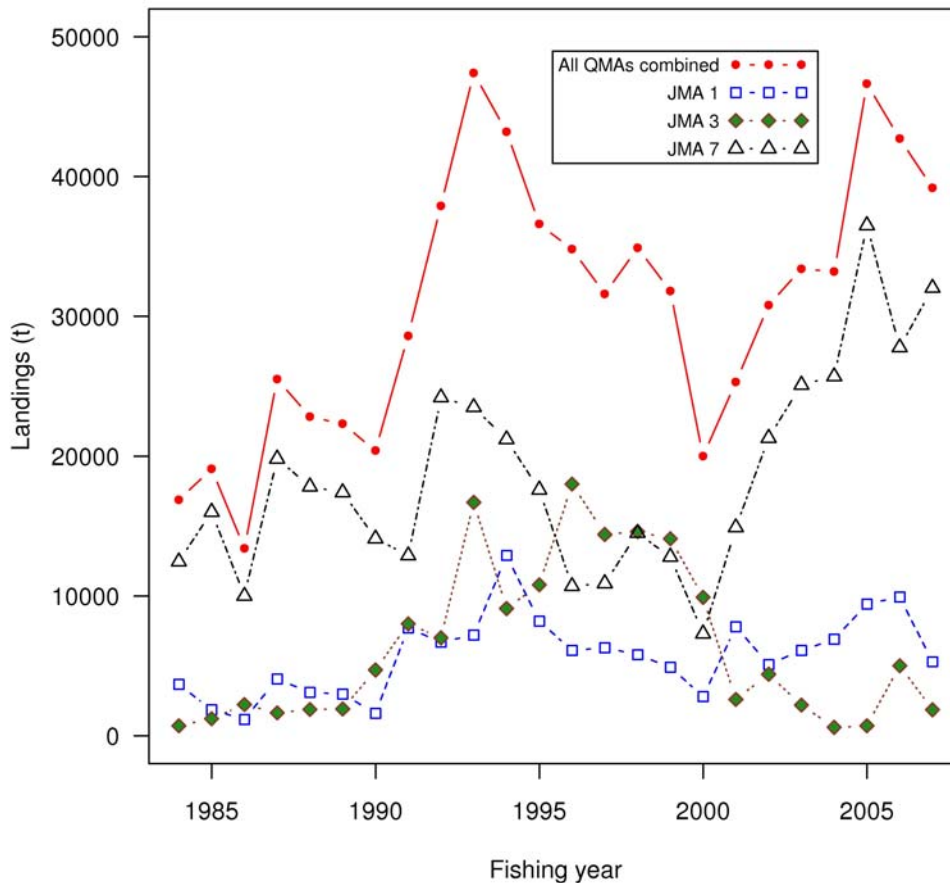


Figure 2: Reported landings of jack mackerels (all species) by Fishstock and for all Fishstocks combined, from 1983–84 to 2006–07; 1990 represents 1989–90 etc. Source: Table 1 of 2008 plenary report (Ministry of Fisheries 2008).

1.2 Yields

Information available on biomass and sustainable yields of jack mackerel varies between areas. In JMA 3 it is not known if catches at the level of the current TACC (18 000 t) or recent catch levels, are sustainable, or if they will allow the stocks to move towards a size that will support the maximum sustainable yield (MSY). The massive decline in catches in JMA 3 in the most recent years suggests that this TAC may not have been sustainable. In 1991, biomass of the two “New Zealand species” was estimated for JMA 7 to be above the size that will support the MSY. The current TACC in JMA 7 (32 536 t) is approximately equal to the MSY for *T. declivis* and *T. novaezelandiae* combined and is considered sustainable for them. There are no estimates of biomass and yield for *T. murphyi* in any of the Fishstocks, and no information is available for any of the *Trachurus* species in JMA 10 (Ministry of Fisheries 2008).

1.3 Invasion of New Zealand waters

It is believed that a major proliferation of *T. murphyi* occurred in South American waters as a result of the decline of the Peruvian anchoveta (*Engraulis ringens*) fishery in the 1970s, with total annual landings in excess of 11 million t. Along with the sardine, *Sardinops sagax*, *T. murphyi* filled the niche previously occupied by the anchoveta (Serra 1991). Proliferation of *T. murphyi* in South America reached a peak in 1994 when total landings in the Chilean fishery reached about 4.5 million t a year.

It seems that changes in the spawning migration of *T. murphyi* resulted in its adoption of an oceanic habitat and eventual invasion of New Zealand waters. Serra (1991) described a cyclic migration in which adults left the Chilean shelf to spawn in oceanic waters, with a return to shelf waters to feed. Young of the year moved eastwards, the direction of the prevailing currents, arriving on the shelf and recruiting to the fishery at about age 3 years. Work by Russian researchers, Vinogradov et al. (1991) and Elizarov et al. (1993) showed that the oceanic population changed its behaviour to adopt a north-south migration, feeding around the sub-tropical convergence as adults, and migrating to the north to spawn where crustacean species were of a size that suited larval foraging.

Three characteristics of the biology of Murphy's mackerel have been cited as the main reasons for its success in oceanic waters. Larvae are adapted to an oceanic habitat, older life history stages are opportunistic feeders with a wide range of known prey species, and Murphy's mackerel is an indeterminate batch spawner (George 1995, see discussion in Taylor 2002), with the ability to reproduce whenever environmental conditions are favourable.

The first appearance of *T. murphyi* in New Zealand waters occurred near the Chatham Islands in the mid 1980s (see Figure 3). Once here, subsequent invasion by the species was rapid, taking place over five or six years and including entry to most areas of shelf waters. Elements of the invasion were documented by Taylor (2002), who also investigated the suitability of New Zealand waters as a habitat for *T. murphyi*, and whether a successful spawning population had become established here. The identification of a small number of juvenile specimens from New Zealand waters led to the conclusion that the New Zealand population is made up mostly of invading fish with a small proportion of locally spawned fish. No attempt was made to estimate the relative proportions of these components and limited evidence precluded a conclusion on the establishment of a self-sustaining stock.

1.4 Species proportion in the catch

The result of catch-sampling jack mackerel landings to determine proportions of the three species has suggested a recent reduction of *T. murphyi* in some areas (Julian & Taylor 2008). Because jack mackerel are of necessity landed under the aggregate code "JMA", regular sampling of landings in the various fisheries are necessary to monitor the individual harvest of each species and ensure that the agreement to maintain landings of the New Zealand species in JMA 1 and JMA 3 at levels similar to the 1992–93 TACs is satisfied. This voluntary agreement was instigated to protect the New Zealand species when increases were made to the JMA 1 and JMA 3 TACs as a strategy to harvest the sudden increase in jack mackerel biomass caused by the invasion of Murphy's mackerel. The most recent summary of species proportions from the purse-seine and midwater trawl fisheries (Julian & Taylor 2008) indicates declines in the proportion of *T. murphyi*, but there is some confounding of the results by low observer coverage and possible changes in the distribution of fishing effort.

1.5 Length frequency of fish

Taylor (2002) used length data from the MFish trawl survey database (*trawl*) and the MFish Observer database (*obs*) to develop series of length frequency distributions for *T. murphyi*. Generally, there was no indication of gross changes over time in the maximum size, but there was evidence for a change in small fish (under 35 cm FL) in both series between 1992–93 and 1996–97. A minimum size of 7 cm FL was recorded in the trawl survey data in 1995–96 and a minimum size in the observer data of 24 cm FL in 1996–97. Small fish were also recorded in the observer data and in the trawl survey data.

More fine scale examination of the length data by area showed that small fish in the trawl survey data were mostly from inshore trawl surveys on the southeast coast of the North Island south of East Cape with evidence for a cohort of small fish centred at 10 cm in 1993–94 and at least two, and possibly three, modes of small fish apparent in 1995–96. Fine scale analysis of the observer data indicated that almost all small fish were taken in JMA 7 except for one fish in JMA 3 in 1992–93.

1.6 Age validation

Age structured stock assessment models have been developed for *T. declivis* and *T. novaezelandiae* (Horn 1991), but not for *T. murphyi* because early attempts at ageing this species in New Zealand were unsuccessful. An ageing methodology was developed for *T. murphyi* in 2002 and provided some qualitative validation of the technique by tracking strong year classes through several years of the JMA 7 midwater trawl fishery (Taylor et al. 2002). Ageing estimation and validation was carried out for the New Zealand species of jack mackerel (*T. declivis* and *T. novaezelandiae*) in the early 1990s (Horn 1993) and, in comparison to Murphy's mackerel, the growth check rings for the New Zealand species were relatively clear and easy to interpret. It is possible that the irregular, multiple-banding structure of Murphy's mackerel is a result of large variations in the oceanic environment inhabited before entering New Zealand coastal waters. Further attempts at validating *T. murphyi* ageing by analysis of marginal states, external ring/corrugation counts, and thin sections were unsuccessful (Beentjes et al. 2013) and validation of the otolith thin section ageing method adopted by Taylor et al. (2002) is still required.

1.7 Objectives

This current project examined abundance and distribution of the New Zealand Murphy's mackerel, spatial and temporal trends in age structure, and produced growth parameters. The overall objective was to determine the relative abundance and population structure of *Trachurus symmetricus murphyi* in New Zealand fisheries waters. Two specific objectives provided the basis for the work.

1. To review and summarise existing data describing the abundance and distribution of *T. murphyi* in New Zealand waters, in particular patterns of significant change in spatial distribution.
2. To analyse otoliths collected from observers and other sources to estimate annual age compositions for *T. murphyi* in New Zealand fisheries waters.

2 METHODS:

2.1 Abundance and distribution analyses

2.1.1 Presence of *T. Murphyi* in research trawl and MFish observer data

The aim here was to examine the spatio-temporal distribution of *T. murphyi* by plotting its presence in research (database *trawl*) and commercial (database *obs_lfs*) trawls in time (annual aggregates) and space (tow positions). Tows were selected according to the presence in them of any fish recorded as code JMM (*T. murphyi*) or any fish recorded as JMA (jack mackerel, species unspecified) that were larger than 57 cm. The cut-off criterion of 57 cm was based on the maximum known size of *T. declivis*, which was determined by examining the size distribution of all fish coded as JMD (*T. declivis*). The maximum size of *T. novaezelandiae* (JMN) is considerably lower than 57 cm. The presence data so generated were aggregated annually and plotted as positions on a series of New Zealand maps.

2.1.2 Aerial sightings data

The MFish aerial sightings database (*aer_sight*) contains data collected by fish-spotter pilots who fly as part of the domestic purse-seine fishing operation (Taylor 2003). The dataset consists of a number of finfish species (and some marine mammal sightings), but is mostly populated by sightings of the main purse-seine-targeted species: skipjack tuna (*Katsuwonus pelamis*), kahawai (*Arripis trutta*), blue

mackerel (*Scomber australasicus*), trevally (*Pseudocaranx dentex*), and the three jack mackerels *Trachurus declivis*, *T. murphyi*, and *T. novaezelandiae* recorded as the aggregate “jack mackerel”. Each sightings record comprises the time of day, the species composition of the group of schools in the sighting (although individual jack mackerel species are not differentiated), the number of schools contained within the sighting, the pilot’s estimates of the minimum and maximum sizes of the schools contained within the sighting (thus providing the numerical range of school sizes), and the geographical position of the sighting.

Sightings of jack mackerel from the aerial sightings database were summarised on an annual basis (calendar year) throughout the history of the dataset (1976–2008). The summary included all sightings in which jack mackerel were present including schools in which jack mackerel were mixed with other species. The aim here was to examine gross changes in the volume of sightings that could be attributed to the presence of *T. murphyi* and how it changed in time and space. Although there were sightings where *T. murphyi* had been identified specifically, these were recorded by only one of the pilots and it was unclear whether they had been recorded consistently throughout the period. Consequently, they were not used independently, but were aggregated within the totals, thus contributing to the overall summary.

2.1.3 Estimated values of jack mackerel species composition

In this case the objective was to examine estimated values of jack mackerel species composition in the purse-seine fishery using data from: 1) the MFish database (*market*); 2) TCEPR (vessel recording catch on Trawl Catch Effort Processing Returns) fisheries in JMA 3 and 7, and 3) using data from the MFish observer database (*obs*). These estimates had been produced under a series of projects and reports, with the most recent summaries for 2004–05 and 2005–06 presented to the Pelagic Working Group on 7 March 2007 (PELWG 07/19, MPI project JMA200401). Brief descriptions of the methods used to produce these summaries are given here.

Estimation methods for the JMA 1 data.

Two methods of estimating species proportions were used. Where sampling covered all landings the method was simple and required only that landing weights for each species be summed over all landings and divided by the total weight of all species in all landings. This provided species proportions for each species in all landings. Where only a subset of landings was sampled, the method was modified and proportions scaled to the total number of landings in the stratum (Appendix A).

Coefficients of variation (c.v.s) were estimated for all species proportions. Where all landings were sampled, i.e., all variance was within-landing variance, variance was estimated for the sample species proportions and c.v.s for the annual species proportions using the equations in the “Estimating Variance” section of Appendix A. The following approximate mean weights were assigned to each of the species for estimations of number of fish: 0.85 kg for *T. declivis*, 1 kg for *T. murphyi*, and 0.45 kg for *T. novaezelandiae*.

In all other cases only a subset of landings was sampled. Variance in species proportions is a combination of within-landing and between-landing variance, but because within-landing variance is a minor component of the total variance (Bull & Gilbert 2001) only the between-landing variance was estimated. This was done by bootstrapping the species proportion estimates and calculating c.v.s using:

$$\hat{c.v.} = \frac{\sqrt{\hat{\text{var}}(\text{bootstrapped species proportions})}{\hat{\text{mean}}(\text{bootstrapped species proportions})}$$

Bootstrapping incorporated 1000 sets of species proportions using data re-sampled from the original sample and landing weights, with replacement. The target value for c.v.s was 10%, based on arguments presented in Taylor (1999).

A c.v. was estimated for the mean species proportion estimated from a time series of species proportions (for *T. murphyi* in the JMA 7 TCEPR fishery from observer data) using:

$$\hat{c.v.}_{(mean(\hat{p}_i))} = \frac{1/n \sqrt{\sum (\hat{c}_i \hat{p}_i)}}{mean(\hat{p}_i)} \quad (1)$$

where \hat{p}_i is the *i*th species proportion in the series and \hat{c}_i is its estimated c.v.

Species composition and seasonality in JMA 3 and 7 using observer data

This work comprised data extracts from the observer database, estimation of species composition in the catch, and characterisation of the variation in species composition over time. Appropriate data were extracted from the MFish observer database (*obs_lfs*). The method used was as follows:

1. Species composition and total catch by tow and trip for 2005–06 were extracted from the database.
2. Species proportions were estimated by weight and number for each tow.
3. Species tow proportions were scaled to the tow tonnage to get species weights for the tow.
4. Means of the species tow weights for each trip were estimated.
5. These species trip estimates were scaled to the trip tonnage.
6. Species estimates were summed for all landings and proportions of the species in the catch were estimated based on the two time frames, fishing year and month.
7. Species proportions were estimated, using the equations in Appendix B.
8. C.v.s were estimated by bootstrapping the sample data.

2.1.4 Standardised stock indices from the deepwater trawl fishery

Work under MFish Project JMA2005/01 included an investigation of the feasibility of producing standardised catch per unit effort (CPUE) indices from the deepwater trawl or TCEPR (vessels recording catch on Trawl Catch-Effort Processing Returns) fishery.

An initial data extract was requested and received from MFish that consisted of all TCEPR catch-effort records from the jack mackerel bottom trawl and mid-water fisheries for vessels operating within JMA 7 between 1989–90 and 2004–05 inclusive. This dataset contained 48 139 tows in which jack mackerel was either targeted or caught. Only tows that targeted and caught jack mackerel were retained (29 020 tows), these tows accounting for 93% of the weight of jack mackerel caught. Approximately 6% of the tows that targeted jack mackerel recorded no jack mackerel catch.

Tow records were then examined to determine which contained fields with quantities that fell outside reasonable bounds (e.g., for tow speed, 6.5 to 12 km/hr). A full list of the fields examined included tow speed, headline height, wingspread, catch, tow duration, tow depth, and method type. Some trawls were recorded as bottom trawl, but the ratio between the wingspread and the headline height indicated that the tow was actually a midwater trawl. All records with fields falling outside the defined ranges were removed from the dataset, leaving 60% of the tows from the initial data set and retaining 86% of the jack mackerel catch.

The *T. murphyi* annual species proportions estimated from observer-sample data were then applied to the reduced jack mackerel catch-effort data to produce the *T. murphyi* catch-effort dataset. These data then formed the basis of a descriptive analysis of the unstandardised catch rate and an exploratory data

analysis (EDA) to determine the most appropriate input to a CPUE standardisation using the generalised linear model (GLM). Based on the results of this EDA, the fleet was split into two: a “past” fleet, comprising vessels operational in the fishery until 1998–99; and a “present” fleet, comprising vessels operational in the fishery throughout the history of the dataset. A standardisation was carried out on data from each of these fleets and a time-series of relative abundance indices produced for each.

2.1.6 Fishing company packing records (red-tail/green-tail)

The aim here was to summarise fishing company packing records of red-tail/green-tail jack mackerel from joint venture TCEPR vessels (vessels recording catch and effort on Trawl Catch Effort and Processing Returns). Red tail and green tail are used to respectively categorise *T. murphyi* and any combination of the two New Zealand species (including the presence of only one), based on the brown-red colouration of the tail of *T. murphyi* when compared with the more green-yellow colouration of *T. declivis* and *T. novaezelandiae*. A summary of these data had the potential to provide a time series of the proportion of *T. murphyi* in TCEPR landings as had been produced for an early period of the fishery by Taylor (2002). A reliable result in the present context required representative data from the fleet, but, while some data were made available, it was not possible to access the necessary hard-copy archives of a particular fishing company with a major contribution to the catch, so the analysis had to be abandoned.

2.2 Age composition and growth analyses

2.2.1 Otolith collections

Reasonable otolith collections and length frequency data were available for 1991, selected years between 1992–93 and 2000–01, and 2005. Catch at age was estimated for these three periods.

1991

Otoliths collected before 1993 were located and catalogued on the *age* database as part of this programme. A total of 355 Murphy’s mackerel otoliths were collected between February 1990 and July 1992 (29 months) from *Cordella* and *Tangaroa* trawl surveys, scientific observer programme, and the stock monitoring programme (Table 1). The collection includes nine samples between 1990 and 1992, although most are too small to be useful for constructing age-length-keys. The largest single collection (N=285) is stock monitoring programme (SMP) data from Statistical Area 018 in March 1991, and provides a reasonable representation of fish length from 41 to 60 cm. A further 17 otoliths collected from the Chatham Rise on *Tangaroa* survey TAN9106 in December 1991 (9 months later) were from small fish (39 to 44 cm). All other samples contained either too few otoliths or the separation of time from collection of the largest set (N=285) was too great to be useful. These 285 SMP otoliths from March 1991 and the 17 *Tangaroa* otoliths from December 1991 were used to construct the age-length-key.

Table 1: Murphy’s mackerel otoliths collected before 1993. Otoliths aged and included in the age-length-key were the sample of 285 (SMP, landing_no 910011, March 1991) and 17 (TAN9106, December 1991). SOP, scientific observer programme; SMP, stock monitoring programme.

Area	Origin	Trip/landing	No. otoliths	Time of collection
North Taranaki	<i>Cordella</i>	COR9001	8	Feb 1990
South Taranaki Bight	<i>Cordella</i>	COR9001	5	Feb 1990
West coast South Island	<i>Cordella</i>	COR9001	5	Feb 1990
Challenger	SOP	420	2	Jun 1990
South-east	SOP	454	7	Dec 1990
Statistical area 018	SMP	910011	285	Mar 1991
Challenger	SOP	474	3	Jul 1991
Chatham Rise	<i>Tangaroa</i>	TAN9106	17	Dec 1991
Challenger	SOP	549	3	Jul 1992

1992–93 to 2000–01

No ageing was necessary for these years and we used the six age-length-keys previously constructed from otoliths collected from JMA 3 and JMA 7 for the years 1992–93, 1994–95, 1995–96, 1996–97, 1997–98, and 2000–01 Taylor et al. (2002). These age length keys were constructed for unsexed fish. The missing years had inadequate otolith collections to enable an age length key to be constructed.

2005

The most comprehensive collection of otoliths and length data in 2005 was from November–December and JMA 7. Age distribution was estimated for this period and area.

Jack mackerel catches have been sampled by the stock monitoring programme (SMP) since October 2003 to determine more accurately the proportions of the jack mackerel catch that is made up of the three species (*T. murphyi*, *T. declivis*, and *T. novaezelandiae*). In addition, from January 2004 onward, otoliths were taken, and length, weight and sex of fish were recorded from a representative size range of Murphy’s mackerel with the aim of sampling about 50 fish per month. Most sampled landings were from JMA 7, with a few from JMA 1. We selected otoliths sampled during November and December 2005 from JMA 7. Note that these otoliths were part of the collection taken over the entire 12 months of 2005 which were used to validate ageing in project JMA200301 (Beentjes et al. 2013). A total of 101 otoliths from the SMP programme were prepared and read.

Additional otoliths collected during November and December 2005 were sourced from the scientific observer programme (SOP) on vessels completing TCEPRs. Using a target of 30 otoliths per size class, additional otoliths were selected and together with those from the SMP, 338 were used in catch at age analyses (Table 2).

2.2.2 Preparation and reading of otoliths

The otolith processing and reading protocol followed the method adopted by Taylor et al. (2002). Otoliths were embedded in araldite (K142) resin and cured at 50°C for 24 hours. The resin blocks were sectioned transversely through the otolith primordia using a Struers Accutom-2 low speed saw with a diamond edged

Table 2: Murphy's mackerel otoliths used to generate age distributions for Nov/Dec 2005. CHA, Challenger, WCSI, West coast South Island; AKW, Auckland west; CEW, Central west.

Month/year	Area	Trip or landing number	Fishstock	Origin	Total
Nov/Dec 05	WCSI, CHA	200561/04/05/08/11 200565/37/38/39/41/42/43/44	JMA 7	SMP	94
Nov/Dec 05	AKW, CEW, CHA	2177–2181	JMA 7	SOP	247
Total					341

wafering blade. The cut surface of the block was then polished using progressively finer carborundum paper (300–1200 grit).

Alternating translucent (light) and opaque (dark zones) zones were evident in otolith thin sections read with a bright field stereomicroscope under transmitted light (magnification of 40). The number of complete opaque zones was counted (i.e., opaque zones with translucent material on the outside) adopting the 'narrow-zone' protocol of Taylor et al. (2002), and these were assumed to be annual growth checks or annuli. The Protocol otolith set was used as a means of calibrating the identification of the opaque dark zones (see Taylor et al. 2002 for more details). The first reader read all otoliths, whereas the second reader read a subsample of the otoliths for comparison. An agreed zone count was then determined for the total set. Counts between readers were compared using linear regression. A readability score ranging from 1 to 5 was assigned to each otolith, with 1 being very readable and 5 unreadable.

2.2.3 Catch at age analyses

Catch at age analyses were carried out using the NIWA programme Catch-at-age (Bull & Dunn 2002). The programme firstly scales the length frequency data to the catch and secondly, an age-length-key, estimated from the otolith length-at-age data, is applied to the scaled length frequency data to estimate numbers at age.

Length weight coefficients used in the catch at age analyses were the same as those used by Taylor et al. (2002). i.e., $a = 0.000010447$ and $b = 2.996637$ for males, females and unsexed fish.

Catches of jack mackerel can comprise any or all of the three species (*T. declivis*, *T. novaezelandiae*, and *T. murphyi*) but these are usually landed as a single species under the code JMA. Observers, however, sample the catch from each tow and estimate the weight of each mackerel species. To scale the observer JMM length frequency data collected to the catch from each tow, we needed to know the weight of Murphy's mackerel in each sampled tow. The actual catch weight of JMM in a tow is not, however, recorded by observers in the table *t_general* of *obs_lfs*, and was calculated from the sampled weight of JMM compared to the total sampled weight of JMA. The proportion of JMM in the sample was then applied to the total tow catch of JMA, thus providing an estimate of JMM in the catch from that tow. The overall proportion of the JMM in the annual landings by year and area was estimated by applying the overall proportion of JMM in the tows that were included in our analyses. Length frequency data were then scaled to JMM tow catch weight and annual landings. The procedure for estimating the proportion of *murphyi* in the jack mackerel catch from each tow and the annual landed catch, was the same as that used by Taylor et al. (2002).

1991

Length frequency data were extracted from the *obs_lfs* and *market* databases. There were insufficient length data to confine the selection period to coincide with the main otolith collection period of March

1991 (285 otoliths, SMP), and hence we included all length data collected in 1991. The 1991 SOP length datasets comprised 2381 individual lengths (945 from JMA 3 and 1436 from JMA 7) from eleven trips and 66 tows. The SMP data included 1457 individual lengths from five landings, all from JMA 3 (statistical area 018). The SOP length frequency data were scaled to the JMM catch from each tow and to the commercial catch in 1990–91 for JMA 3 and JMA 7, adjusted for the proportion of JMM in the jack mackerel catch. Similarly, the SMP data was scaled to the landing weight of JMM in the sampled catch and to the commercial catch in JMA 3 in 1990–91, adjusted for the proportion of JMM in the jack mackerel catch — the proportion of the catch that was JMM was estimated from the procedure described above. For a few observer tows, catch weights were not provided and here the length-weight relationship was used to generate a catch weight, with the assumption that all fish were measured. Age distributions were estimated separately for the SOP and SMP length data. The single age-length key constructed from the 1991 otolith set was applied to the SOP scaled length frequencies for JMA 3 and JMA 7 separately, and SMP data for JMA 3 data. Scaled length frequencies and numbers at age were estimated for males and females separately.

1992–93 to 2000–01

Previous catch at age estimates for Murphy’s mackerel were carried out for the six fishing years 1992–93, 1994–95, 1995–96, 1996–97, 1997–98, and 2000–01 using otoliths collected from JMA 3 and JMA 7 to construct age-length-keys (unsexed), but applied to observer length data only from JMA 7 (Taylor et al. 2002). For 1994–95, 1999–2000, and 2000–01 there were no age length keys generated because otolith numbers were low. The current project aimed to extend the catch at age analysis to produce age distributions for different areas. Accordingly, we interrogated the *obs_lfs* database and extracted all length and tow catch data over these six years. Apart from JMA 7, all other length data were from JMA 3 and these were scaled to the tow catch and to the annual landed catch in each year. The six existing age-length keys were then applied to JMA 3 scaled length data, to estimate numbers at age. Scaled length frequencies and numbers at age were estimated for males and females combined because age-length keys did not distinguish between sexes.

2005

Length frequency data from JMA 7 were extracted from the *obs_lfs* database for the period November – December 2005. The dataset comprised 4149 individual lengths and were scaled to the catch from each tow and also to the commercial catch from 2004–05 in JMA 7. The proportion of the catch in each tow and the 2004–05 annual JMA 7 landing that was JMM was estimated from the procedure described above. For a few tows, catch weights were not provided and here the length-weight relationship was used to generate a catch weight, with the assumption that all fish were measured. The age-length-key, constructed from the Nov/Dec 2005 otoliths set, was applied to the scaled length frequency data to estimate numbers at age. Scaled length frequencies and numbers at age were estimated for males and females separately.

2.2.4 Sex ratios

A preliminary examination of sex ratios from a comparison of length frequency distributions of male and female fish suggested higher proportions of males than females in the early years, and a relative increase in the representation of females in 2005–06 (see section 3.7). With the aim of examining the spatiotemporal variations in these distributions and determining whether males and females were taken together in time and space, a fine-scale examination of the data was performed where the proportion of males (number of males divided by the sum of males and females) from individual trawls were compared. Datasets were constructed for the two Fishstocks (JMA 3 and JMA 7) and their constituent statistical areas. A weighted “contribution” for each tow was taken as the sample size (i.e., number of fish) and frequency distributions were constructed as the sum of the weighted contributions in a series of sequential “proportion-of-male” cells. Cell totals from each dataset were divided by the largest cell total from all datasets to normalise the frequency distributions and allow direct comparisons between areas and years. Two levels of this fine-scale analysis were performed, with summaries produced by Fishstock and statistical area. Thus annual summaries (by calendar year) were produced for JMA 3

and 7 (too few data were available to produce reliable summaries for JMA 1) and for SOU, SOI, and SEC (JMA 3), and CEW and CHA (JMA 7).

2.2.5 Growth parameter estimation

Von Bertalanffy growth models were fitted to the 2005 length-age data used in the catch at age analysis (Nov/Dec 2005), supplemented with ageing data from February 2005 to Jan 2006 (Beentjes et al. 2013), plus seven juvenile otoliths sourced from Chile, giving a total of 706 age-lengths. Two growth models were fitted, a full model that estimated growth for males and females separately, and a reduced model that combined the sexes. A likelihood ratio test was used to compare the fits of the full and reduced models. Diagnostics of residuals against fitted values and quantiles of standard normal distributions are presented to evaluate the two models.

3 RESULTS

3.1 Presence of *T. murphyi* in research trawl and MFish observer data

A summary of these data indicated that the earliest appearance in New Zealand waters of fish meeting the definition for *T. murphyi* described above (Section 2.1.1) was at least 1984 (Figure 3). Their first appearance occurred around the Chatham Islands, with their numbers peaking about 1992 to 1997. Since then their numbers have declined again, although the summary suggests greater residual numbers now than were present during the earliest years of the invasion.

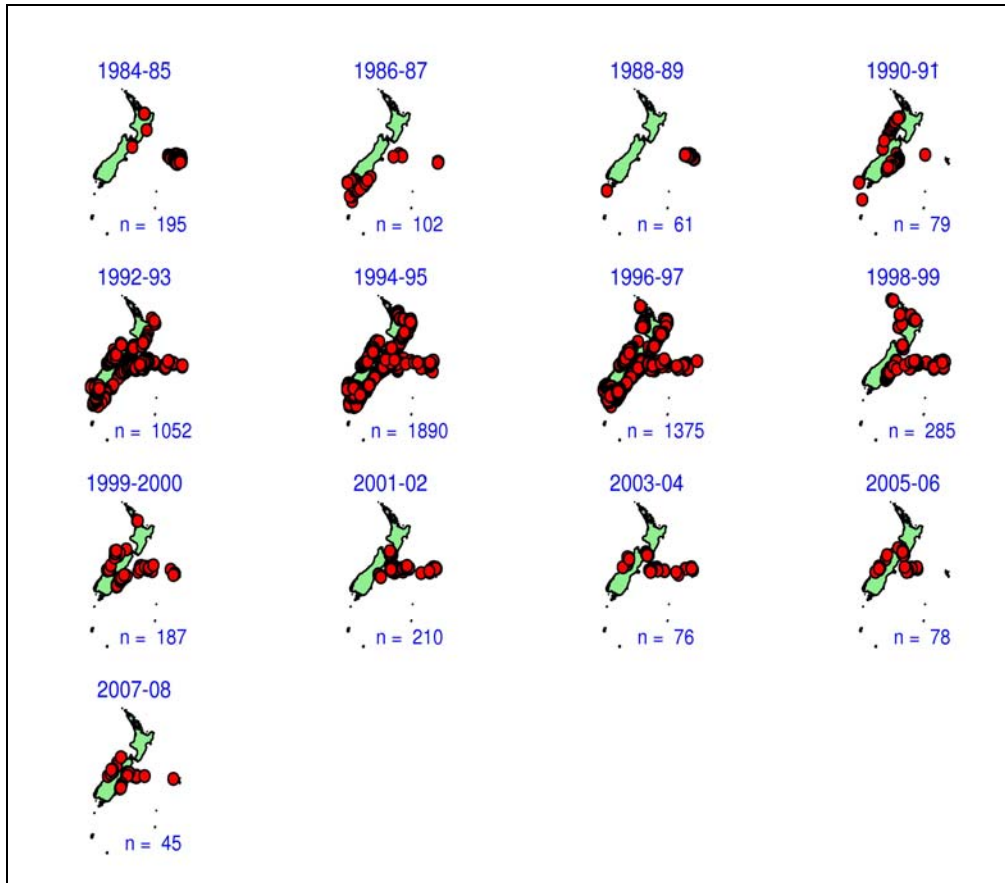


Figure 3: Distribution of the number (n) of biennially aggregated research and commercial trawls containing *T. murphyi* from 1984 to 2008, illustrating its earliest appearance in New Zealand, its peak representation in 1994–95, and its gradual waning since; note that 2008 data are incomplete at the compilation of these data in August 2008; circles register only the presence of JMM and their size provides no information on quantity. Source: MFish trawl and obs databases.

3.2 Aerial sightings data

A summary of the aerial sightings data showed changes over time from a baseline distribution of sightings over the half-degree square grid in the early years that persisted until 1989 when numbers of Jack Mackerel (all species) showed a marked increase that continued through a peak in 1993 and returned to the baseline level in 1997 (Figure 4). Aerial sightings data are largely restricted to the continental shelf from Kaikoura northwards.



Figure 4: Distribution of aerial sightings in which jack mackerel (all species combined) were recorded, by calendar year between 1976 and 2008, illustrating the large increase in jack mackerel sightings between 1990 and 1997 that coincides with *T. murphyi*'s invasion of New Zealand waters and the subsequent reduction to previous base-line levels in more recent years; circles are centred on the elements of a grid of "half-degree" squares used routinely with the aerial sightings data (Appendix C); circle diameter is proportional to the number of sightings in a grid square in a calendar year. Source: MFish aerial sightings database, *aer_sight*.

3.3 Species composition

3.3.1 JMA 1

The jack mackerel purse-seine fishing season in JMA 1 begins in about May or June each year and runs until about December (Figure 5). For 2004–05 the main period of catch was between June and September. As with previous years, no seasonal pattern of species composition was evident. The proportion of *T. novaezelandiae* has dominated throughout the time series since sampling began, although this was interspersed with occasional high proportions of *T. murphyi* until March 2000, after which catches of the latter species became a rare event (Table 3).

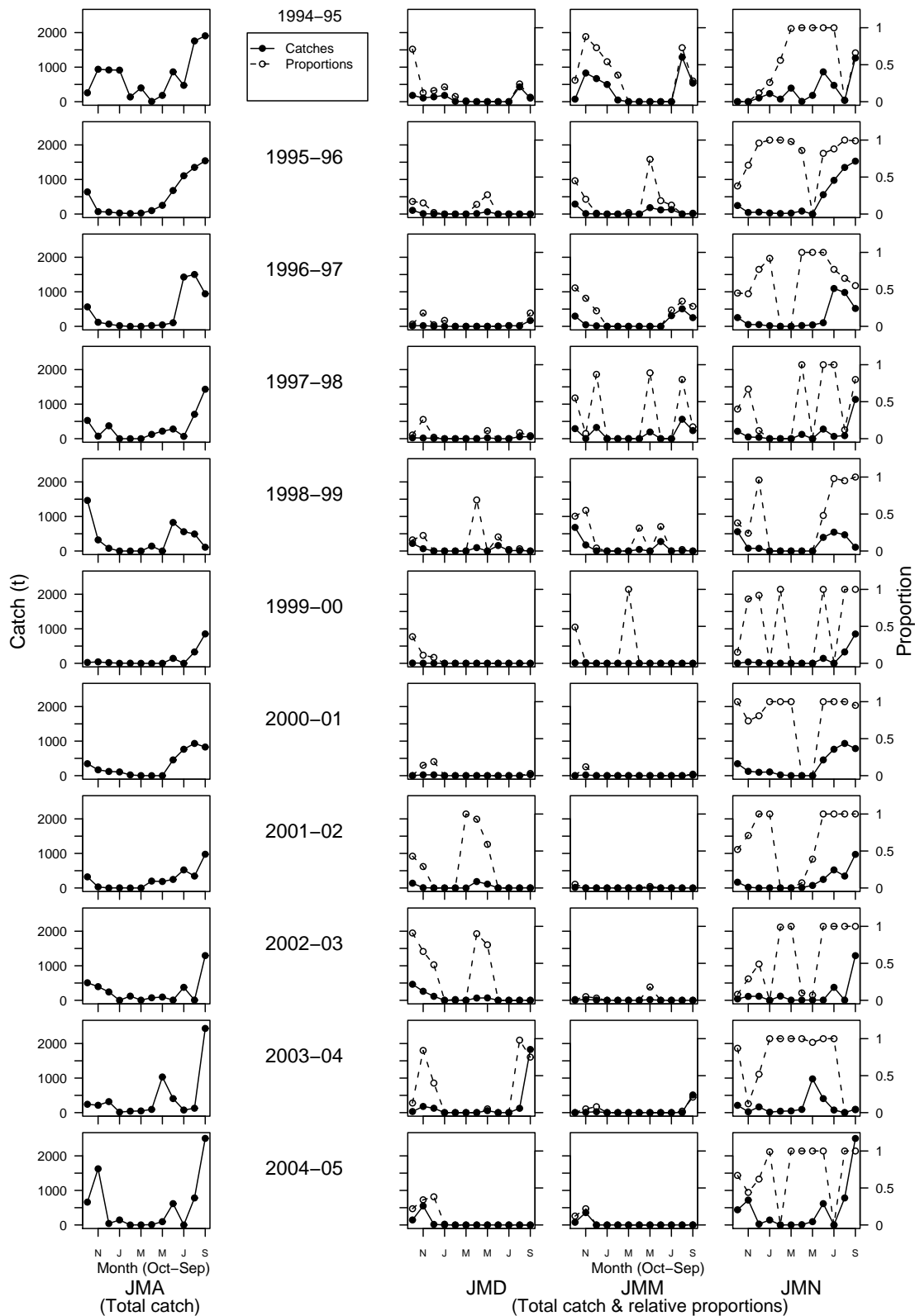


Figure 5: Time series of catch and species proportions in the JMA 1 purse-seine fishery between October 1994 and September 2005; JMA is the total jack mackerel catch, JMD is *T. declivis*, JMM is *T. murphyi*, and JMN is *T. novaezelandiae*; individual species catches were generated as scaled portions of the sampled catch using estimated species proportions (source MFish market database).

Table 3: Species composition of the purse-seine catch of jack mackerel; North is Sanfords and Pelco (Tauranga), South is Sanfords (Nelson); JMD is *Trachurus declivis*, JMM is *T. murphyi*, JMN is *T. novaezelandiae* (source: Sanford Ltd sampling data).

Shed	Fishstock	Fishing year	No of landings sampled	% of landings sampled	Species proportions		
					JMD	JMM	JMN
North	JMA 1	1994–95	81	100	0.13	0.45	0.42
		1995–96	73	100	0.03	0.13	0.84
		1996–97	79	100	0.05	0.30	0.65
		1997–98	44	25	0.05	0.42	0.53
		1998–99	49	100	0.14	0.30	0.56
		1999–00	42	100	0.01	0.01	0.98
		2000–01	74	100	0.02	0.01	0.97
		2001–02	53	100	0.18	0.01	0.81
		2002–03	59	100	0.25	0.02	0.73
		2003–04	63	100	0.54	0.09	0.46
		2004–05	63	100	0.12	0.07	0.81
		South [‡]	JMA 1 [†]	1999–00	1	100	0.92
2000–01	3			100	0.62	0.09	0.29
JMA 3	1997–98		1	100	0.29	0.69	0.02
	1999–00		4	100	0.23	0.77	0.00
JMA 7	1998–99		9	100	0.51	0.49	<0.01
	1999–00		1*	100	0.34	0.66	0.00
		2000–01	5	100	0.23	0.76	0.1

*No of landings for JMA 7 in 1999–2000 is 1 plus a partial landing

[†]Wairarapa coast

[‡]Sanfords (Nelson) closed in November 2002; data collected during 2001–02 were from landings taken in an unspecified part of JMA 1 or mixed landings taken in JMA 1 and JMA 7; none were used in the analysis.

3.3.2 JMA 3 and 7

JMA 7 inshore trawl

Bycatch of jack mackerels in the JMA 7 inshore trawl fishery is continuous throughout the year (Table 4 and Figure 6), although a declining trend is evident in most years for the total monthly catches in this fishery. Estimates of species proportions using market sampling data from October 1999 to September 2005 are summarised in Table 4 and presented, along with catches of the three species as time series plots, in Figure 6. No sampling data were available for 2002–03. There was no evidence for any regular seasonal patterns in species proportions, but there was evidence that species composition changed frequently, and that all three species were taken regularly in the CELR (vessels recording catch on Catch Effort Landing Returns) inshore trawl fishery. *T. murphyi* has seldom been the dominant species in the catch, but it has been taken regularly at a level that has continued throughout the series. In 2003–04, *T. novaezelandiae* was often the most highly represented of the three species in the fishery, but for 2004–05 this was true only late in the year. Earlier in 2004–05, *T. declivis* was usually the predominant species in the catch. The break in data from January 2002 to October 2004 was an extended period when no sampling was required in this fishery.

Observer data (JMA 3 and 7)

The annual TCEPR catch in JMA 3 has been dominated by *T. murphyi* in all years since 1987–88 except 2002–03, when its proportion declined to 0.32, less than half its previous lowest value (Table 5) although few tows were sampled before 1992–93. The apparent increase to 0.81 in 2003–04 suggests a return to previous levels, but it is estimated from only 7 samples (tows). In 1999–2000 *T. novaezelandiae* reappeared for the first time since 1987–88, but has been absent from samples since. Coefficients of variation on the species proportions often met the target value of 5% or less for *T. murphyi*, although there were several instances where the variance was too high to be acceptable.

Table 4: Scaled species composition of inshore trawl catch of jack mackerel in JMA 7 by fishing year; JMD is *Trachurus declivis*, JMM is *T. murphyi*, JMN is *T. novaezelandiae*, *N* is the number of landings sampled, c.v.s are coefficients of variation (source: MFish Market sampling database, market, Talley's Ltd sampling data).

Fishing year	Month	N	Species proportions			c.v.		
			JMD	JMM	JMN	JMD	JMM	JMN
1998–99	August	2	0.03	0.05	0.92	0.17	0.14	0.01
	September	2	0.26	0.00	0.74	0.02	0.50	0.01
	Overall	4	0.17	0.02	0.81	0.02	0.14	0.01
1999–2000	November	5	0.31	0.40	0.30	0.30	0.02	0.02
	December	2	0.25	0.60	0.15	0.08	0.03	0.04
	January	3	0.33	0.23	0.44	0.04	0.06	0.03
	February	3	0.20	0.05	0.76	0.07	0.13	0.02
	March	3	0.12	0.03	0.85	0.06	0.13	0.01
	Overall	16	0.28	0.33	0.39	0.02	0.02	0.01
	2000–01	November	6	0.38	0.57	0.05	0.03	0.02
December	2	0.62	0.37	0.01	0.03	0.05	0.39	
February	1	0.35	0.65	0.00	0.05	0.03	0.00	
May	5	0.60	0.13	0.27	0.03	0.07	0.06	
June	2	0.67	0.33	0.00	0.02	0.04	0.00	
July	6	0.59	0.15	0.25	0.01	0.05	0.03	
August	2	0.16	0.08	0.76	0.19	0.32	0.05	
September	3	0.29	0.21	0.50	0.04	0.04	0.02	
Overall	27	0.48	0.40	0.12	0.01	0.02	0.02	
2001–02	October	10	0.47	0.22	0.31	0.01	0.03	0.02
	November	7	0.32	0.42	0.27	0.02	0.02	0.02
	December	5	0.38	0.38	0.23	0.03	0.03	0.02
	Overall	22	0.40	0.33	0.28	0.01	0.01	0.01
2003–04	October	2	0.39	0.05	0.57	0.03	0.13	0.02
	November	8	0.37	0.29	0.34	0.04	0.04	0.02
	December	6	0.25	0.27	0.48	0.04	0.04	0.01
	January	5	0.23	0.12	0.65	0.04	0.06	0.01
	February	7	0.41	0.34	0.25	0.03	0.03	0.02
	March	9	0.56	0.27	0.17	0.02	0.05	0.02
	April	3	0.15	0.01	0.84	0.05	0.28	0.01
	May	3	0.51	0.15	0.34	0.03	0.11	0.02
	June	7	0.24	0.02	0.74	0.03	0.08	0.02
	July	5	0.38	0.07	0.54	0.03	0.10	0.02
	August	1	0.69	0.31	0.00	0.03	0.07	0.00
	September	7	0.26	0.22	0.52	0.07	0.11	0.05
	Overall	61	0.35	0.22	0.43	0.02	0.04	0.01
2004–05	October	2	0.82	0.02	0.17	0.02	0.37	0.07
	December	4	0.75	0.12	0.13	0.02	0.09	0.04
	January	1	0.13	0.87	0.00	0.17	0.02	0.00
	February	1	0.69	0.31	0.00	0.05	0.10	0.00
	March	5	0.55	0.08	0.37	0.03	0.09	0.05
	April	2	0.70	0.30	0.00	0.04	0.09	0.00
	May	4	0.62	0.36	0.01	0.04	0.06	0.01
	June	8	0.69	0.26	0.04	0.02	0.04	0.02
	July	2	0.03	0.00	0.96	0.13	0.38	0.00
	August	1	0.23	0.04	0.73	0.11	0.31	0.04
	September	7	0.22	0.14	0.64	0.04	0.04	0.01
	Overall	37	0.49	0.23	0.28	0.03	0.05	0.02

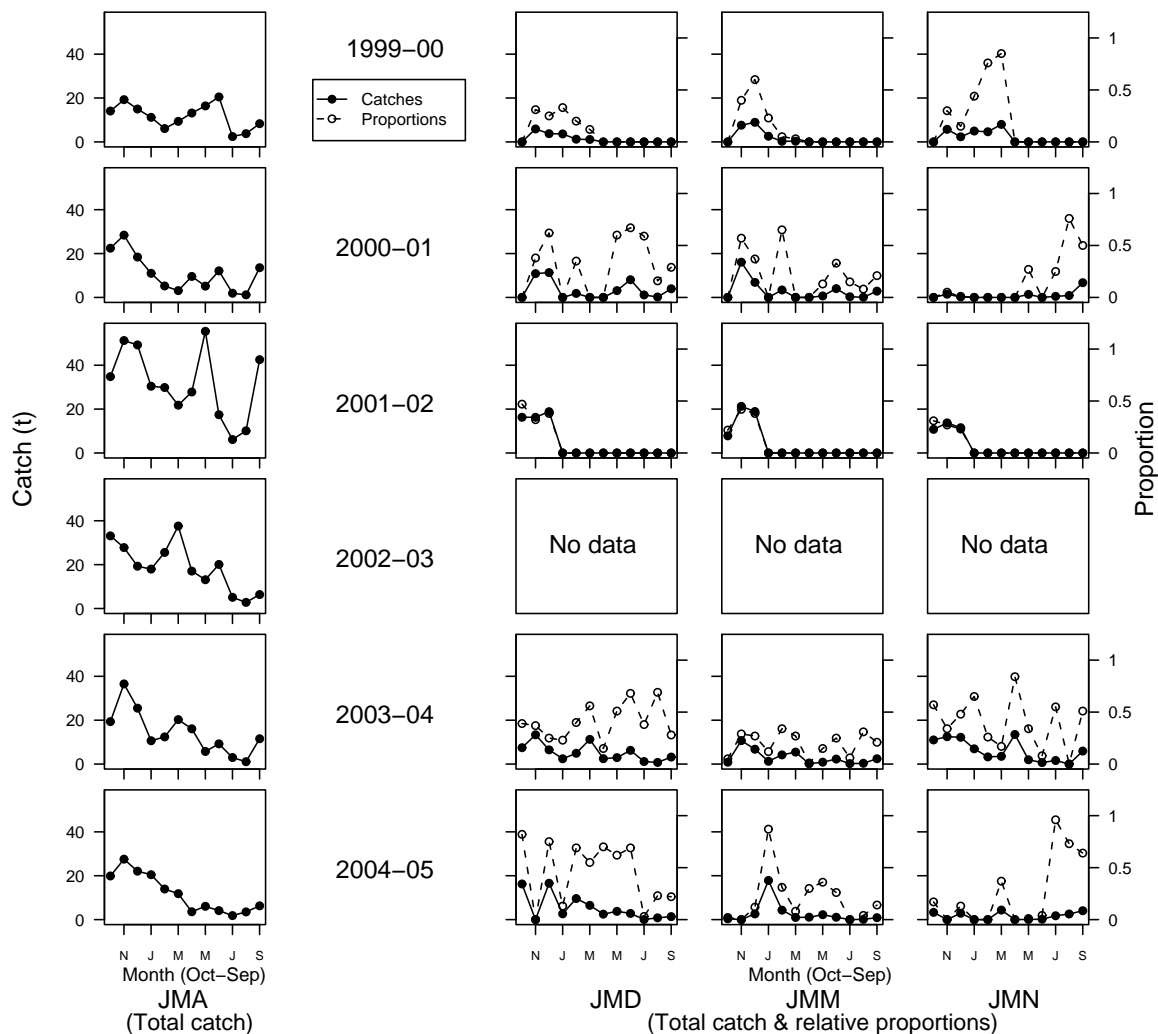


Figure 6: Time series of catch and species proportions and catch of the three jack mackerel species in the JMA 7 inshore trawl catch (vessels using Catch Effort Landing Returns — CELR) between October 1999 and September 2005; JMA is the total jack mackerel catch, JMD is *T. declivis*, JMM is *T. murphyi*, and JMN is *T. novaezelandiae*; individual species catches were generated as scaled portions of the sampled catch using estimated species proportions; sampling data were unavailable as follows — October and April–September in 1999–00, October, January, March, April in 2000–01, January–September in 2001–02, all months in 2002–03, November in 2004–05 (source MFish market database).

In JMA 7 the pattern has been much more variable (Table 5). In most years the proportion of either *T. declivis* or *T. novaezelandiae* was the highest, with *T. declivis* having the highest proportion most often. The annual proportion of *T. murphyi* was highest only in 1995–96. Between 1996–97 and 2000–01 its proportion varied between 0.12 and 0.19, but in 2001–02 it fell markedly to 0.05 where it has remained. This most recent level is similar to that estimated for the early years of the invasion of New Zealand waters. The proportion of *T. novaezelandiae* in JMA 7 was highest in 1989–90 and 1990–91. In contrast to *T. murphyi*, the proportion of *T. novaezelandiae* rose to 0.32 in 2001–02 and 2002–03, decreased slightly to 0.21 in 2003–03, and rose to 0.44 in 2004–05. The c.v.s for proportions of *T. declivis* and *T. novaezelandiae* were usually higher than 10%, although they were 5% or less in a number of cases for both species.

At a finer temporal scale (Table D1), the predominance of *T. murphyi* in the monthly catch from JMA 3 has been striking, although there have been recent instances during 2001–02 and 2002–03 when *T. declivis* was the major component, an event that had been absent since 1993–94. By contrast,

T. novaezelandiae has been almost nonexistent in the time series, reappearing in seven tows during 1999–2000 and two single tows in 2000–01 and 2001–02, after being absent since 1987–88.

Table 5: Scaled species composition by fishing year of the catch of jack mackerels in the TCEPR fleet (vessels using Trawl Catch Effort Processing Returns) in JMA 3 and 7; JMD is *Trachurus declivis*, JMM is *T. murphyi*, JMN is *T. novaezelandiae*, N is the number of sampled tows that contained a particular species (source: MPI market sampling database, *market*).

Fishstock	Fishing year	Species proportions			c.v.			N		
		JMD	JMM	JMN	JMD	JMM	JMN	JMD	JMM	JMN
JMA 3	1985–86	0	1	0	0	0	0	0	1	0
	1986–87	0.78	0	0.22	0.17	0	0.54	7	0	4
	1987–88	0.19	0.79	0.02	0.98	0.73	0.75	2	1	1
	1988–89	0	1	0	0	0	0	0	1	0
	1989–90	0.3	0.7	0	0.24	0.12	0	2	2	0
	1990–91	0	1	0	0	0	0	0	7	0
	1991–92	0	1	0	2.11	0	0	3	14	0
	1992–93	0.14	0.86	0	0.27	0.04	3.51	18	119	1
	1993–94	0.24	0.76	0	0.68	0.21	0	5	38	0
	1994–95	0.04	0.96	0	0.83	0.04	0	2	15	0
	1995–96	0.02	0.98	0	0.27	0	0	49	102	0
	1996–97	0	1	0	0	0	0	1	15	0
	1997–98	0.02	0.98	0	0.17	0	0	31	60	0
	1998–99	0.15	0.85	0	0.33	0.06	0	29	48	0
	1999–00	0.29	0.65	0.06	0.31	0.16	0.5	20	27	7
	2000–01	0.17	0.83	*0.00	0.33	0.06	0	38	73	1
	2001–02	0.33	0.66	*0.00	0.25	0.14	1.57	48	70	1
	2002–03	0.68	0.32	0	0.37	0.59	0	6	16	0
	2003–04	0.03	0.97	0	1.64	0.11	0	1	7	0
	2004–05	0.24	0.76	0	0.86	0.27	0	2	27	0
JMA 7	1985–86	0.68	0	0.32	0.02	0	0.04	3	0	3
	1986–87	0.58	0	0.42	0.05	0	0.07	186	0	170
	1987–88	0.58	0	0.42	0.25	0	0.34	13	0	9
	1988–89	0.63	0.07	0.3	0.11	0.72	0.26	28	5	17
	1989–90	0.29	0.01	0.7	0.13	0.67	0.06	92	11	88
	1990–91	0.38	0.03	0.6	0.07	0.31	0.04	190	28	172
	1991–92	0.46	0.09	0.45	0.12	0.31	0.12	88	47	77
	1992–93	0.59	0.17	0.25	0.04	0.1	0.08	159	150	145
	1993–94	0.37	0.35	0.28	0.08	0.11	0.11	146	109	104
	1994–95	0.3	0.34	0.36	0.06	0.09	0.09	140	127	129
	1995–96	0.36	0.41	0.23	0.23	0.38	0.26	61	41	49
	1996–97	0.58	0.15	0.27	0.04	0.16	0.09	128	123	102
	1997–98	0.49	0.14	0.38	0.04	0.12	0.05	168	152	164
	1998–99	0.68	0.12	0.2	0.05	0.17	0.14	122	68	41
	1999–00	0.66	0.19	0.14	0.07	0.25	0.29	61	48	31
	2000–01	0.66	0.19	0.14	0.05	0.10	0.21	77	65	57
	2001–02	0.64	0.05	0.32	0.07	0.37	0.14	67	23	42
	2002–03	0.62	0.06	0.32	0.08	0.17	0.17	102	67	74
	2003–04	0.73	0.06	0.21	0.04	0.17	0.15	60	46	42
	2004–05	0.49	0.07	0.44	0.05	0.13	0.06	273	176	223

**T. novaezelandiae* appeared in 1 tow in each of these years, but at very low levels.

In JMA 7 the pattern of high proportions of *T. murphyi* has been seasonal, occurring regularly around July–August from 1990–91. However, this pattern was absent for the first time in 2000–01, with *T. murphyi* present in very few tows. Observer coverage was low in 2002–03 and 2003–04, resulting in reduced sampling and unreliable estimates, but in 2004–05 increased sampling provided estimates showing a very low rate of representation of *T. murphyi* from the fishery, and a switching predominance between the other two species. High proportions of *T. novaezelandiae* in April–June probably reflect increased fishing north of the North Taranaki Bight. For both *T. declivis* and *T. novaezelandiae*, species proportions are highly variable, with neither showing a clear seasonal pattern. In 2000–01, *T. declivis* dominated the catch and this continued throughout most of 2001–02, 2002–03, and 2003–04, except in April–May 2002–03 when *T. novaezelandiae* represented the highest proportion. Coefficients of variation of less than 5% were associated with the highest proportion in the species composition estimates in about 40% of cases, suggesting that these estimates were acceptable and could be used to examine patterns of seasonality.

3.4 Standardised stock indices from the deepwater trawl fishery

The past and present JMM CPUE indices are tabulated (Table 6) and graphed (Figures 7 and 8). The past-vessel standardised bottom trawl index shows a five-fold increase for JMA 7 between the 1989–90 and 1990–91 fishing years, followed by a larger decrease in the 1991–92 fishing year. From 1991–92 to 1996–97 the index increases nearly nine-fold. Subsequently, from 1997 to 2000 the index halves in value. The present-vessel standardised index follows an irregular decline from 1991–92 to 1997–98, reaching about one third of its initial value in 1997–98. From 1997–98 onwards the index is flat.

Table 6: Standardised CPUE indices for the present vessel JMM standardisation.

Fishing year	Present vessel standardisation			Past vessel standardisation		
	Index	c.v.	Number of tows	Index	c.v.	Number of tows
1989–90				0.011	0.25	79
1990–91				0.051	0.17	127
1991–92	0.724	0.21	93	0.006	0.14	411
1992–93	0.900	0.23	59	0.016	0.14	476
1993–94	0.384	0.19	120	0.014	0.14	793
1994–95	0.720	0.19	171	0.018	0.14	361
1995–96	0.733	0.20	102	0.022	0.14	571
1996–97	0.376	0.19	160	0.053	0.14	411
1997–98	0.169	0.17	252	0.049	0.15	394
1998–99	0.237	0.16	712	0.036	0.19	98
1999–00	0.187	0.16	717	0.025	0.32	23
2000–01	0.213	0.16	1240			
2001–02	0.223	0.15	1760			
2002–03	0.171	0.15	2272			
2003–04	0.166	0.15	2055			
2004–05	0.193	0.15	2002			

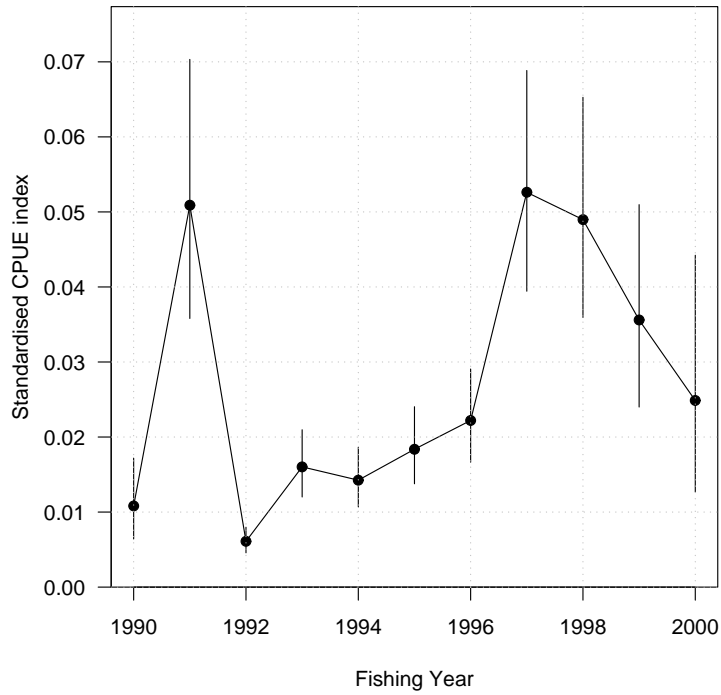


Figure 7: Standardised index for the past vessel JMM CPUE data set with 95% confidence intervals shown.

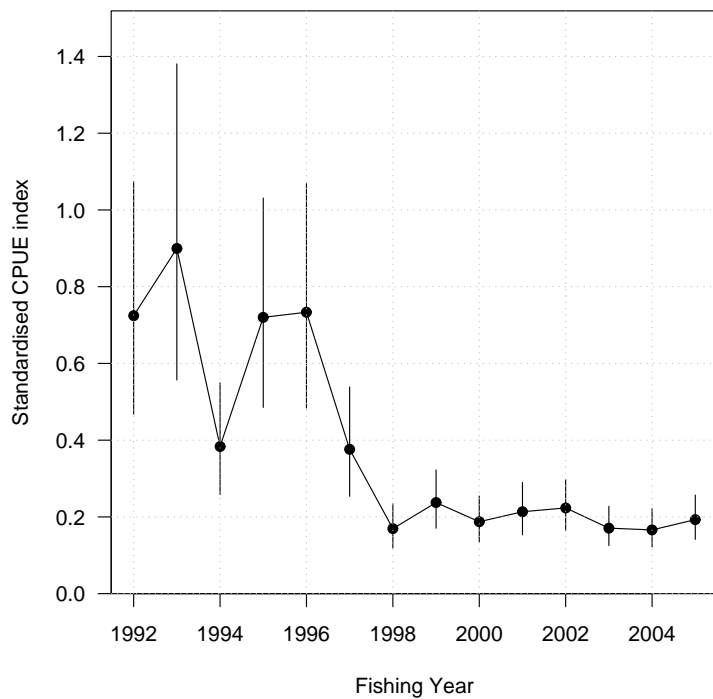


Figure 8: Standardised index for the present vessel JMM CPUE data set with 95% confidence intervals shown.

3.5 Otolith age readings

For 1991, a total of 279 otolith thin sections were assigned a number of zones using the narrow-zone method (Taylor et al. 2002) (Figure 9). The opaque dark zones appear to be well defined in some locations and obscure in others. About 60% of the read otoliths were ranked as difficult to read (4 and 5), and about a third as having average readability (3) (i.e., 0% for 1, 2.4% for 2, 37.2% for 3, 56% for 4, and 4.4% for 5). Otoliths with a readability of 5 were not assigned an age. The linear regression model indicated that there was less agreement between the two readers than for 2005, with a slope of 0.73, and 54% of the variance explained by the model (Figure 10), but the poor fit was mainly a result of the narrow age range in these otoliths (Figure 11). The difference in counts between readers was similar to that in 2005 (Figure 11).

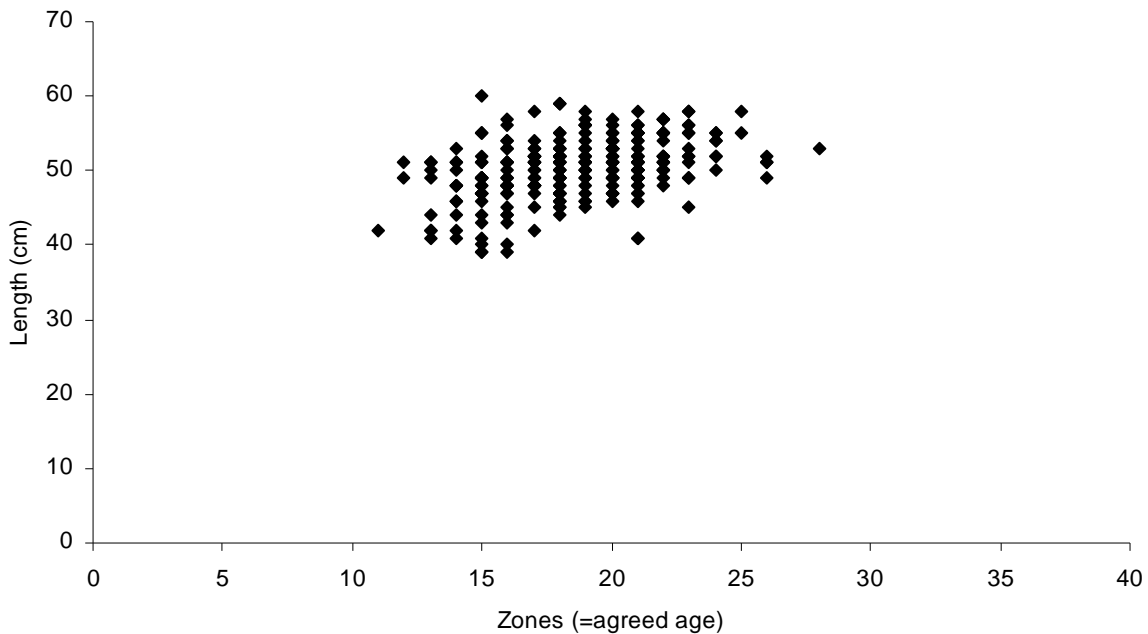


Figure 9: Length and agreed age of 1991 otoliths. N=279.

The results of the ageing for the 1992–93 to 2000–01 otolith set are detailed in Taylor et al. (2002)(2002) and will not be covered in this report.

For 2005, a total of 338 otolith thin sections were assigned a number of zones using the narrow-zone method Taylor et al. (2002) (Figure 12). Nearly three-quarters of the read otoliths were ranked as difficult to read (4 and 5), and about one-quarter with average readability (3) (i.e., 0% for 1, 1.4% for 2, 27.2% for 3, 68.8% for 4, and 2.6% for 5). Otoliths with a readability of 5 were not assigned an age. There was reasonable agreement between the two readers with a slope of 0.88, and 82% of the variance explained by the model (Figure 13). The variation in the number of zones for a given length and the extreme outliers reflects the difficulty in reading *T. murphyi* otoliths (Figure 14).

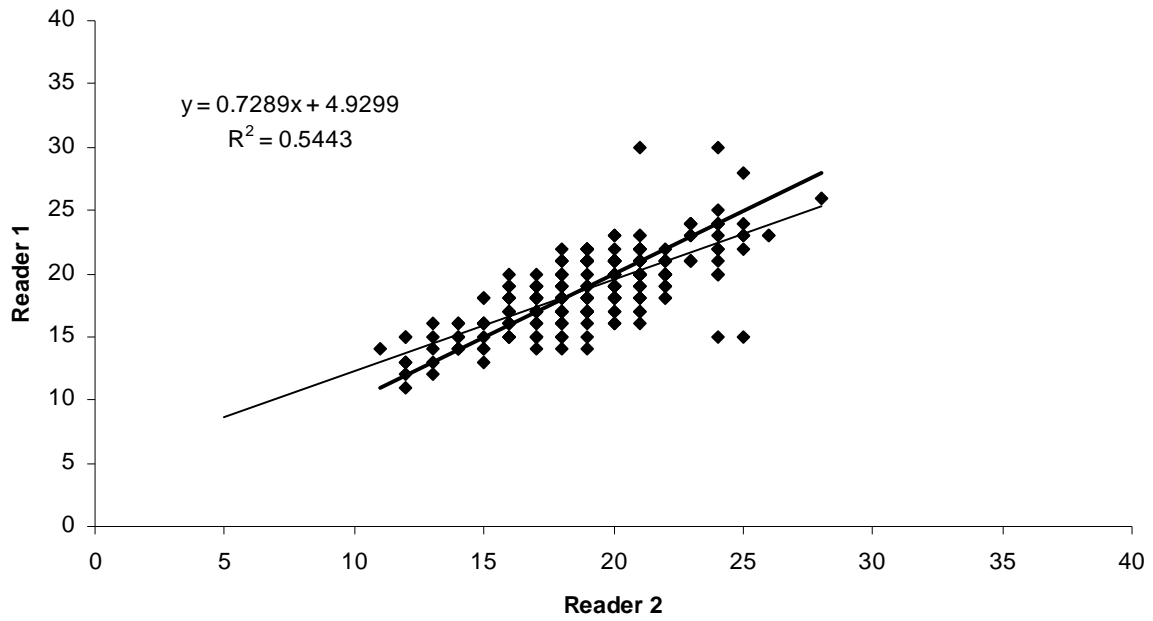


Figure 10: Between reader comparison of thin section zone counts for the 1991 otoliths. N = 231. The lighter line is the linear regression fit to the scatter plot and the regression equation for this fit is shown. The dark line indicates where a 1 to 1 relationship would lie.

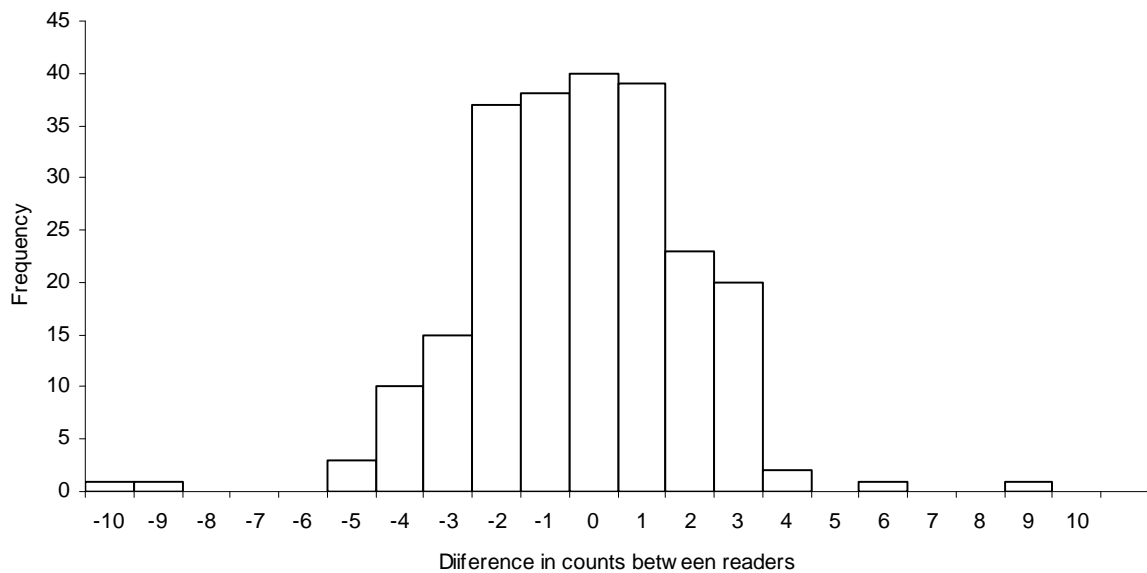


Figure 11: Difference between reader 1 and reader 2 in the zone counts from thin sections for the 1991 otoliths. N=231.

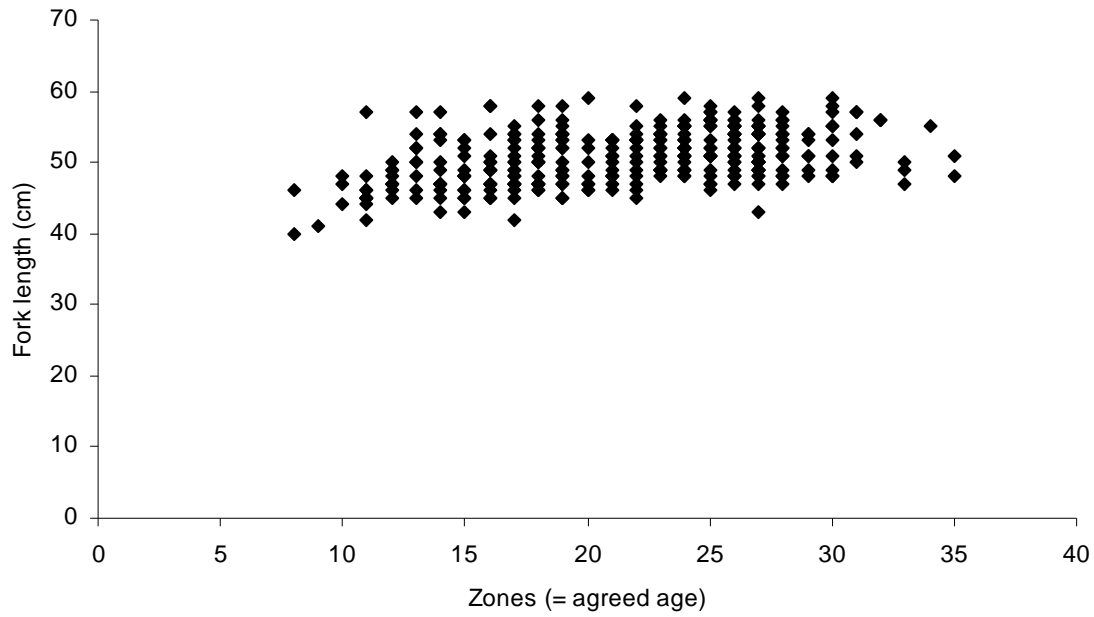


Figure 12: Length and agreed age of Nov/Dec 2005 otoliths. N=338.

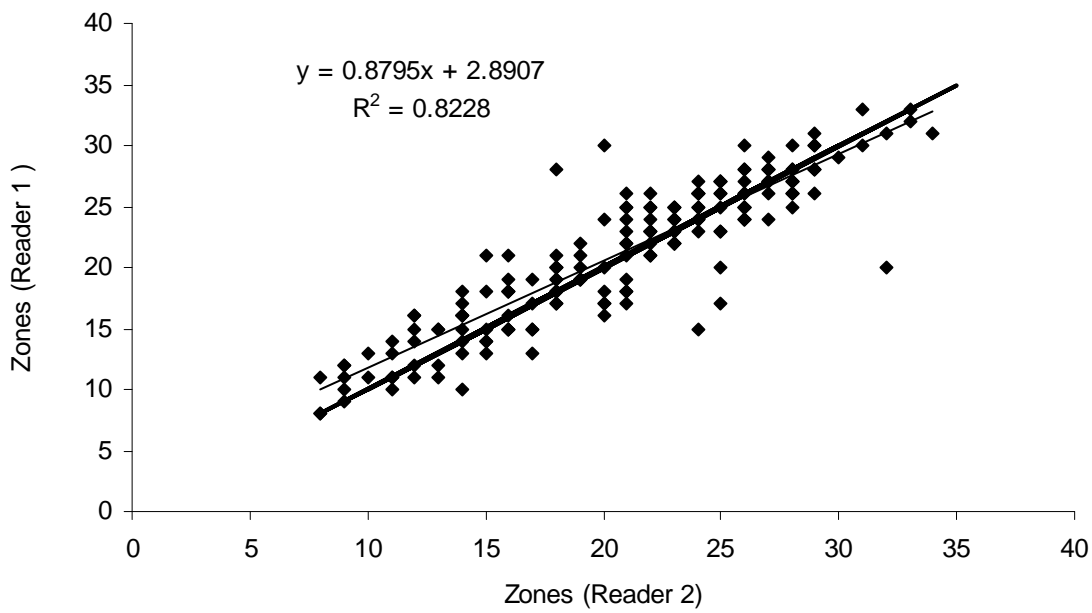


Figure 13: Between reader comparison of thin section zone counts for the Nov/Dec 2005 otoliths. N = 184. The lighter line is the linear regression fit to the scatter plot and the regression equation for this fit is shown. The dark line indicates where a 1 to 1 relationship would lie.

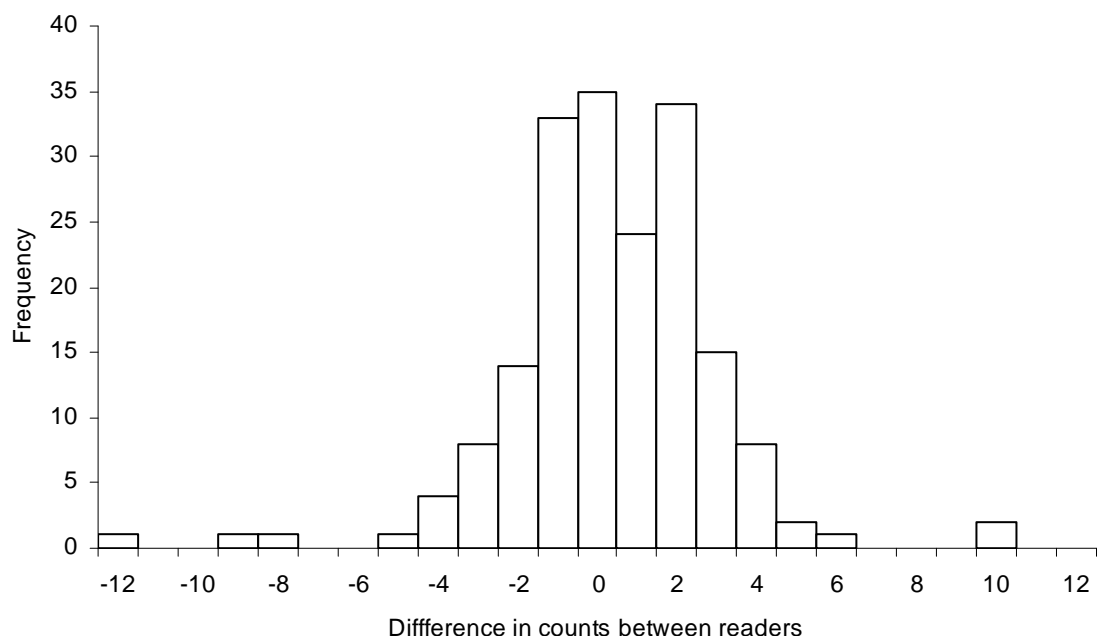


Figure 14: Difference between reader 1 and reader 2 in the zones counts from thin sections for the Nov/Dec 2005 otoliths. N=184.

3.6 Length and age distributions

1991

The three 1991 scaled length frequency distributions (SMP data from JMA 3, and SOP data from JMA 3 and JMA 7) are similar, although the JMA 3 SOP data have a more pronounced right hand tail (Figure 15). All three distributions are strongly unimodal, with the bulk of fish between about 40 and 60 cm, and modes centred at between 50 and 52 cm. The larger fish tended to be males in all three distributions and males comprised 69%, 74%, and 74% of numbers respectively, for JMA 3 SMP, JMA 3 SOP, and JMA 7 SOP data. Correspondingly, the age distributions for all three data sets are remarkably similar with the bulk of the fish aged between 13 and 25 years old with maximum and minimum ages of 12 and 28 years (Figure 16). The shapes of the age distributions follow the same trends to the extent that the 18 and 21 year olds are the strongest year classes, and the youngest and oldest ages are the same, in all three data sets.

1992–93 to 2000–01

The scaled length frequency distributions from JMA 7 are similar among the 6 years with a clear single mode between 40 and 60 cm and centred at about 48 cm, although in 1995–96 and 1996–97 there is also a mode of smaller fish between about 30 and 35 cm (Figure 17). The results indicate that overall the size distribution of Murphy's mackerel in JMA 7 was reasonably consistent over this nine year period. The annual age distributions indicate that the bulk of the fish are between 14 and 28 years old although the minimum and maximum ages were 3 and 31 years, respectively (Figure 18). Progression of age modes through time is not obvious, although there is some indication of modal progression of the 15 and 17 year old fish in 1992–93 through to 1996–97. Further, the overall age of fish in the larger mode appears to increase progressively from 1992–93 through to 2000–01, i.e., from about 14 to 25 years through to 18 to 31 years.

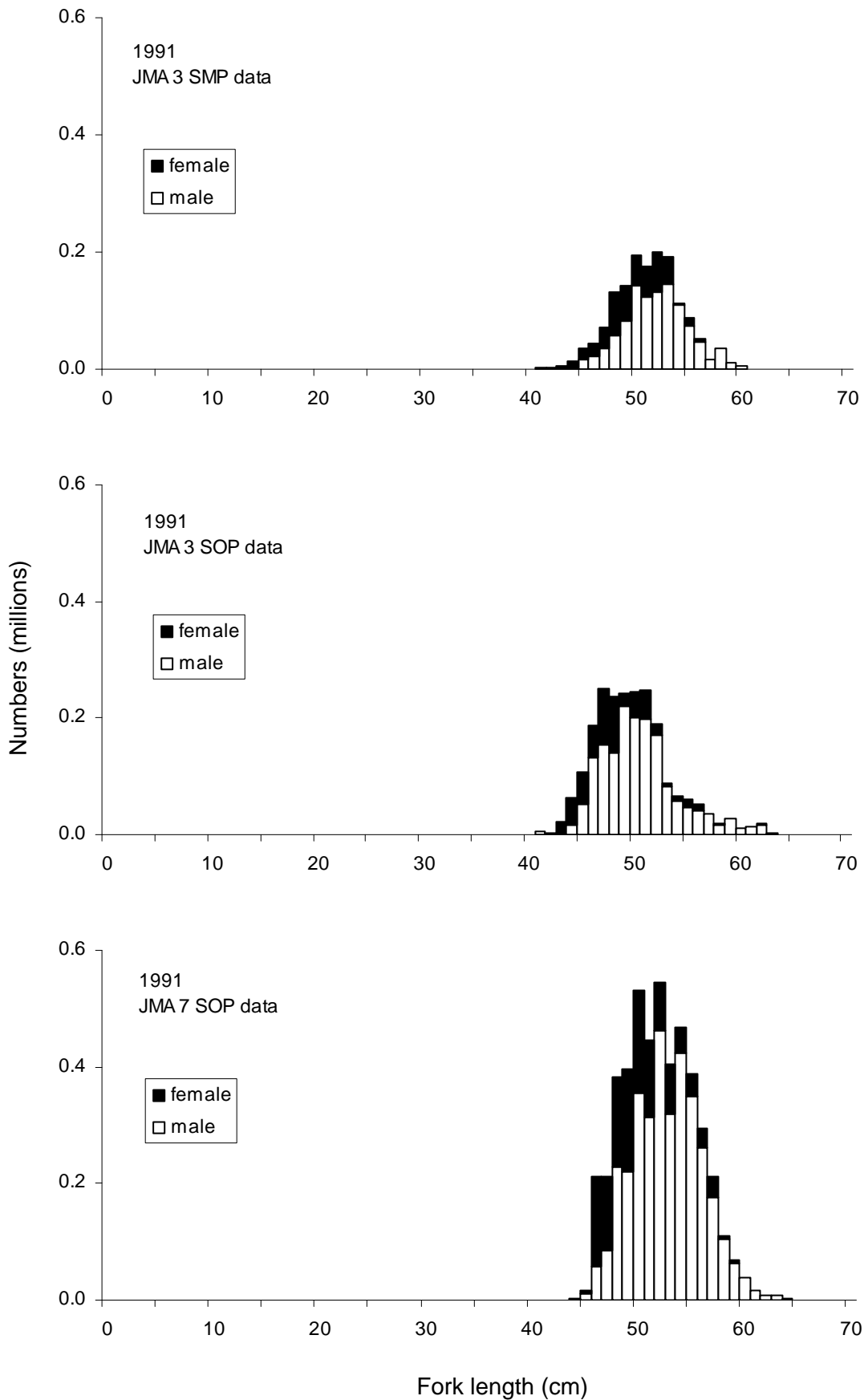


Figure 15: Scaled length frequency distribution of Murphy's mackerel from JMA 3 and JMA 7 in 1991. SMP, stock monitoring programme; SOP, scientific observer programme.

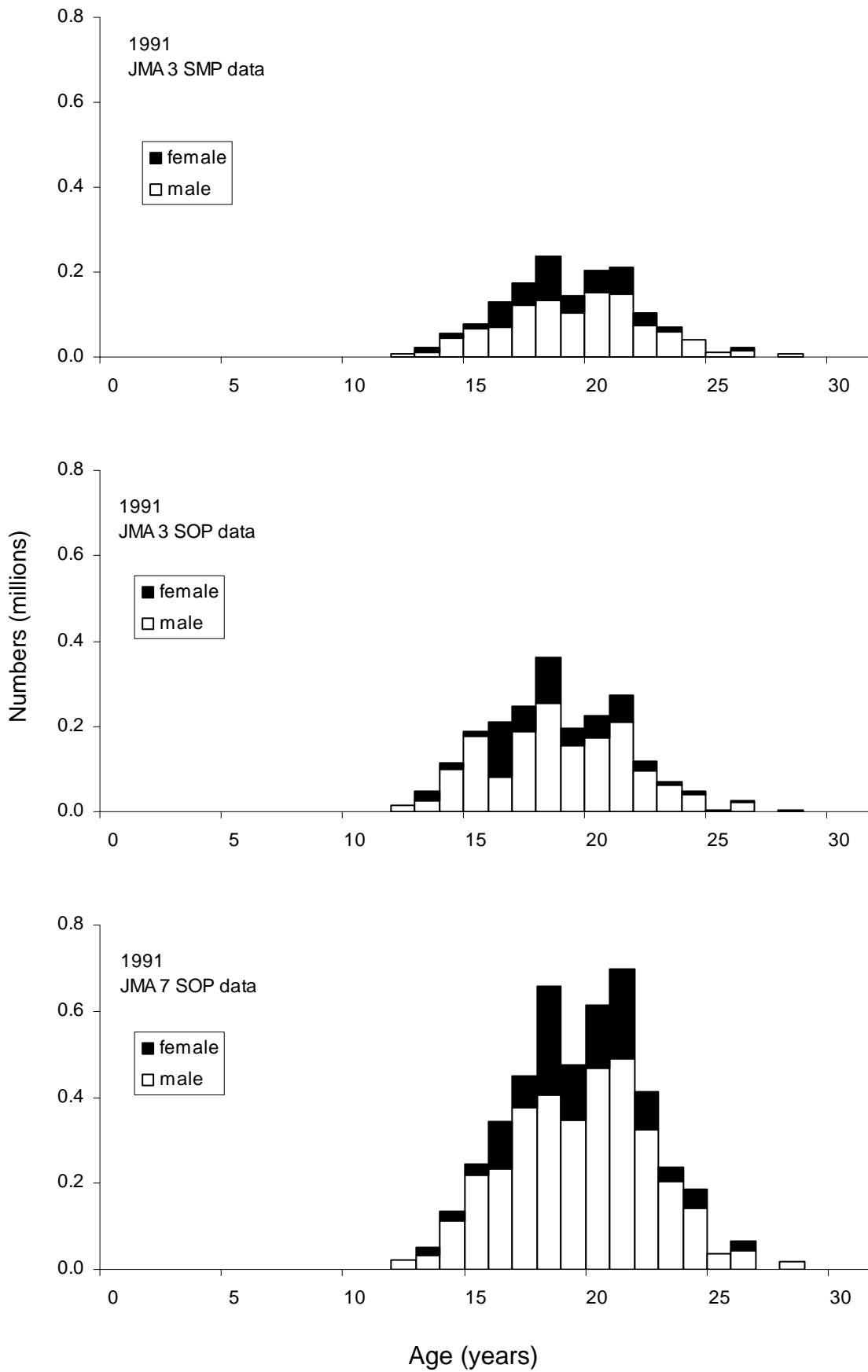


Figure 16: Estimated age frequency distribution of Murphy's mackerel in JMA 3 and JMA 7 in 1991. SMP, stock monitoring programme; SOP, scientific observer programme.

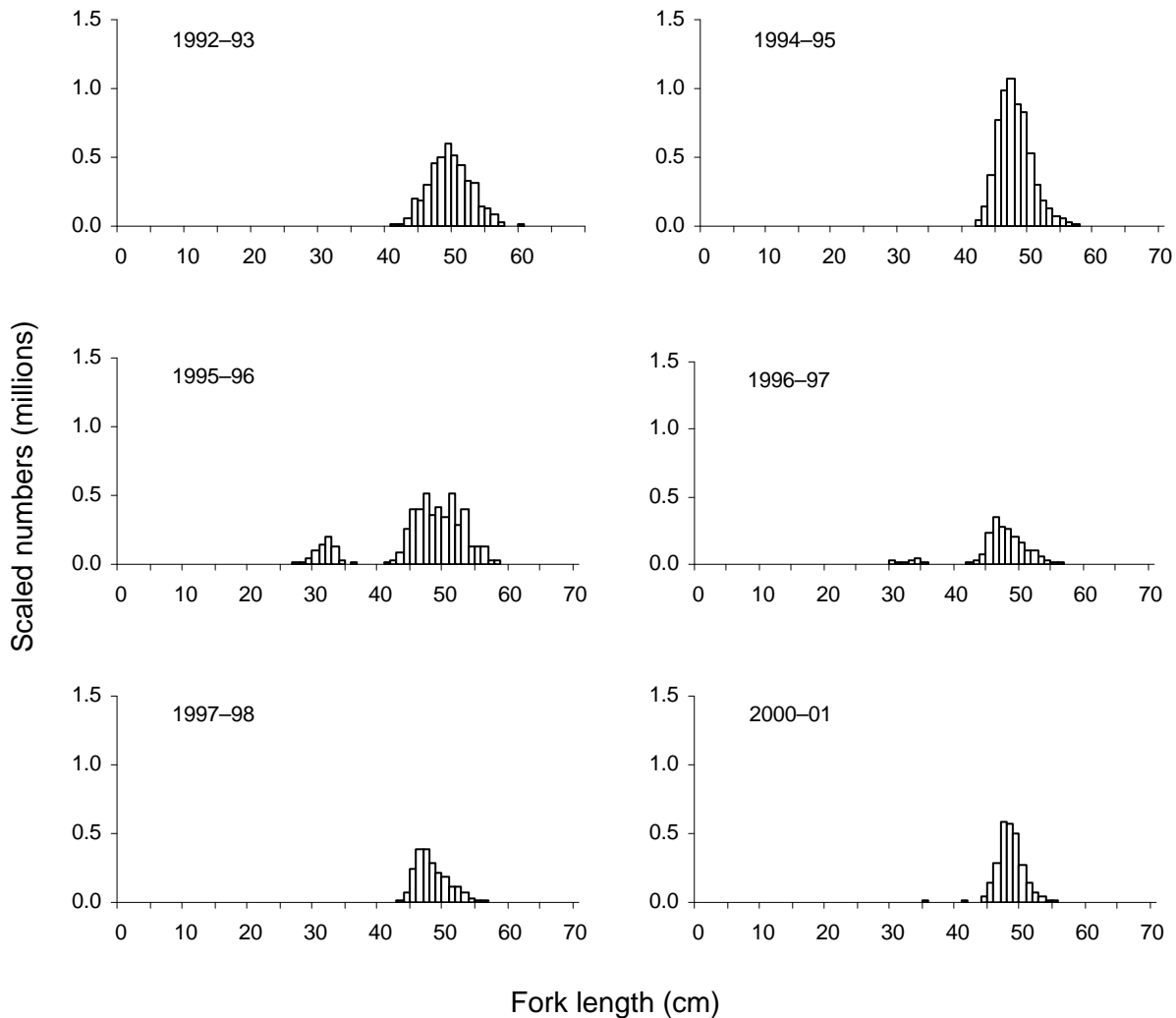


Figure 17: Scaled length frequency distributions for Murphy's mackerel in JMA 7 for selected fishing years from 1992-93 to 2000-01.

With the exception of 1992-93, the scaled length frequency distributions from JMA 3 are uni-modal with a size range between about 40 and 60 cm (Figure 19). The 1992-93 distribution is bi-modal with peaks at about 44 cm and 54 cm, the larger mode also apparent in 1994-95. Although there are some differences in the shapes of the length distributions, overall the size distribution of Murphy's mackerel in JMA 3 was reasonably consistent over this nine year period. Most fish are between about 14 and 25 years in 1992-93 but by 2000-01 the population appears to have aged and the bulk of ages are between 17 and 28 years (Figure 20). There are some young fish between 5 and 10 y, throughout but numbers are very low. There is evidence of modal progression of a 17 year old cohort in 1992-93 until aged 22 in 1997-98. The length and age distributions in JMA 3 and JMA 7 are generally similar, although the small mode of fish present in JMA 7 in 1995-96 is absent in JMA 3.

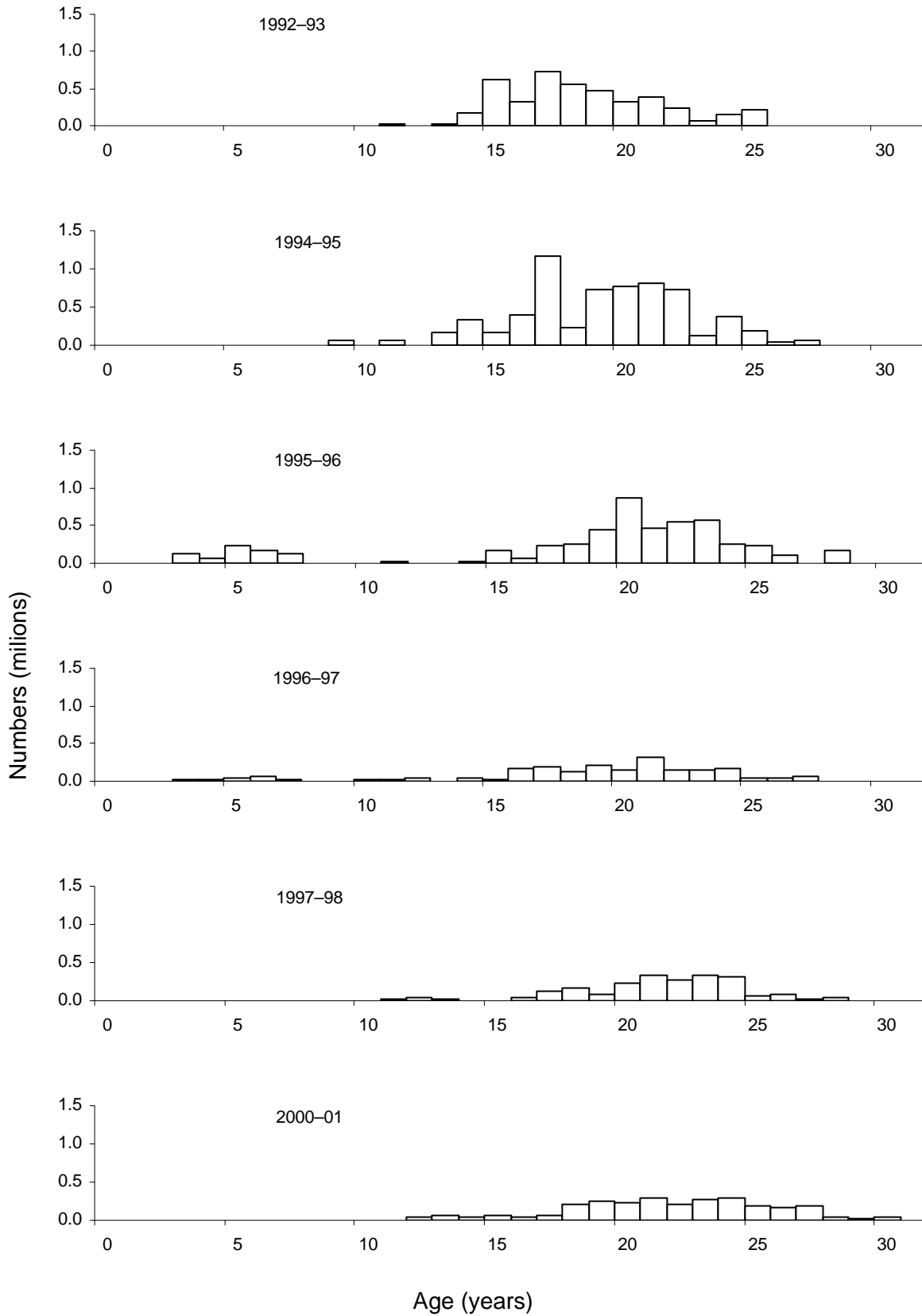


Figure 18: Estimated age frequency distribution of Murphy's mackerel in JMA 7 for selected fishing years from 1992-93 to 2000-01.

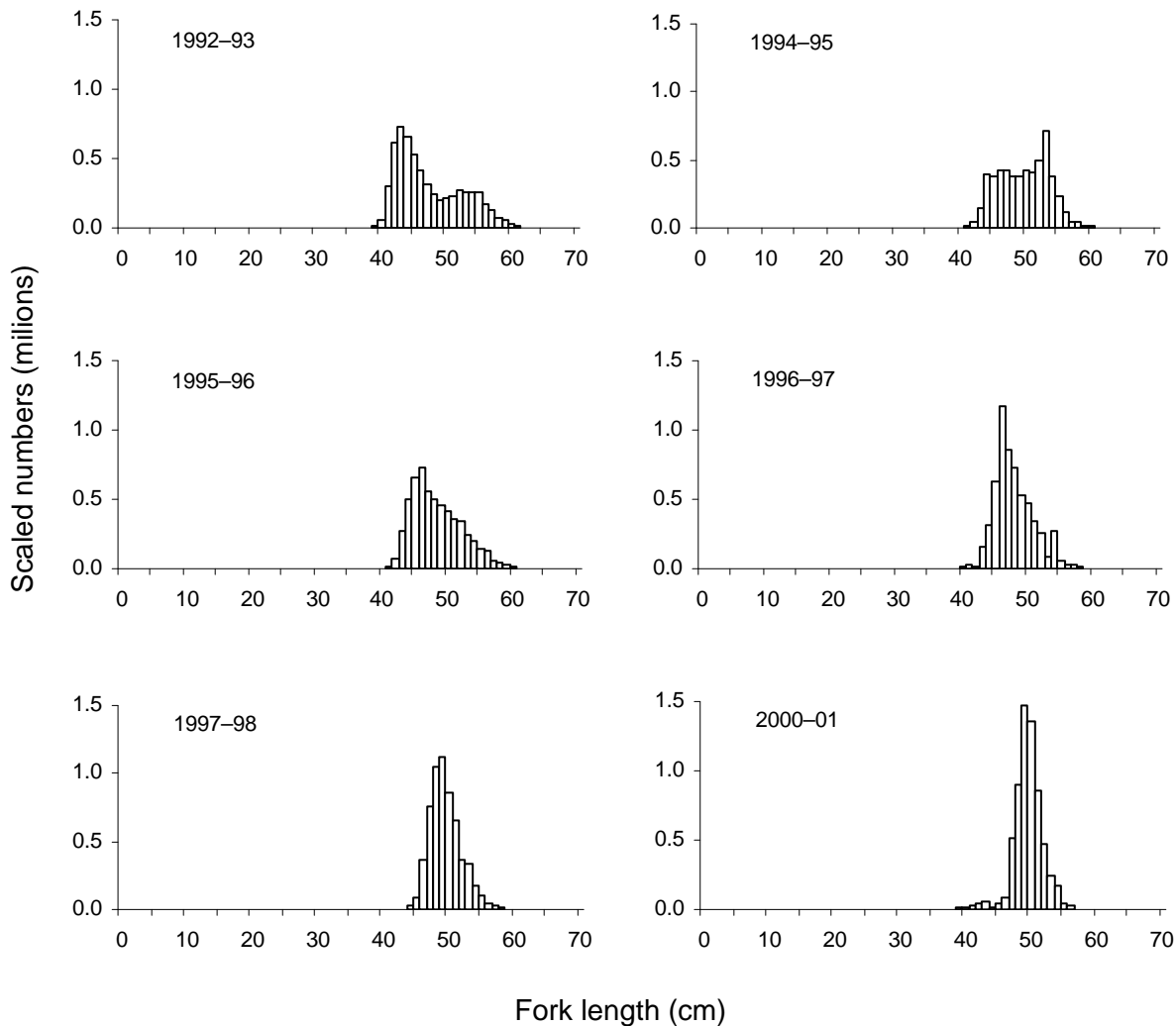


Figure 19: Scaled length frequency distributions for Murphy's mackerel in JMA 3 for selected fishing years from 1992-93 to 2000-01.

2005

The 2005 scaled length frequency distribution in JMA 7 is strongly unimodal with similar shaped left and right tails (Figure 21). Males tend to be the largest fish and comprise 45% of the numbers. Virtually all fish are between 40 and 60 cm with a mode centre at about 51 cm. The bulk of fish are between 10 and 30 years age but the minimum and maximum ages are 8 and 35 years. There are two particularly strong year classes of 24 and 27 year old fish (Figure 22).

3.7 Sex ratios

In 1991 about three quarters of fish that were sampled were male (Figures 15 and 16), and from 1992-93 to 2000-01 overall there were 63% males (JMA 3 data - not shown in results). This contrasts with 2005 when males comprised only 45% of Murphy's mackerel sampled by observers (Figures 21 and 22).

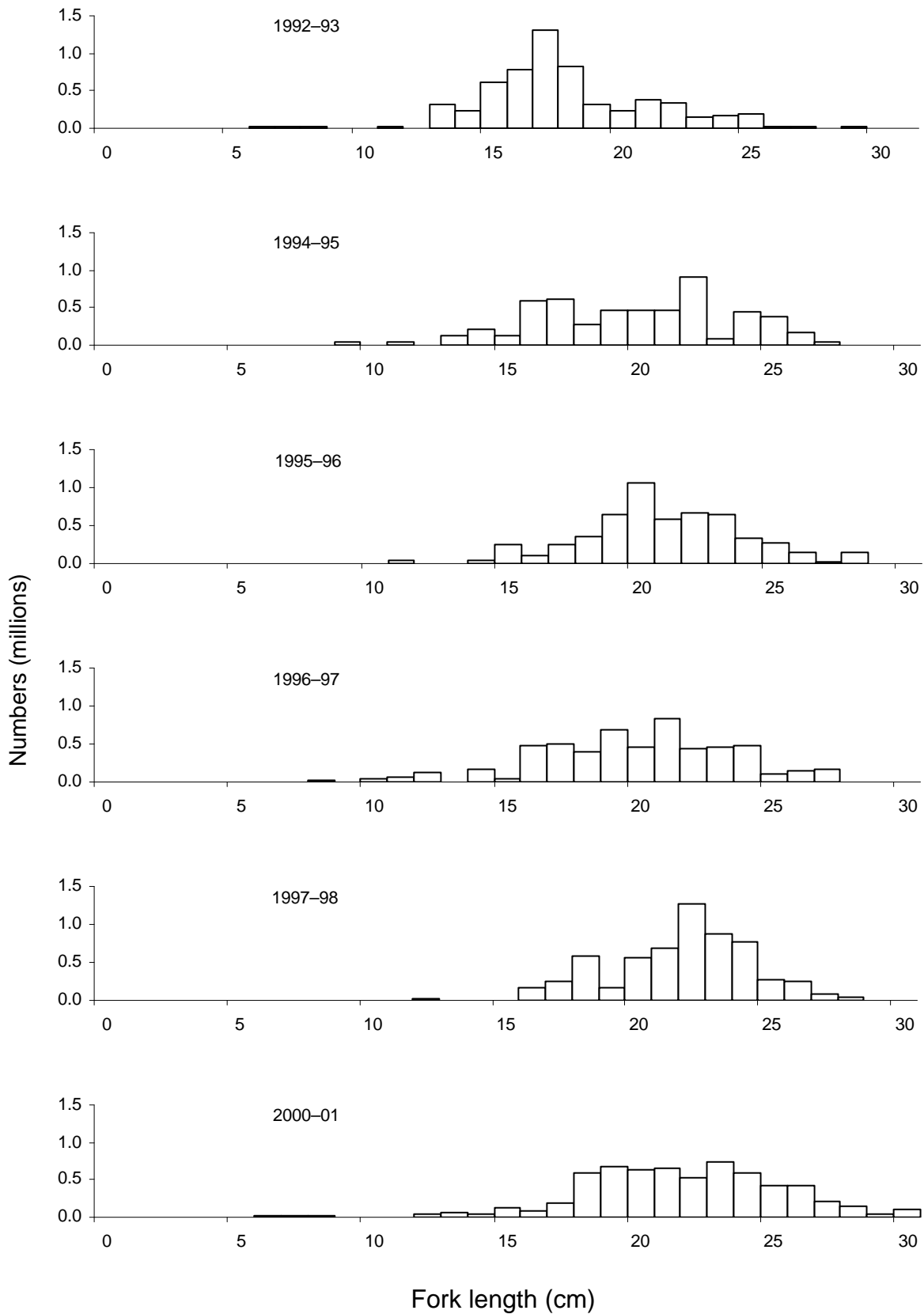


Figure 20: Estimated age frequency distribution of Murphy's mackerel in JMA 3 for selected fishing years from 1992-93 to 2000-01.

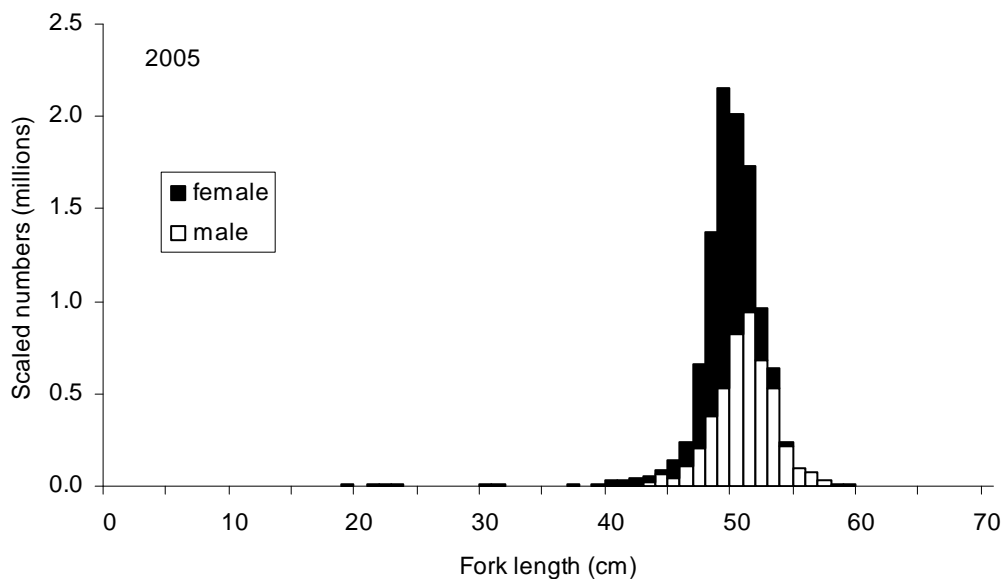


Figure 21: Scaled length frequency distribution of Murphy’s mackerel in JMA 7 for 2005.

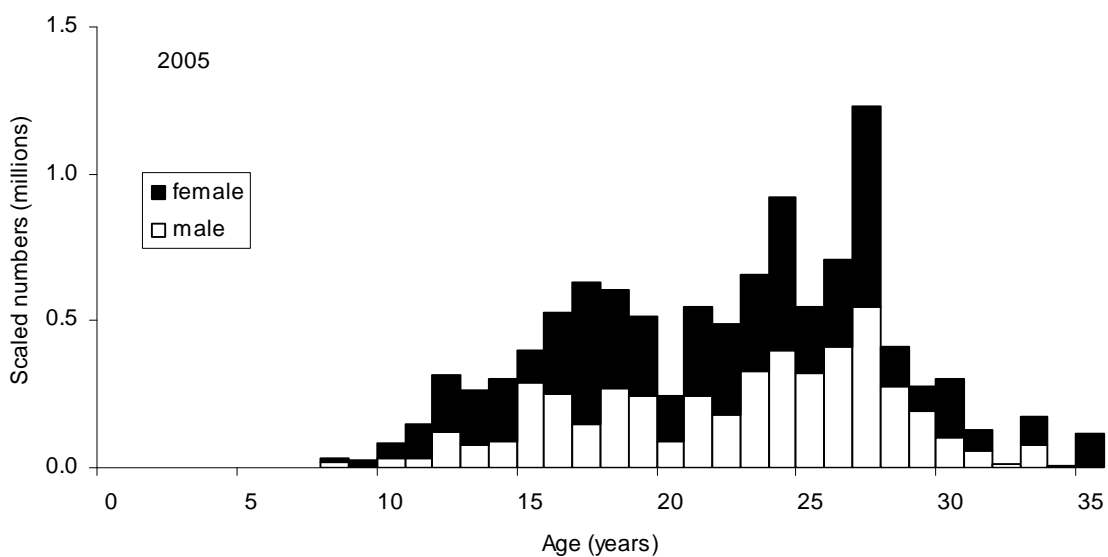


Figure 22: Estimated age frequency distribution of Murphy’s mackerel in JMA 7 for 2005.

Before 2005, an apparent feature of the Murphy’s mackerel population in New Zealand was a consistently high proportion of males. Taylor (2002) documented the sex ratios from research trawl surveys from 1989 to 1999 and from stock monitoring sampling from 1994 to 1996, showing that males predominated, usually comprising between 60 and 70% of numbers. From the length frequency distributions presented here for fish sampled in JMA 7, about 75% were males in 1991 and about 63% were males in samples from 1992–93 to 2000–01 (Figure 15). By contrast, in 2005 males made up only 45% of Murphy’s mackerel sampled by observers (Figure 21).

3.9.1 Results of the fine-scale analysis

Generally, more tows were sampled annually in JMA 7 (Table 7) except in 1996 and 2001 when there were more sampled tows from JMA 3, and in 1993, when sampled tow numbers were similar in each

Fishstock. In other years the overall proportion from JMA 7 was greater than 0.80, with more than 70% of the tows sampled in JMA 7 overall. By contrast, more fish were sampled overall in JMA 3 than in JMA7, although annual totals varied considerably between each of the Fishstocks. Consequently, numbers of fish per sample were considerably higher in JMA 3 than in JMA 7 with an overall mean of 63 in JMA 3 in contrast with 18 in JMA 7.

Table 7: Number of tows sampled by scientific observers for length frequency data, thus providing data for estimating sex ratios, by Fishstock and calendar year. Source: MFish catch and effort database.

Year	Numbers of sampled tows				Numbers of fish sampled				Mean fish/sample	
	JMA1	JMA3	JMA7	Propn JMA7	JMA1	JMA3	JMA7	Propn JMA7	JMA3	JMA7
1991	0	11	42	0.79	0	829	789	0.49	75	19
1992	0	0	44	1.00	0	0	485	1.00		11
1993	0	119	108	0.48	0	7031	1396	0.17	59	13
1994	0	24	121	0.83	0	1121	4228	0.79	47	35
1995	0	17	111	0.87	0	1521	2379	0.61	89	21
1996	0	91	49	0.35	0	7242	1801	0.20	80	37
1997	0	28	195	0.87	0	2425	3481	0.59	87	18
1998	1	42	84	0.67	69	3567	1152	0.24	85	14
1999	0	48	97	0.67	0	3615	1522	0.30	75	16
2000	1	30	67	0.69	3	1487	1517	0.50	50	23
2001	0	72	4	0.05	0	3138	55	0.02	44	14
2004	0	0	143	1.00	0	0	2068	1.00		14
2005	1	27	292	0.92	69	177	3417	0.95	7	12
Totals	3	509	1357	0.73	141	32153	24290	0.43	63	18

At the statistical area level, total tows in all years within JMA 7 were distributed between CEW (742), CHA (402), and AKW (213) (Table 8). Total tows in JMA 3 were distributed between SOU (352), SEC (105), SOI (44), and SOE (8). Numbers of fish sampled in all years in JMA 7 were distributed as CHA (12 596), CEW (8893), and AKW (2801); in JMA 3 as SOU (19 820), SEC (9557), SOI (2198), and SOE (578).

Annual frequency distributions from JMA 7 (Figure E1) indicate high proportions of males in the earliest years followed by a gradual shift over time to a balanced distribution with a peak at 0.5 in the two most recent years, 2004 and 2005. A different pattern is evident from data collected in JMA 3 (Figure E2). Here, the ranges of the distributions are similar in most years, falling between about 0.3–0.4 and 0.9–1.0. However, there is some variation in this pattern with high proportions of males dominating in 1991 and 1994. The distribution in 2000 is also different, including quite low proportions of males and possibly exhibiting a bimodal pattern. Frequently within the JMA 3 data, the peak in the frequency distributions lies at a male proportion of 0.6.

Patterns in CEW (Figure E3) and CHA (Figure E4) reflected the patterns observed for JMA 7, with little difference between the two sub-areas. However, patterns for stat areas in JMA 3 were considerably more indicative of some degree of segregated schooling, particularly in SEC (Figure E5) where separated bimodal distributions occurred annually with some regularity; this pattern was also evident in SOI (Figure E6) in the one year when sufficient data were available. By contrast frequency distributions in SOU (Figure E7) did not exhibit this segregation, often reflecting patterns for the entire JMA 3.

Table 8: Number of tows sampled by scientific observers for length frequency data, thus providing data for estimating sex ratios, by statistical area and calendar year. Source: MFish catch and effort database.

Year	JMA 1		JMA 7		JMA 3			
	CEE	AKW	CEW	CHA	SEC	SOE	SOI	SOU
Number of tows sampled								
1991	0	3	27	12	0	0	0	11
1992	0	0	41	3	0	0	0	0
1993	0	0	103	5	36	0	0	83
1994	0	0	43	78	8	0	3	13
1995	0	0	96	15	10	0	0	7
1996	0	6	25	18	20	2	36	33
1997	0	56	54	85	0	2	4	22
1998	1	4	61	19	0	0	0	42
1999	0	0	24	73	12	0	0	36
2000	1	0	36	31	3	2	1	24
2001	0	0	1	3	16	1	0	55
2004	0	119	23	1	0	0	0	0
2005	1	25	208	59	0	1	0	26
Totals	3	213	742	402	105	8	44	352
Number of fish sampled								
1991	0	5	96	688	0	0	0	829
1992	0	0	284	201	0	0	0	0
1993	0	0	1 156	240	3 661	0	0	3 370
1994	0	0	670	3 558	809	0	22	290
1995	0	0	1 829	550	1 068	0	0	453
1996	0	48	962	791	2 083	258	2 021	2 880
1997	0	577	339	2 565	0	202	153	2 070
1998	69	33	477	642	0	0	0	3 567
1999	0	0	222	1 300	1 056	0	0	2 559
2000	3	0	675	842	127	9	2	1 349
2001	0	0	1	54	753	107	0	2 278
2004	0	1988	70	10	0	0	0	0
2005	69	150	2 112	1 155	0	2	0	175
Totals	141	2801	8 893	12 596	9 557	578	2 198	19 820
Grand totals	141			24 290				32 153

3.8 Growth

The bulk of the 2005 ages were estimated at between about 10 and 30 years and there was considerable variation in length at age (Figure 23). The von Bertalanffy growth parameters and 95% confidence intervals for the full and reduced models for the 2005 age-length data set are shown in Table 9. The Log likelihood ratio test (Appendix F, Table F1) indicates that the full model is a better fit than the reduced model and hence growth curves are fitted for males and females separately (Figure 23). The model fit diagnostics also indicate a better fit to the full model (Appendix F, Figure F1). The fits and the raw data indicate that males grow to a larger size than females, but both sexes have similar longevity.

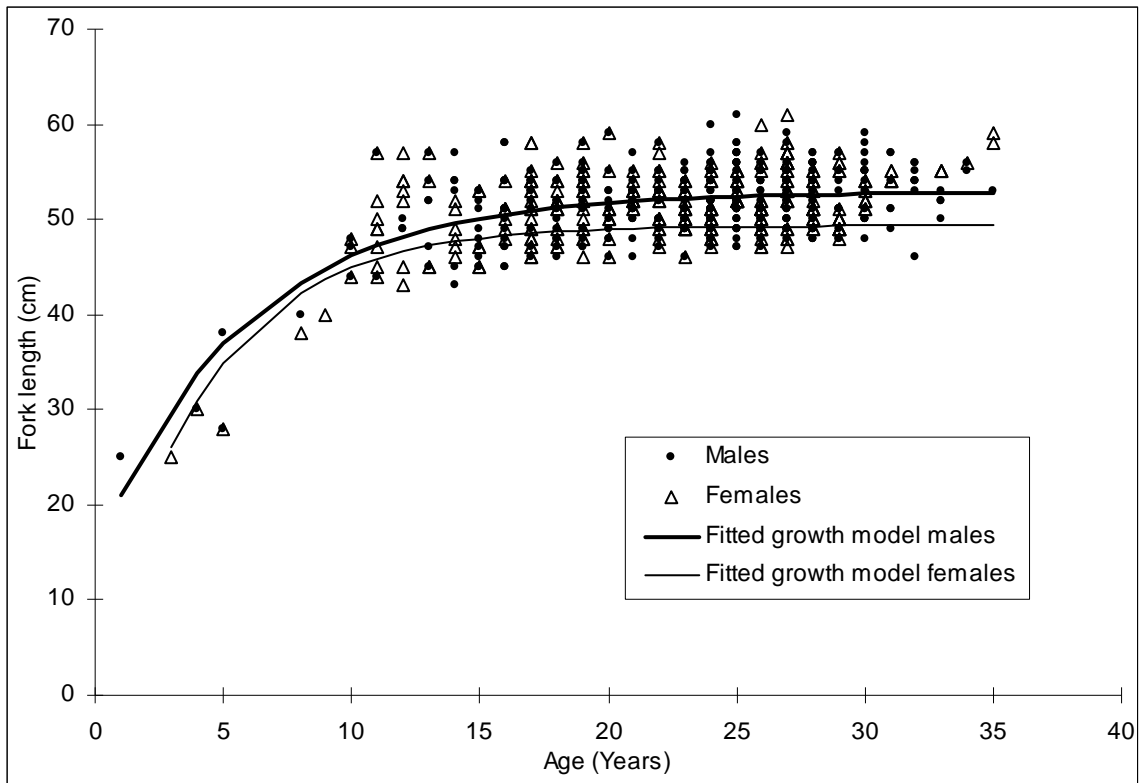


Figure 23: 2005 length at age data for males and females. von Bertalanffy growth models are fitted to the data for each sex (see Table 9 for von Bertalanffy parameters).

Table 9: Von Bertalanffy growth parameters and 95% confidence intervals for the 2005 age-length data for the full model (males and females separately) and reduced model (males and females combined).

Parameter	Reduced model	Full model	
		Males	Females
L_{∞}	51.5 (51.1, 51.9)	52.9 (52.4, 53.3)	49.3 (48.9, 49.7)
K	0.180 (0.156, 0.204)	0.173 (0.147, 0.199)	0.238 (0.185, 0.291)
t_0	-1.64 (-2.66, -0.617)	-1.90 (-3.02, -0.780)	-0.13 (-1.42, 1.15)
Age range (y)	1–35	1–35	3–35
σ^2	9.8	7.7	7.7
N	706	392	311

4 DISCUSSION

4.1 Abundance and distribution

Results from the three analyses summarising the presence of *T. murphyi* in research trawl and MFish data, the distribution of aerial sightings of jack mackerel, and the standardised stock indices of relative abundance from the deepwater trawl fishery all suggest a peak in presence/abundance of this species in about 1993 or 1994, followed by a decline to a markedly lower level from about 1998. Although there was some concern over the reliability of the past-vessel standardised index, which didn't give a plausible result, the second model, which used data from vessels extant in the fishery, produced a result that reflected the reduction in abundance. Both the research/commercial trawl and aerial sightings summaries were of sufficient duration to illustrate an increase over time preceding the peak.

What can we conclude from this information? The research/commercial trawl analysis is based on records of *T. murphyi* and therefore provides, within some unknown measure of uncertainty or error, a crude measure of the rise and fall of the abundance of *T. murphyi* since its earliest appearance in New Zealand waters in 1984 (assuming that this is the only invasion or series of invasions of New Zealand by this species). The aerial sightings analysis is based on sightings of all three jack mackerel species, so, for us to infer that the large peak it displays is of *T. murphyi*, we must consider the timing of the increase and its similarity to the trawl analysis result, as well as what we know from catches of jack mackerel.

Total catches (all areas combined) of jack mackerel throughout the history of the fishery peaked in 1992–93 at almost 50 000 t (see Figure 2), with the JMA 7 component comprising almost half this total, and those from JMA 3 and JMA 1 comprising about 17 000 t and 7 000 t respectively. This peak is the third year in a major increase that persisted for a total of 9 years, from 1990–91 to 1998–99. The increase in the first year of this series resulted from similar increases in JMA 1 and JMA 3, but the main contribution occurred over the next four years from a major increase of catch in JMA 7 and for the final four years from catches in JMA 3. Catches in JMA 1 were lower, peaking at about 13 000 t in 1994 and consistently contributing around 7 000 t for the other eight years.

Annual estimates of species proportions for JMA 3 and JMA 7 are available from 1985–86 to 2004–05 (see Table 5). In JMA 3, *T. murphyi* predominated in the catch throughout this entire period. In JMA 7, *T. murphyi* first appeared in samples in 1987–88, reaching its highest representation between 1993–94 and 1995–96 (inclusive). The estimates from these two Fishstocks over this period provides evidence that the increase is a result of increased volumes of *T. murphyi*, although there is at least one discrepancy in the datasets for JMA 7, in that the increase in the proportion of *T. murphyi* lags behind the catch increase by about one year. Nevertheless, the representation of *T. murphyi* of up to about 41% is approximately consistent with the amount that the catch increased from 1990–91 to 1992–93. The discrepancy could result from a number of sources, including poor species identification in the early years of the series and poor spatio-temporal representativeness of the catch in the sampling (Julian & Taylor 2008).

Annual estimates of species proportions in JMA 1 have only been available since 1994–95 (Figure 5, Table 3), but their values are consistent, with high representations of *T. murphyi* (30–45%) from the beginning of the series until 1998–99. However, results from this fishery are not as clear as in JMA 3 and 7. Here, a market preference for small jack mackerel may have affected targeting of *T. murphyi* towards the end of the peak period (Taylor 2008).

Features of the more recent catch suggest that the abundance of *T. murphyi* has continued to decline since the peak period of the 1990s. This is particularly evident in JMA 3, where a high proportion of the catch has been *T. murphyi*, and the catch has declined dramatically since 2000. In JMA 1, annual catches have been sustained at around the same level as they were during the peak period, with a temporary increase to about 10 000 t in 2004–05 and 2005–06. However, the proportion of *T. murphyi* has remained below 5% in most years, suggesting a net decline overall, although it is interesting that there was an increase to 9 and 7% in 2003–04 and 2004–05 respectively, which is about coincidental

with the catch increase in 2004–05. This latter feature could be interpreted as a recent increase in the abundance of *T. murphyi*, which is also suggested by an increase in catch in JMA 3 in 2005–06. In 2006–07, catches in both JMA 1 and 3 returned to previous low levels.

In JMA 7, catches have undergone an increasing trend that began in 2000–01 and is still occurring. This increase has resulted in the highest recorded catch for the Fishstock of about 37 000 t in 2004–05. However, the estimated proportion of *T. murphyi* in the catch in 2004–05 was only 0.07, and it has been around this low level since 2001–02.

Based on this discussion we can infer that the rapid and large increase in aerial sightings of jack mackerel that first became evident in 1990 (see Figure 4) and peaked in about 1993 was a result of the influx of large numbers of *T. murphyi*. Variations in the spatial distribution of the high sightings-counts between years may be a result of the highly mobile nature of this species, or may reflect varying flying effort in some areas. Whatever the cause, it is generally clear that there were increased sightings at some time throughout the main areas of aerial sightings activity from North Cape to Kaikoura on the east coast, and in the South Taranaki Bight. The incidence of high sightings counts is absent from 1998 onwards. It should be noted that, while this decrease is a general feature of the aerial sightings summary, the total disappearance of all jack mackerel sightings from northern South Island and South Taranaki Bight in most years after 1996 is more likely the result of a major reduction in sightings effort caused by the retirement of the Sealord's purse-seiner, *FV Shemara*, on 28 April 1996.

An examination of JMA 7 species proportions at a finer scale yields some interesting information. Since 1990–91, a consistent feature of the fine-scale time series (by month) from the JMA 7 TCEPR fishery has been the dominance of *T. murphyi* during the July–August “season” (see Table D1). In 2000–01 however, this feature was absent and remained absent during 2001–02. No sampling occurred during these months in 2002–03 and 2003–04, but sampling from 2004–05 and 2005–06 showed an almost total absence of the species during the most recent years.

Estimates from the JMA 3 TCEPR fishery suggest that the representation of *T. murphyi* has remained high although there has been some indication of a possible change, with proportions of *T. declivis* higher than those of *T. murphyi* in March 2001–02 and April 2002–03, although this may have been the result of a change in the distribution of *T. declivis* rather than a reduction in the relative abundance of *T. murphyi*. The predominance of *T. murphyi* was again evident during 2004–05 and 2005–06, but this is only part of the story. Also important is the fact that fishers operating in this fishery have identified declining catch rates and changed their fishing practices. Total catch in JMA 3 declined gradually from a peak of almost 20 000 t in 1995–96, to around 700 t in both 2003–04 and 2004–05, but it has also shown a relatively large increase to 5 000 t in 2005–06.

4.2 Ageing methodology

Although an age-estimation technique for New Zealand Murphy's mackerel (*T. murphyi*) has recently been developed (Taylor et al. 2002), validation is still required (Beentjes et al. 2013). Murphy's mackerel otoliths from New Zealand are known to be difficult to read and by comparison growth check rings for the New Zealand species of jack mackerel (*T. declivis* and *T. novaezelandiae*) are relatively clear and easy to interpret (Horn 1993). Beentjes et al. (in press) suggest that the complex structure of the otolith and the difficulty in interpreting growth checks may be related to the peculiar life history of the New Zealand caught Murphy's mackerel, i.e., they form part of an extensive trans-Pacific stock, which emigrated from the eastern South Pacific near the coast of South America. The absence of large numbers of small recruited fish suggests that the stock is not self sustaining in New Zealand waters and hence, we might expect growth to be affected by different environmental conditions between the east and western Pacific. The estimation of age based on growth check rings in the sagittal otoliths for 1991 and 2005 were equally difficult to interpret and there was considerable variation in length at age consistent with the previous ageing studies (Taylor et al. 2002, Beentjes et al. 2013). However, because ageing was calibrated against a protocol set of otoliths, the interpretation of

age is consistent with earlier estimates, if not necessarily correct. Interpretation of age distributions and the growth parameters presented in this report should therefore be viewed cautiously in the absence of age validation.

4.3 Length and age distributions

Apart from the presence of some fish around 30–35 cm in two years in JMA 7, the length frequency distributions have remained unchanged from 1991 to 2005 (see Figures 15, 17, 19, and 21). The distributions generally have a characteristic single mode with a peak at about 50 cm, and the bulk of the fish range in size from about 40 to 60 cm. Further there were no major differences in the length distributions between JMA 3 and JMA 7, with exception of the mode of small fish (26–35 cm) sampled by the observers in JMA 7 in 1995–96 (see Figure 17), but not in JMA 3 — these fish may have been spawned in New Zealand waters. These findings are consistent with those of Taylor (2002) who examined length frequency data from both trawl survey and observer data. Given that the bulk of Murphy's mackerel in New Zealand immigrate from the north-eastern South Pacific, this suggests that there has been ongoing immigration and recruitment into the fishery over the last 14 years or so.

By contrast, the estimated age distributions suggest that the population has aged over this time. The age distribution in the early 1990s has few fish older than 25 years. In 2000–01 the maximum age has increased to 31 years, and by 2005 to 35 years, consistent with the pattern of an ageing population. Young fish continue to recruit to the fishery, however, supporting the suggestion of ongoing invasions into New Zealand waters. There are no year classes that can be continually tracked from 1991 through to 2005 but there is evidence of modal progression of strong year classes for several years from 1992–93 and 1997–98 (see Figure 20). The small length frequency mode apparent in 1995–96 in JMA 7 was estimated to be comprised of fish between 3 and 7 years old. As stated, the ageing has still not been fully validated and therefore the estimated ages and interpretation of the results should be viewed in this context.

4.4 Sex ratios¹

The annual patterns of sex ratios appear to differ between JMA 3 and JMA 7. A gradual shift is apparent in JMA 7 from a male dominated population in the early years to a situation where the sexes are equally represented in 2004 and 2005. This pattern is not evident in JMA 3 where there is a consistent pattern of higher numbers of males in samples, although females are also occasionally well represented, a detail that is particularly well illustrated in 1993, when sampled-fish numbers were high, and in 1997 and 2000.

At the Fishstock level, frequency distributions of male proportions in data from individual tows show little evidence of samples that are purely males or females. From these results, males and females appear to be taken most often in the same tows. However, there is evidence in the results that aggregation of data from broad Fishstock areas masks patterns at finer scales. The bimodal distributions from SEC and SOI suggest that there are areas where, although the spatial distributions are not clearly segregated by sex, they are dominated by one or other of the sexes. These patterns are particularly clear in 1993 and 1996

There is no similar evidence from statistical areas in JMA 7 that these almost segregated distributions from the bimodal distributions occur there. What is evident, from a comparison of annual distributions from CEW and CHA, is that in CHA frequency distributions are shifted to the left in a number of years, suggesting a higher representation of female fish there than in CEW.

¹ It must be noted that all these patterns are based on the basic unit of the individual tow and do not provide definitive information on relative numbers of each sex at the school level.

4.5 Growth

Estimates of precise growth parameters for Murphy's mackerel are hampered by a lack of otoliths from juvenile fish, important in estimating the steep part of the growth curve, where growth is most rapid. To resolve this we used several juvenile otoliths sourced from Chile. The results of the analysis suggest that the sexes have distinct growth curves and growth parameters, with males attaining a greater L_{∞} than females (L_{∞} of 52.9 and 49.3 and K of 0.17 and 0.24, for males and females respectively). The growth coefficient parameter (K) indicates that females grow faster initially, but the lack of data in this region and the overlap in confidence intervals suggest that they may not be any real difference between the sexes. These results are consistent with those of Taylor et al. (2002)(2002) who estimated L_{∞} of 53.4 and 48.9 and K of 0.13 and 0.16 for males and females, respectively. Their estimates of K are probably more accurate than ours since they incorporated ages from substantially more juvenile otoliths sourced from Chile. It is unusual in gonochoristic (sexes are separate) teleosts for males to grow larger than females.

4.6 Summary

Probably the most prominent feature of this study has been the scale of changes in abundance that have occurred throughout the rise and fall of Murphy's mackerel since the beginning of its invasion of New Zealand waters in the mid 1980s. The predominance of this species in a number of areas that resulted from the large numbers that apparently gained access through waters around the Chatham Islands has now declined considerably, which is evident in a shrinking of its range of distribution and the volumes available to the fisheries that target it.

However, the decline is not necessarily indicative of *T. murphyi*'s impending disappearance from New Zealand. A second feature of this study is the age structure of the catches and how it has changed over time. Maximum age has increased, consistent with an ageing population, which is perhaps to be expected. What is probably more interesting, however, is that the minimum age has not changed over time, consistent with a population that is self sustaining, although there is little information to test whether the source of recruits is from the on-shelf population or whether they are the product of ongoing invasions from the South Pacific. Whatever the cause, the result appears to be a sustained population.

Thus, it seems that we had a major invasion into New Zealand waters during the late 1980s and early 1990s that resulted in huge volumes of *T. murphyi* here. Since then numbers have declined, perhaps as a result of large numbers being taken, mainly in the TCEPR fishery, but also by purse-seine. The age structure suggests that the population will persist. Changes in sex ratios from JMA 7 over time show a gradual change from a high representation of males in the early years to a more balanced male-female population recently, but this is not evident in JMA 3.

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Appendix A: Estimating species composition (proportions of the 3 jack mackerels) of the total annual purse-seine catch of *Trachurus* species in JMA 1

Definitions

w_{kl} is the weight of a sample of species l in sampled landing k .

W_k is the weight of landing k .

W_{kl} is the weight of species l in landing k .

1. Step a: to estimate proportions of species l in the sampled landings (k)

The proportion of species l in sampled landing k was based on its weight in the sample:

$$\hat{P}_{kl} = \frac{w_{kl}}{\sum_l w_{kl}}$$

2. Step b: to estimate proportions of *Trachurus* species in the annual landings

Proportions of species in the total annual catch were estimated as the total annual weight of the species in the sampled landings divided by the total annual weight of the sampled landings:

$$\hat{P}_{.l} = \frac{\sum_k \hat{P}_{kl} W_k}{\sum_k W_k}$$

where K is the number of sampled landings.

3. Estimating variance

The estimated within landing variance is defined as:

$$\hat{\text{var}}(\hat{P}_{.l}) = \frac{\sum_k \hat{\text{var}}(\hat{P}_{kl}) W_k^2}{\left(\sum_k W_k\right)^2}$$

where K is all landings (sampled and unsampled) and:

$$\hat{\text{var}}(\hat{P}_{kl}) = \frac{\hat{P}_{kl}(1 - \hat{P}_{kl})}{N}$$

N is the total number of fish (of all three species) in the sample and is given by:

$$\hat{N} = \sum_{l'} w_{kl'} / \hat{t}_k$$

where \hat{t} is the estimated mean fish weight.

The c.v. for species proportions over a given time frame was estimated as:

$$c\hat{v} = \frac{\sqrt{\text{var}(\hat{p}_i)}}{\hat{p}_i}$$

Appendix B: Estimating species proportions in the JMA 7 trawl fishery from MFish Observer data

Definitions:

i, j, k denotes species, tows, and trips respectively

S'_k is the set of all tows in trip k , sampled and unsampled

S_k is the set of sampled tows in trip k

w_{ijk} is the weight of a sample of species i in sampled tow j during trip k

w_{jk} is the total weight of jack mackerel (all species combined) in tow j during trip k

w'_{jk} is the total weight of jack mackerel (all species combined) in sampled tow j during trip k

w''_{jk} is the total weight of jack mackerel (all species combined) in the sample from sampled tow j during trip k

Estimating species proportions

The estimated proportion of species i in sampled tow j in trip k is:

$$\hat{P}_{ijk} = w_{ijk} / w''_{jk} .$$

The estimated weight of species i in trip k , is obtained by scaling up the total weight of catch:

$$\hat{W}_{ik}^m = \sum_{j \in S_k} w'_{jk} \hat{P}_{ijk} \cdot \frac{\sum_{j \in S'_k} w_{jk}}{\sum_{j \in S_k} w'_{jk}} .$$

The estimated proportion of species i in the total catch is obtained by summing over all trips:

$$\hat{P}_i = \frac{\sum_k \hat{W}_{ik}^m}{\sum_i \sum_{j \in S'_k} w_{jk}} .$$

Appendix C: Half degree squares

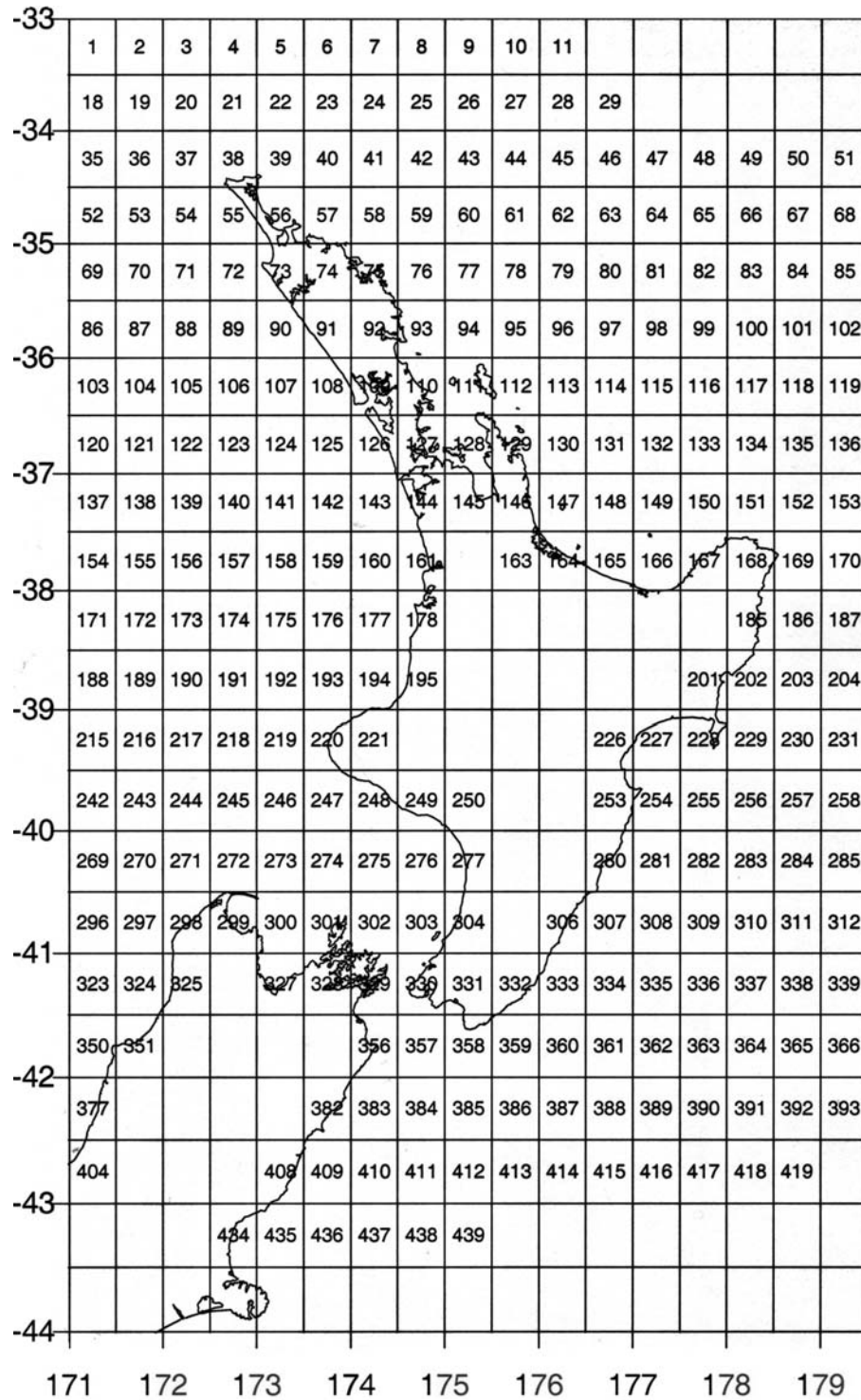


Figure C1: Northern and central grid squares and their codes.

Appendix D: Scaled species composition of jack mackerel in TCEPR fleet in JMA 3 and JMA 7.

Table D1: Scaled species composition by fishing year and month of the catch of jack mackerels in the TCEPR fleet (vessels using Trawl Catch Effort Processing Returns) in JMA 3 and 7; JMD is *Trachurus declivis*, JMM is *T. murphyi*, JMN is *T. novaezelandiae*, c.v.s are coefficients of variation, N is the number of sampled tows that contained a particular species (source: MFish MOBY).

Fishstock	Fishing		Species proportions			c.v.			N		
	Year	Month	JMD	JMM	JMN	JMD	JMM	JMN	JMD	JMM	JMN
JMA 3	1985–86	September	0	1	0	NA	0	NA	0	1	0
	1986–87	January	1	0	0	0	NA	NA	1	0	0
		March	0.77	0	0.23	0.33	NA	1.02	3	0	1
		June	0.78	0	0.22	0.22	NA	0.62	3	0	3
	1987–88	January	0.19	0.79	0.02	0.95	0.72	0.75	2	1	1
	1988–89	February	0	1	0	NA	0	NA	0	1	0
	1989–90	November	0.3	0.7	0	0.24	0.12	NA	2	2	0
	1990–91	October	0	1	0	NA	0	NA	0	2	0
		February	0	1	0	NA	0	NA	0	1	0
		March	0	1	0	NA	0	NA	0	4	0
	1991–92	October	0.01	0.99	0	0.87	0.01	NA	2	6	0
		November	0	1	0	1.48	0.02	NA	1	2	0
		January	0	1	0	NA	0	NA	0	1	0
		February	0	1	0	NA	0	NA	0	2	0
		March	0	1	0	NA	0	NA	0	2	0
		April	0	1	0	NA	0	NA	0	1	0
	1992–93	January	1	0	0	0	NA	NA	1	0	0
		February	0	1	0	NA	0	NA	0	40	0
		March	0	1	0	NA	0	NA	1	26	0
		April	0.19	0.8	0	0.27	0.06	1.91	16	51	1
		May	0	1	0	NA	0	NA	0	2	0
	1993–94	November	0	1	0	NA	0	NA	0	2	0
		February	0	1	0	NA	0	NA	0	9	0
		March	0.84	0.16	0	0.78	0.95	NA	2	16	0
		April	0.74	0.26	0	0.46	0.85	NA	2	3	0
		May	0	1	0	10.48	0	NA	1	6	0
		June	0	1	0	NA	0	NA	0	2	0
	1994–95	February	0	1	0	NA	0	NA	0	7	0
		March	0	1	0	NA	0	NA	0	4	0
		April	0.07	0.93	0	1.01	0.09	NA	1	3	0
		May	0.04	0.96	0	0	0	NA	1	1	0
	1995–96	December	0.03	0.97	0	0.17	0.01	NA	7	8	0
		January	0.02	0.98	0	0.32	0.01	NA	17	22	0
		February	0	1	0	NA	0	NA	0	6	0
		March	0.01	0.99	0	0.62	0.01	NA	6	15	0
		April	0.01	0.99	0	0.35	0	NA	19	49	0
	1996–97	May	0	1	0	NA	0	NA	0	2	0
		January	0	1	0	NA	0	NA	0	1	0
		February	0	1	0	NA	0	NA	0	3	0
		March	0	1	0	NA	0	NA	0	4	0
	April	0	1	0	NA	0	NA	0	5	0	

Table D1 — Continued

Fishstock	Fishing Year	Month	Species proportions			c.v.			N		
			JMD	JMM	JMN	JMD	JMM	JMN	JMD	JMM	JMN
JMA 3	1997–98	May	0.01	0.99	0	0.77	0	NA	1	2	0
		December	0.02	0.98	0	0.23	0	NA	10	15	0
		January	0.03	0.97	0	0.19	0.01	NA	16	20	0
	1997–98	February	0	1	0	NA	0	NA	0	17	0
		March	0.01	0.99	0	0.71	0.01	NA	2	4	0
		April	0.04	0.96	0	0.37	0.02	NA	3	4	0
	1998–99	February	0.15	0.85	0	0.57	0.1	NA	4	14	0
		March	0.15	0.85	0	0.48	0.09	NA	16	17	0
		April	0.16	0.84	0	0.74	0.13	NA	9	17	0
	1999–00	February	0.05	0.95	0	0.75	0.04	NA	3	6	0
		March	0.4	0.51	0.1	0.28	0.22	0.44	16	17	7
		April	1	0	0	0	NA	NA	1	0	0
		May	0	1	0	NA	0	NA	0	3	0
		June	0	1	0	NA	0	NA	0	1	0
		October	1	0	0	0.75	1.5	NA	1	1	0
	2000–01	January	0	1	0	NA	0	NA	0	1	0
		February	0	1	0	NA	0	NA	0	22	0
		March	0.21	0.79	0	0.38	0.11	NA	17	25	0
		April	0.35	0.65	0	0.36	0.18	NA	20	17	1
		May	0	1	0	NA	0	NA	0	5	0
		September	0	1	0	NA	0	NA	0	1	0
		October	0.42	0.58	0	0.62	0.26	NA	4	8	0
	2001–02	February	0.32	0.65	0.04	0.22	0.1	0.99	18	25	1
		March	0.53	0.47	0	0.18	0.19	NA	20	20	0
		April	0.25	0.75	0	0.6	0.22	NA	6	15	0
		May	0	1	0	NA	0	NA	0	2	0
		December	0	1	0	NA	0	NA	0	1	0
	2002–03	January	0	1	0	NA	0	NA	0	2	0
		February	0	1	0	NA	0	NA	0	4	0
		March	0.03	0.97	0	1.11	0.07	NA	2	5	0
		April	0.86	0.14	0	0.11	0.49	NA	4	3	0
		September	0	1	0	NA	0	NA	0	1	0
2003–04	February	0.19	0.81	0	0.98	0.20	NA	1	5	0	
2004–05	February	0	1	0	NA	0	NA	0	9	0	
	March	0.49	0.51	0	0	0	NA	2	10	0	
	April	0	1	0	NA	0	NA	0	7	0	
	May	0	1	0	NA	0	NA	0	1	0	
2005–06	January	0.43	0.57	0	0.74	0.54	NA	1	2	0	
	February	0.34	0.66	0	0.00	0.00	NA	1	1	0	
	March	0.53	0.33	0.14	0.24	0.31	1.15	18	21	1	
	August	0.09	0.91	0	0.08	0.01	NA	2	2	0	
JMA 7	1985–86	September	0.68	0	0.32	0.02	NA	0.04	3	0	3
	1986–87	November	0.65	0	0.35	0.09	NA	0.16	49	0	48
		December	0.57	0	0.43	0.07	NA	0.09	92	0	84
	January	0.54	0	0.46	0.11	NA	0.13	32	0	27	
	April	0.08	0	0.92	0	NA	0	1	0	1	
	May	0.31	0	0.69	0.35	NA	0.17	12	0	10	

Table D1 — Continued

Fishstock	Fishing Year	Month	Species proportions			c.v.			N		
			JMD	JMM	JMN	JMD	JMM	JMN	JMD	JMM	JMN
JMA7	1987–88	November	0.99	0	0.01	0	NA	0	1	0	1
		January	0.52	0	0.48	0.35	NA	0.4	6	0	4
		February	0.92	0	0.08	0.24	NA	1.55	3	0	1
		March	0.32	0	0.68	0.66	NA	0.35	3	0	3
	1988–89	December	0.53	0	0.47	0.14	NA	0.16	18	0	15
		August	0.97	0.03	0	0.19	1.2	NA	3	2	0
		September	0.74	0.18	0.08	0.18	0.71	0.95	7	3	2
	1989–90	October	0.48	0.2	0.32	0.16	0.44	0.32	13	4	9
		November	0.47	0	0.52	0.12	1.44	0.11	66	7	47
		December	0.13	0	0.87	0.06	NA	0.01	2	0	2
		March	0.03	0	0.97	0.47	NA	0.02	5	0	16
		April	0.1	0	0.9	0.48	NA	0.05	5	0	13
		June	0.68	0	0.32	0	NA	0	1	0	1
		December	0.67	0	0.33	0.37	NA	0.7	4	0	3
	1990–91	February	0.57	0.01	0.43	0.23	1.03	0.31	9	2	6
		March	0.47	0	0.52	0.09	9.95	0.09	51	5	52
		April	0.3	0	0.7	0.12	NA	0.05	89	2	89
		May	0.28	0	0.71	0.15	12.88	0.06	18	1	18
		July	0.66	0.34	0	0.54	0.69	NA	3	3	0
		August	0.17	0.83	0	0.63	0.14	NA	3	6	0
		September	0.48	0.39	0.13	0.23	0.29	0.73	13	9	4
		October	0.48	0.02	0.5	0.34	0.84	0.31	3	1	3
	1991–92	November	0.51	0.04	0.45	0.14	0.25	0.18	33	24	28
		December	0.4	0.04	0.56	0.18	0.44	0.16	16	8	16
		March	0.33	0.02	0.65	0.25	1.04	0.13	17	1	23
		May	0.86	0.07	0.07	0.16	1.14	1.14	8	2	1
		July	0.15	0.7	0.15	0.69	0.45	0.75	6	6	6
		August	0	1	0	NA	0	NA	0	2	0
		September	0.48	0.52	0	0.43	0.49	NA	5	3	0
		October	0.84	0.16	0	0.4	1.12	NA	2	2	0
	1992–93	December	0.67	0.11	0.22	0.06	0.16	0.19	51	42	45
		January	0.61	0.14	0.25	0.05	0.09	0.14	58	56	52
		February	0.5	0.21	0.3	0.05	0.09	0.08	47	47	47
		March	0.68	0.05	0.28	0	0	0	1	1	1
		June	0	1	0	NA	0	NA	0	1	0
		August	0	1	0	NA	0	NA	0	1	0
		October	0.18	0.16	0.65	0.67	0.67	0.24	2	2	7
		November	0.64	0	0.36	0.13	NA	0.23	25	0	18
	1993–94	December	0.69	0.05	0.27	0.18	1.02	0.44	11	1	5
		January	0.54	0.07	0.39	0.1	0.26	0.14	20	14	17
		February	0.32	0.26	0.42	0.11	0.2	0.13	24	24	24
		May	0.33	0.24	0.43	0.21	0.33	0.28	17	13	15
		July	0.08	0.92	0	0.32	0.03	NA	14	20	0
		August	0	1	0	NA	0	NA	0	4	0
		September	0.65	0.35	0	0.33	0.53	NA	4	3	0
		October	0.65	0.35	0	0.33	0.53	NA	4	3	0
	1994–95	December	0.32	0.36	0.33	0.13	0.22	0.22	18	16	13
January		0.31	0.22	0.47	0.08	0.18	0.11	98	84	92	
March		0.29	0.5	0.21	0.11	0.11	0.17	23	26	24	

Table D1 — Continued

Fishstock	Fishing Year	Month	Species proportions			c.v.			N			
			JMD	JMM	JMN	JMD	JMM	JMN	JMD	JMM	JMN	
JMA7	1994–95	July	0.06	0.94	0	0	0	NA	1	1	0	
	1995–96	February	0.39	0.22	0.39	0.06	0.26	0.14	27	17	25	
		March	0.56	0.21	0.23	0.08	0.23	0.22	31	19	24	
		June	0	1	0	NA	0	NA	0	1	0	
		August	0.05	0.95	0	0.57	0.03	NA	3	4	0	
		December	0.66	0.07	0.27	0.14	0.31	0.3	8	8	8	
	1996–97	January	0.59	0.07	0.34	0.05	0.15	0.1	53	49	53	
		February	0.64	0.06	0.3	0.07	0.24	0.15	36	31	35	
		March	0.51	0.22	0.26	0.13	0.29	0.19	6	6	6	
		June	0.53	0.47	0	0.23	0.25	NA	9	9	0	
		July	0.09	0.91	0	0.61	0.04	NA	1	2	0	
		August	0.1	0.9	0	0.35	0.04	NA	3	3	0	
		September	0.08	0.92	0	0.31	0.03	NA	12	15	0	
		1997–98	November	0.44	0.19	0.37	0.1	0.09	0.12	45	45	43
			December	0.38	0.12	0.5	0.09	0.15	0.09	40	36	40
			January	0.61	0.09	0.3	0.04	0.15	0.07	64	53	63
	February		0.52	0.04	0.44	0.09	0.27	0.09	18	13	18	
	July		0.17	0.83	0	1.13	0.22	NA	1	5	0	
	1998–99	December	0.44	0.15	0.41	0.13	0.18	0.16	13	13	13	
		January	0.47	0.13	0.41	0.03	0.14	0.05	20	19	20	
		April	0.87	0	0.13	0.1	NA	0.65	11	0	5	
		June	0.98	0.02	0	0.01	0.45	NA	48	17	0	
		July	0.79	0.21	0	0.09	0.34	NA	23	15	0	
		August	0	1	0	NA	0	NA	0	1	0	
		September	0.41	0.26	0.33	0.2	0.69	0.46	7	3	3	
		1999–00	October	0.78	0.14	0.08	0.06	0.26	0.45	42	32	20
	November		0.56	0.13	0.31	0.15	0.2	0.34	10	10	11	
	June		1	0	0	0	NA	NA	1	0	0	
	July		0.27	0.73	0	0.48	0.31	NA	5	3	0	
	August		0.52	0.48	0	0.48	0.5	NA	3	3	0	
	2000–01	October	0.84	0.08	0.08	0.05	0.37	0.45	10	7	5	
		November	0.71	0.21	0.08	0.03	0.11	0.32	28	27	23	
		December	0.54	0.24	0.23	0.12	0.16	0.30	28	27	26	
April		0.65	0.03	0.32	0.05	0.2	0.1	2	2	2		
July		0.99	0	0	0.01	3.16	3.16	6	1	6		
August		1	0	0	0	NA	NA	1	0	0		
September		0.67	0.33	0	0.15	0	NA	2	1	0		
2001–02	October	0.59	0.03	0.38	0.07	0.43	0.08	52	13	39		
	July	1	0	0	0	NA	NA	1	0	0		
	August	0.68	0.18	0.13	0.19	0.56	0.56	2	1	1		
	September	0.8	0.1	0.09	0.07	0.31	1.13	12	9	2		
2002–03	October	0.76	0.06	0.17	0.05	0.12	0.2	78	55	48		
	November	0.56	0.31	0.12	0.09	0.14	0.51	10	10	10		
	April	0.38	0	0.61	0.2	2.24	0.09	10	2	12		
	May	0.24	0	0.76	0.72	NA	0.23	4	0	4		
2003–04	October	0.60	0	0.39	0.21	3.20	0.44	6	0	3		
	December	0.74	0.06	0.20	0.04	0.20	0.17	46	36	32		
	January	0.75	0.05	0.20	0.05	0.30	0.16	8	8	7		

Table D1 — Continued

Fishstock	Fishing Year	Month	Species proportions			c.v.			N		
			JMD	JMM	JMN	JMD	JMM	JMN	JMD	JMM	JMN
JMA7	2004–05	October	0.6	0	0.39	0.12	NA	0.23	6	2	3
		December	0.74	0.06	0.2	0.02	0	0.06	46	36	32
		April	0.37	0.00	0.63	0.19	NA	0.03	4	1	4
		May	0.2	0.00	0.8	0	NA	0	1	0	1
		June	0.39	0.00	0.61	0.1	NA	0.04	9	1	8
	2004–05	July	0.97	0.03	0.00	0.04	1.41	0.00	32	5	0
		August	0.97	0.03	0.00	0.08	0.06	0.00	4	3	0
		September	0.6	0.17	0.23	0.01	0.08	0.1	2	2	1
	2005–06	November	0.81	0.05	0.15	0.03	0.22	0.17	68	48	58
		December	0.70	0.08	0.22	0.02	0.08	0.07	299	254	278
		June	0.66	0.01	0.33	0.15	0.66	0.25	29	8	22
		July	0.79	0.02	0.18	0.12	0.94	0.58	12	1	7
		August	0.61	0.00	0.39	0.31	NA	0.43	2	0	2

Appendix E: Sex ratio analysis — frequency distributions of the proportions males in tows

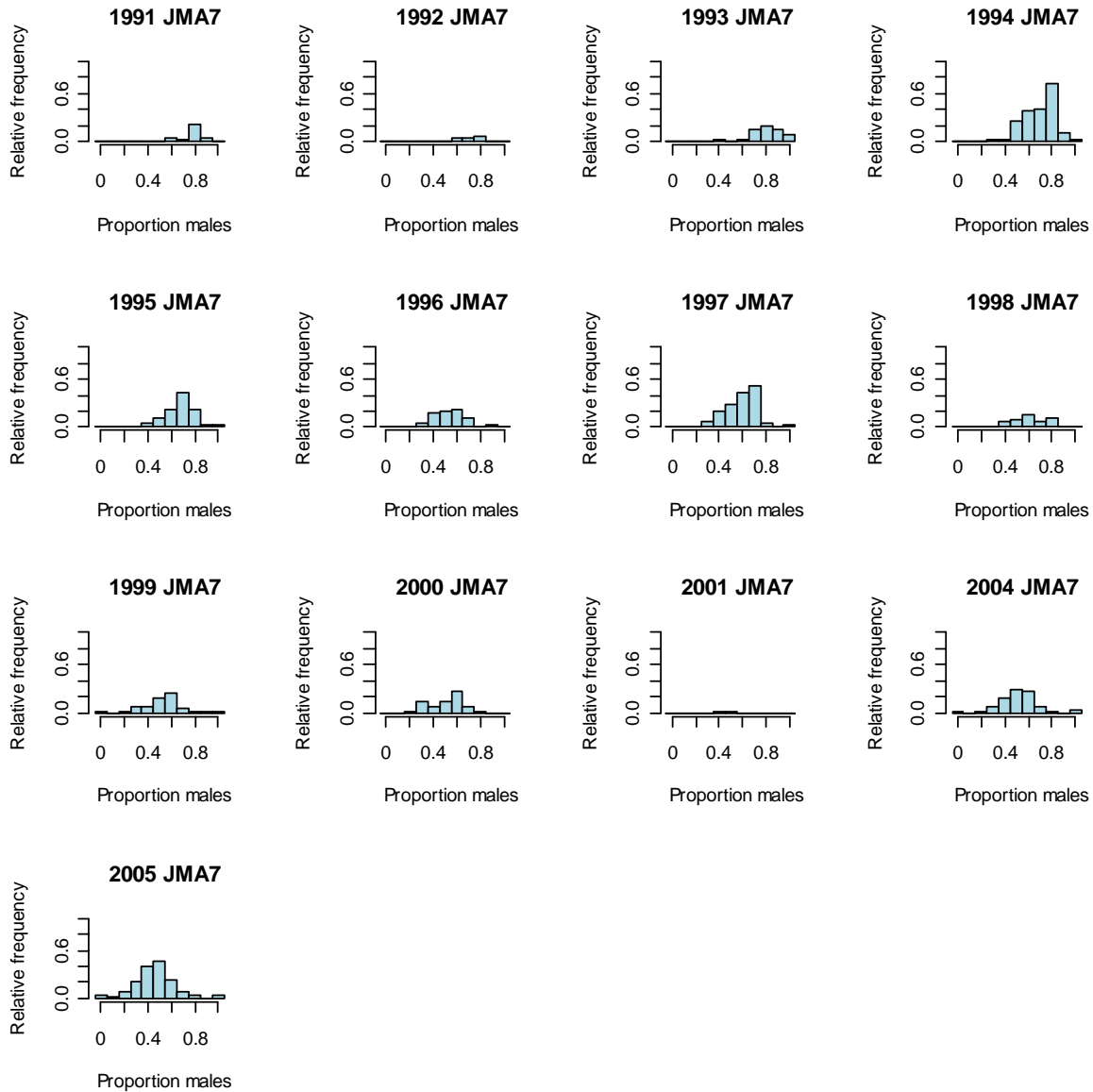


Figure E1: Annual frequency distributions (calendar year) of proportions of males in individual tows sampled in JMA 7; contributions from each tow were weighted by the number of specimens of *T. murphyi* in the sample. Source: SOP data.

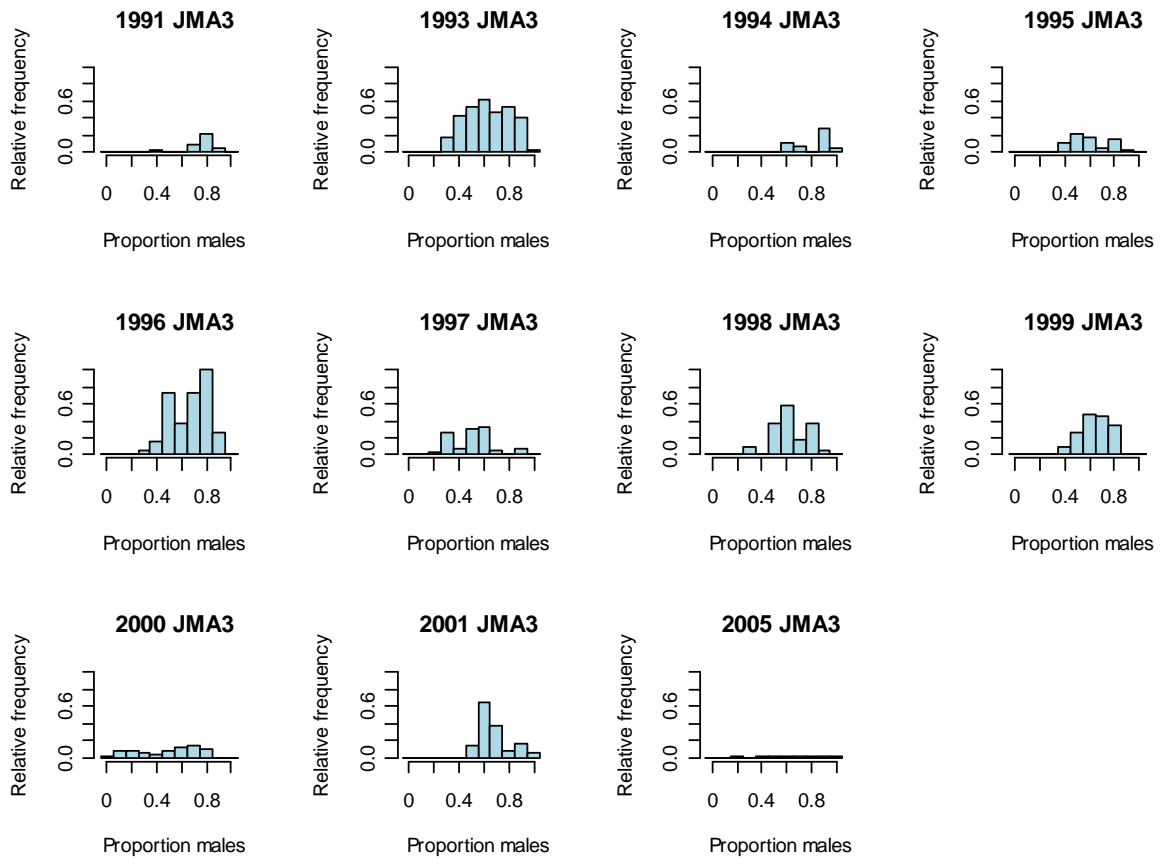


Figure E2: Annual frequency distributions (calendar year) of proportions of males in individual tows sampled in JMA 3; contributions from each tow were weighted by the number of specimens of *T. murphyi* in the sample. Source: SOP data.

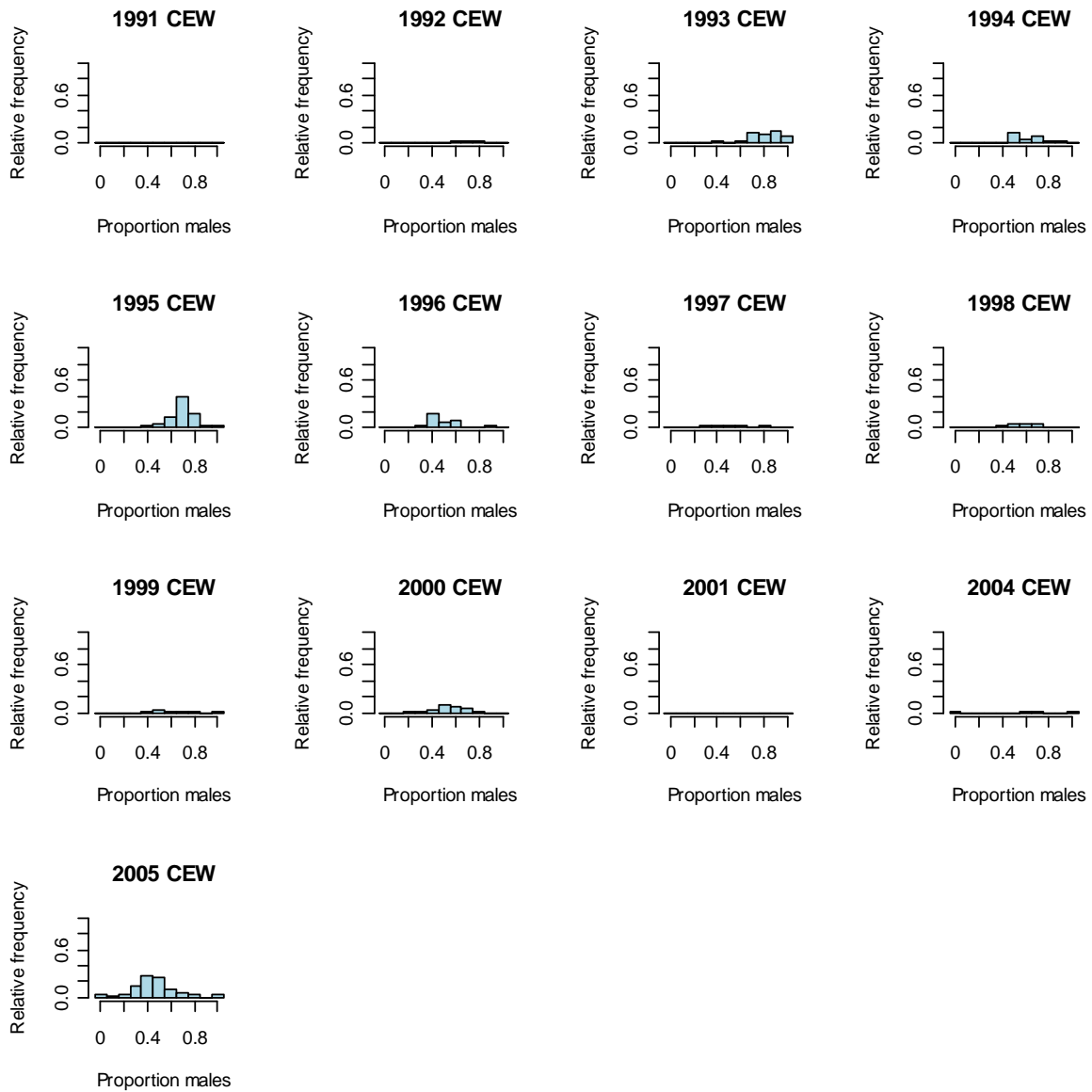


Figure E3: Annual frequency distributions (calendar year) of proportions of males in individual tows sampled in CEW; contributions from each tow were weighted by the number of specimens of *T. murphyi* in the sample. Source: SOP data.

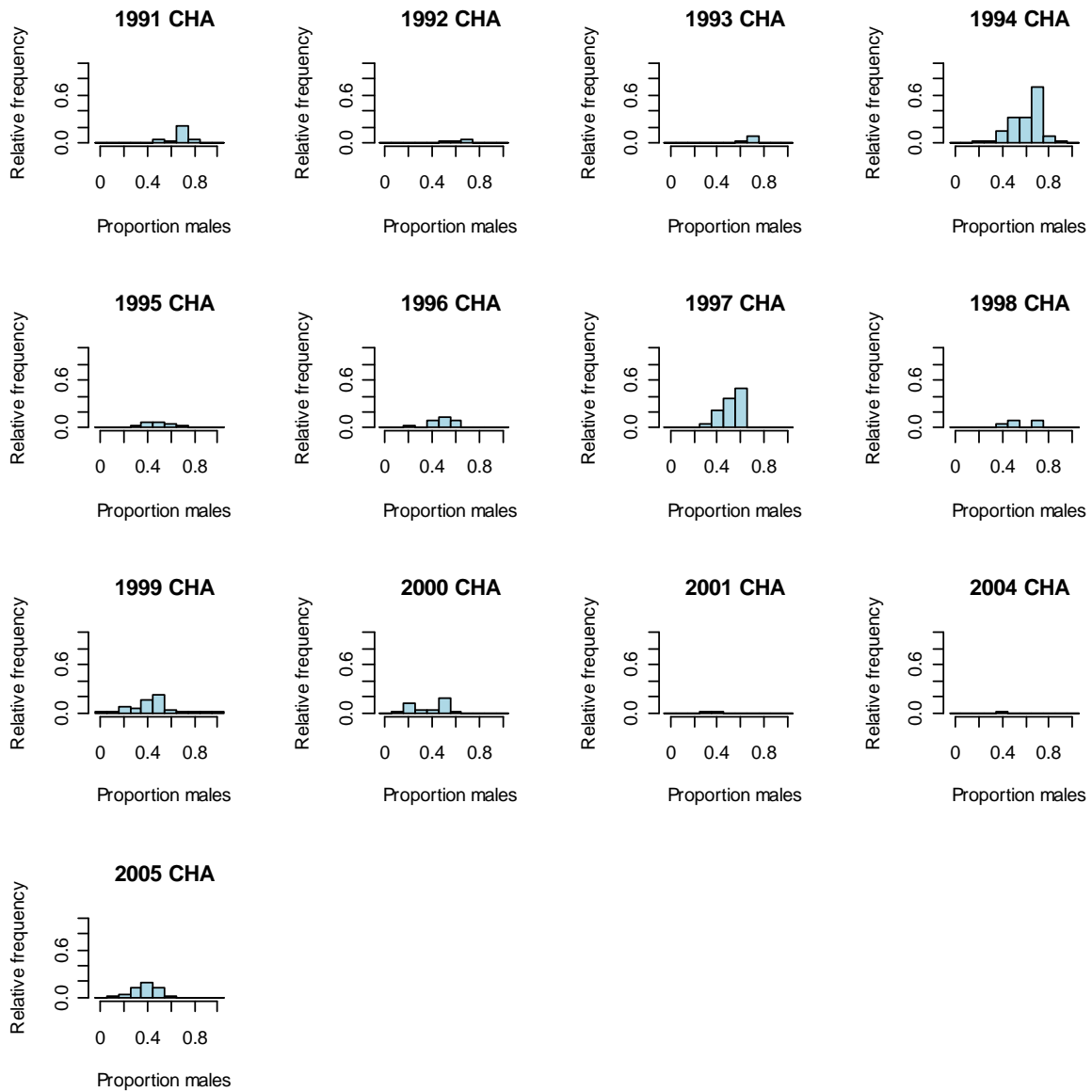


Figure E4: Annual frequency distributions (calendar year) of proportions of males in individual tows sampled in CHA; contributions from each tow were weighted by the number of specimens of *T. murphyi* in the sample. Source: SOP data.

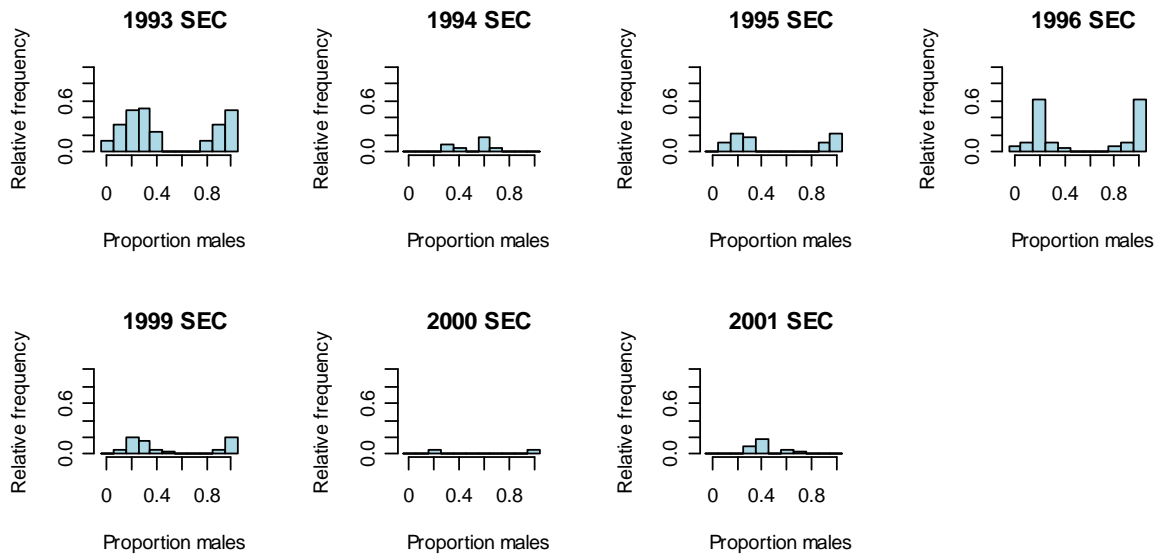


Figure E5: Annual frequency distributions (calendar year) of proportions of males in individual tows sampled in SEC; contributions from each tow were weighted by the number of specimens of *T. murphyi* in the sample. Source: SOP data.

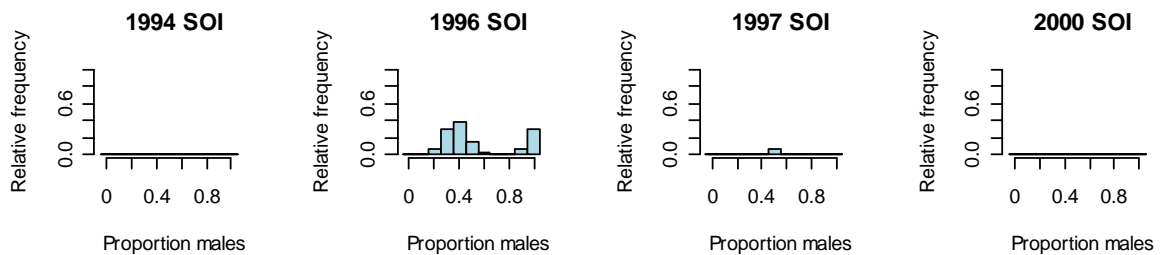


Figure E6: Annual frequency distributions (calendar year) of proportions of males in individual tows sampled in SOI; contributions from each tow were weighted by the number of specimens of *T. murphyi* in the sample. Source: SOP data.

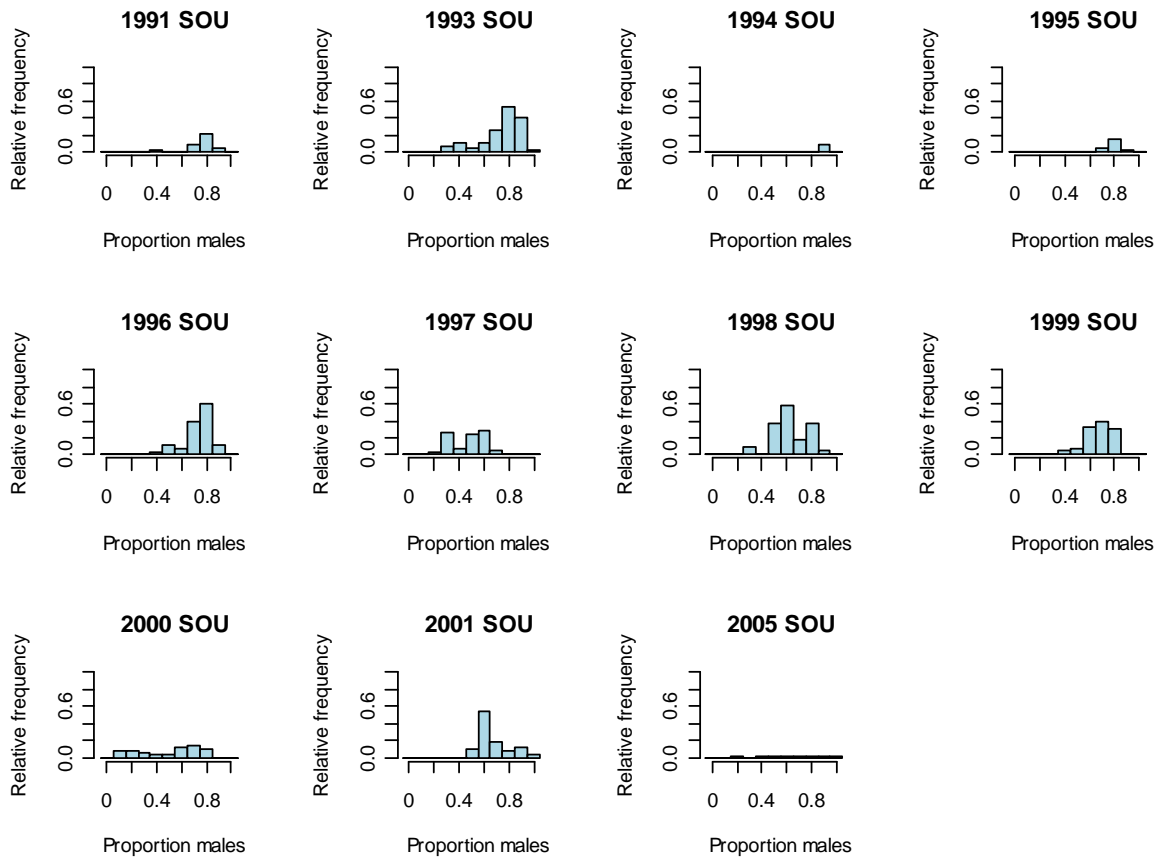


Figure E7: Annual frequency distributions (calendar year) of proportions of males in individual tows sampled in SOU; contributions from each tow were weighted by the number of specimens of *T. murphyi* in the sample. Source: SOP data.

Appendix F: Diagnostics for growth curve fits

Table F1: Log likelihood ratio test comparing the fits of the full and reduced models. Max Log Like, Maximum Log Likelihood; d.f., degrees of freedom; χ^2 , chi square test statistic.

Max Log Like	(full, -1715.8; reduced -1801.41)
d.f.	3
χ^2	171.3
$P(X > x H_0)$	0.0000

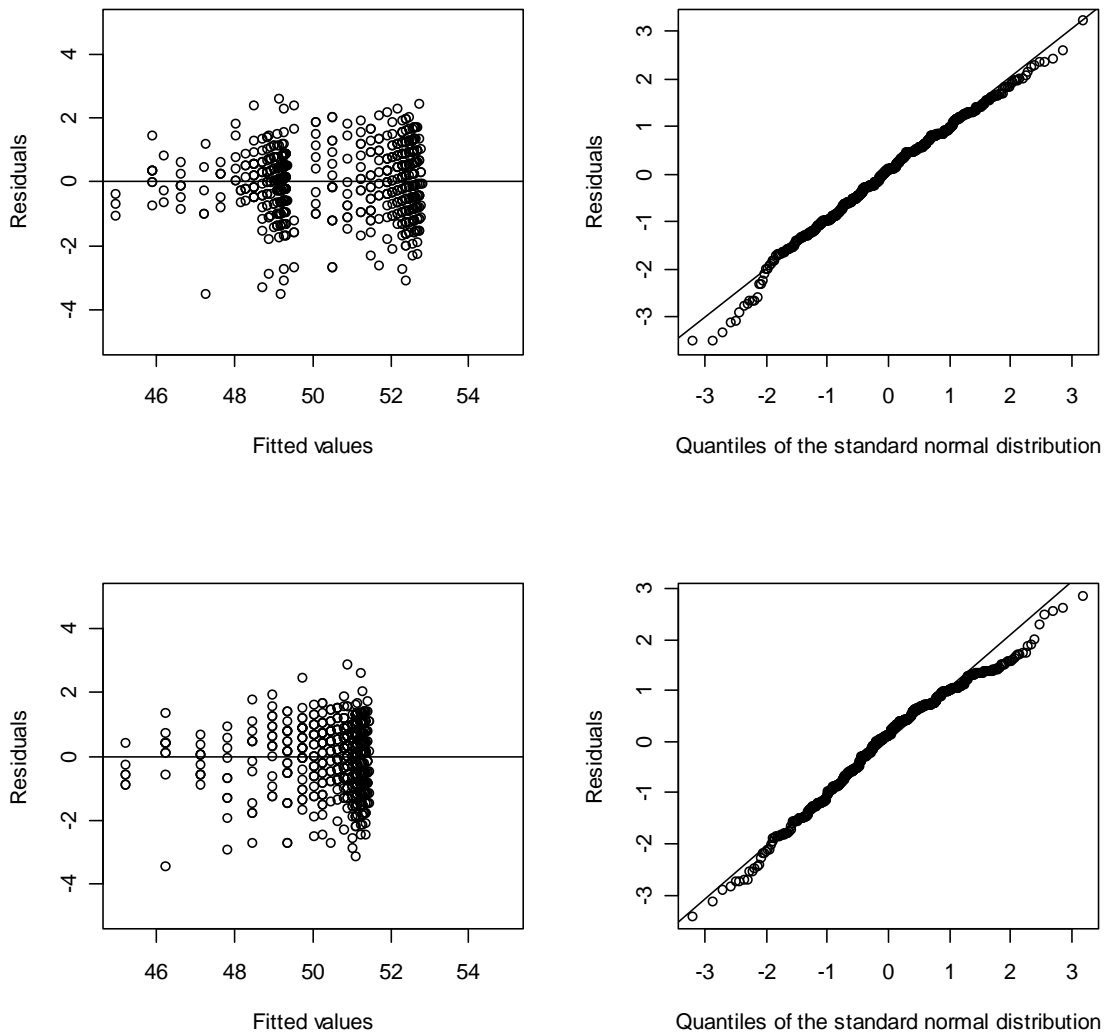


Figure F1: Paired diagnostic plots for full (top) and reduced (bottom) von Bertalanffy growth models.