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EXECUTIVE SUMMARY

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Catches of blue mackerel have increased substantially since the early 1990s, and in some years have exceeded 13 000 t. However, little information is available on the status of the stocks, even for basic biological parameters such as growth, age, and mortality. This report presents the current state of knowledge on blue mackerel stocks in New Zealand waters.

Aerial sightings data have been collected for blue mackerel and other surface schooling pelagic species since 1975. Aerial sightings data from East Northland, the Bay of Plenty, and QMA 1 (the two areas combined) were used to generate temporal abundance indices. Three trimming ranges (0, 20, 50%) were used to assess the influence of large data outliers. Significant positive relationships of abundance with fishing year were found for some of the indices generated; in particular for East Northland and QMA 1 for indices involving a tonnage estimated by spotter plane pilots over the first one or two hours of flying. Only one significant negative relationship was found, for a 50% trimmed analysis. These results suggest that blue mackerel aerial sightings data are not suitable for use as an index in a stock reduction analysis, as declines in abundance over time were not present (a necessary condition for such an analysis).

The catch per unit effort (CPUE) of the northern purse-seine fishery was also examined for explanatory power. This data source held little or no information that would be useful in a stock reduction analysis. Some of the basic assumptions required for the application of CPUE analyses were also violated, due to the fishery targeting surface schools, and variability in fishing effort due to market forces, and the availability of other target purse-seine species, independent of blue mackerel abundance.

An otolith collection taken from the purse-seine fishery in 1997–98 (with the addition of some historical archived samples) was processed and used to estimate growth and mortality rates. Growth was relatively rapid over the first 5 years, but become negligible after 12 years. No difference in growth rate was apparent between the sexes. Application of a derived age-length key to a length frequency generated from catch sampling of the purse-seine fishery found the fished population to be dominated by 3–12 year old males, and 4–13 year old females. Using age estimates from otoliths collected during the mid 1980s when fishing pressure was presumably light, natural mortality estimates of 0.22 for males and 0.20 for females were derived (Hoenig's method).

Currently, insufficient data are available to carry out a successful stock assessment of this species.

1. INTRODUCTION

1.1 Overview

Three species of scombrid mackerel (*Scomber japonicus*, *S. scombrus*, and *S. australasicus*) occur in the world's waters which support substantial pelagic fisheries (Sato 1990, Matsuda et al. 1992, Villacastin et al. 1992, Gregoire 1993, 1996). Only *S. australasicus* (blue mackerel) occur in New Zealand waters, and they are widespread in North Island and northern South Island waters, as well as being found in Australian waters (Robertson 1978). Work by Rodhe (1987) using parasitological indicators strongly suggested that the New South Wales and New Zealand populations form separate stocks.

Little is known about *S. australasicus* in comparison with the other two species. In recent years the catch of this species in New Zealand waters has grown substantially, primarily through the purse-seine fishery. Catches peaked in 1991–92 at more than 15 000 t, of which 60-70% was taken by purse-seine. Most of the purse-seine catch comes from the Bay of Plenty and east Northland, where it is primarily from July to December. There is also a significant bycatch of blue mackerel in the jack mackerel trawl fishery of the Challenger region.

Blue mackerel are not currently managed within the Quota Management System (QMS), but are likely to be brought into this system in the near future. Little is currently known about the status of blue mackerel stocks. Even basic biological parameters such as age, growth, and natural mortality are not available. No estimates of current and reference biomass or yield are available. Given the impending introduction of blue mackerel into the QMS, a review of the information available for a possible stock assessment is required. This report presents results from an analysis of the aerial sightings database for blue mackerel, an ageing study carried out on otolith samples from the Bay of Plenty purse-seine fleet, and a catch per unit effort (CPUE) analysis on the purse-seine fishery for 1991–99. These constitute the main sources of available information on the fishery. If sufficient information content is present, then a formal stock assessment may be carried out.

The work was funded by the Ministry of Fisheries through contract EMA9801.

The objectives of this study were as follows

1. To determine age, growth and natural mortality of blue mackerel in QMA 1.

2. To develop a stock assessment model for the blue mackerel fishery in QMA 1.

1.2 Description of the fishery

Blue mackerel are taken by a number of methods in all QMAs, but principally north of 43° S (Kaikoura). They are not currently in the Quota Management System but comprise a significant proportion of the landings from purse-seine fisheries. Overall reported catches from all methods peaked in 1991–92 at about 15 000 t, of which 60–70 % was taken by purse-seine operations. Most of the purse-seine catch comes from the Bay of Plenty and east Northland. There is a distinct seasonality of catches, with most being taken from July through to December. Significant landings are also taken as a bycatch of the jack mackerel trawl fishery in QMAs 7 and 8.

2. REVIEW OF THE FISHERY

2.1 Catch limits and landings

Reported landings are given in Table 1.

Table 1: Reported landings (t) of blue mackerel by QMA, and where area was unspecified (Unsp.), from 1983–84 to 1998–99.

QMA	1	2	3	4	5	6	7	8	9	10#	Unsp	Total
1983–84*	480	259	43	0	<1	0	36	190	19	0	1	548
1984–85*	565	222	18	0	0	0	144	716	5	0	73	1 743
1985–86*	618	30	189	0	<1	0	216	190	2	0	51	1 296
1986–87†	1 431	7	423	0	<1	0	248	231	10	0	49	2 399
1988–89†	2 641	168	863	<1	<1	0	1 114	781	<1	0	58	5 625
1989–90†	1 580	<1	1 115	0	0	26	662	332	27	0	469	4 211
1990–91†	5 783	94	477	0	<1	0	2 469	535	0	0	0	9 358
1991–92†	10 926	530	65	0	0	0	2 255	1 352	0	0	0	15 128
1992–93†	10 684	309	124	2	7	0	1 494	386	0	0	0	13 006
1993–94†	4 178	218	219	3	<1	0	975	367	60	5	0	6 025
1994–95†	6 734	94	148	5	<1	0	1 188	385	231	10	149	8 944
1995–96†	4 170	119	171	1	<1	<1	1 205	12	1	0	1	5 680
1996–97†	6 754	78	339	<1	<1	0	2 475	40	22	0	<1	9 708
1997–98†	4 595	122	77	0	<1	<1	2 116	106	88	0	<1	7 104
1998–99†	4 505	145	61	<1	0	0	5 466	3 306	6	0	4	13 493

*, FSU data, † CLR data, # Landings reported from QMA 10 are probably attributable to Statistical Area 010 in the Bay of Plenty (i.e., QMA 1).

2.2 Non-commercial fisheries

Blue mackerel do not rate highly as a recreational species although they are popular as bait. Recreational catch in the northern region (QMA 1) was estimated at 114,000 fish by a diary survey in 1993–94 (Bradford 1996) and 47 000 fish in a national recreational fishing survey in 1996 (Bradford 1998). Catches in other regions are low (1 000–3 000 fish). Some confusion exists between blue and jack mackerels in the recreational data.

3. RESEARCH

Two data series were examined for possible changes in relative indices; sightings from the aerial sightings database, and catch per unit effort (CPUE) from the purse-seine fishery in Tauranga. Age, growth, and mortality estimates were also made from an otolith collection available from the Tauranga purse-seine fishery, and from archived otoliths from the west coast of the North Island, the Hauraki Gulf, and the Bay of Plenty. Data from catch sampling of the purse-seine fishery in 1997–98 (courtesy of Sanfords Ltd) was also available in the form of scaled length frequencies for male, female, and all fish combined.

3.1 Analysis of aerial sightings data

3.1.1 Background

Aerial sightings data are recorded by pilots working in conjunction with the purse-seine fleet. Their primary aim is to identify fish schools of appropriate species composition and size according to the target requirements of the vessels, which are controlled mostly by market demands. Because data collection is incidental to the fishing operation and standard methods like line transect and quadrat surveys are not followed, the method is often referred to as "opportunistic". Data collection includes the pilots' estimates of school size and the number of schools in each sighting, the location of each sighting, takeoff and landing times and airfields, and the amount of time they spend within coded areas as defined by a grid of half-degree squares.

With experience, pilots are able to determine school size and the species composition of each school, using a combination of colour, swimming movements, and schooling behaviour. The pilots' ability to determine these characteristics of the schools is learned by comparing their estimates with information from the vessels after the targeted schools are landed. The accuracy of this estimation has not been quantified, although anecdotal information suggests that pilots become highly skilled, to ensure that the schools chosen for fishing meet the vessels' target requirements.

Blue mackerel is one of the seven main purse-seine target species, which also include skipjack tuna (*Katsuwonus pelamis*), trevally (*Pseudocaranx dentex*), jack mackerels (*Trachurus declivis, T. symmetricus murphyi*, and *T. novaezelandiae*), and kahawai (*Arripis trutta*). Pilots record all sightings of each species they encounter within a flight, although there may be a tendency to ignore schools that lie at the extreme of a pilot's vision when it is clear to the pilot that they are not of the size or species composition required by the vessel(s). Therefore, there is probably some bias in the data, depending on whether a species was target or non-target at the time the sightings data were collected.

The purse-seine fishery in QMA 1 dates back to 1976 and has developed from being a summer fishery primarily targeting skipjack tuna. As the fishery expanded, "off-season" targets of trevally and kahawai were included, and this "tri-species" fishery continued, with occasional targeting of the other species, until 1993–94, when more restrictive catch limits were introduced for kahawai. This resulted in a change to the "off-season" target species, which now include kahawai, jack mackerel, and blue mackerel. Because there are no catch limits on blue mackerel and its market value is higher than that of jack mackerels, blue mackerel have now become the preferred "off-season" species.

A number of indices of relative abundance have been described for blue mackerel in QMA 1 using the aerial sightings data. Bradford & Taylor (1995) produced several indices, including a presence-absence or binomial index, annual medians of the number of schools and total tonnage sighted, and smoothed indices using monthly medians summed over half-degree squares. They found some conflict between the indices, and apart from a peak in the late 1980s, little change throughout the time series. Annual means (by fishing year) of total tonnage and number of schools were used as indices by Taylor (1999, unpubl. results), but an independent examination of the aerial sightings data by Sampson (2000) has shown that that they are not a reliable measure of relative abundance because they are not standardised by the amount of flying.

3.1.2 Methods

Tonnage and number of schools.

Estimates of sightings tonnage were based on methods described by Taylor (unpubl. results), who showed that estimates based on the geometric mean are more reliable than those based on an arithmetic mean. Therefore, tonnage ($\hat{T}$) of the *i*th sighting of the *j*th species in the *k*th area can be estimated using the geometric mean of the maximum and minimum tonnage, and the number of schools

$$\hat{T}_{ijk} = n_{ijk}\left(x_{1_{ijk}} \cdot x_{2_{ijk}}\right)^{\frac{1}{2}} \qquad (1)$$

where n is the pilot's estimate of the number of schools sighted, and x_1 and x_2 are the pilot's estimates of the minimum and maximum school size. In the present case $\hat{T}_{ijk}$ reduces to $\hat{T}_i$, because there is a single area and species.

Relative abundance indices — tonnes sighted per hour of flying.

Pilots sometimes record an estimate of the total tonnage in the sighting. This "pilot's estimate" was identified by Taylor (unpubl. results) as the best estimate of total tonnage compared with the "calculated estimate" in Equation 1. Following Taylor's approach, the relationship between the "pilot's estimate" and the "calculated estimate" was used to calculate a best estimate of total tonnage for those sightings where a pilot estimate was not provided. The method comprised the following eight steps.

1. Sightings of blue mackerel over two different time frames were extracted from the database: during the first hour and during the first 2 hours.
2. Sightings where the "pilot's estimate" was recorded were extracted as a subset of the data.
3. "Calculated estimates" were determined for the subset using Equation 1.
4. Coefficients for the regression of the "calculated estimate" and "pilot's estimate" from the subset were determined using

   $$\ln\left(\hat{p}_i\right) = \ln\left(\hat{T}_i\right) + \varepsilon \qquad (2)$$

5. Best estimates of total tonnage were calculated in the overall dataset where the "pilot's estimate" was missing, using

   $$\hat{C} = \exp^{a + b\ln\hat{T}_i} \qquad (3)$$

   where a and b are the parameters (intercept and slope respectively) from the regression in step 4.
6. The missing "pilot's estimates" in the overall dataset were replaced with best estimates from step 5.
7. Best estimates for the overall dataset were summed by individual flights and, to standardise to 1 hour, divided by the number of hours flying that was used as the basis for data selection in step 1 — this gave a "tonnes sighted per hour" estimate for each sighting.

8. Annual indices of relative abundance were estimated as the means and standard errors of the estimates for each sighting by fishing year, using all data to estimate untrimmed means, and the method of Staudte & Sheather (1990) to estimate trimmed means at the 20% and 50% levels (Appendix 1).

Each of the time series was investigated for the presence of linear trends through linear regression. Regressions were weighted using the inverse of the standard error, so that those points less well estimated had less influence on the curve fit. Curves were fitted using the non-linear curve fitter in Sigmaplot 6.00 (SPSS Inc.) Curves were fitted for the full data sets, and with the 1991 data omitted, to assess the effect of this year on fits (given the unusually high values for many of this years indices).

3.1.3 Aerial sightings results

Mean annual tonnages per standardised hour for east Northland showed significant positive trends over time, for the hour observation period, for both untrimmed and trimmed data (Figure 1). No significant trends were found for the two hour observation period. For all East Northland indices, omitting the 1991 data improved regression fits. Mean annual tonnages per standardised hour for the Bay of Plenty showed no significant trends for any of the indices, apart from a positive relationship for the 2 hour observation period with a 50% trim factor (Figure 2). Omission of the 1991 data had little or no effect. For QMA 1, all mean annual tonnage indices per standardised hour showed a significant positive relationship with time (Figure 3). Omission of the 1991 data improved the regression fits.

3.2 Purse-seine CPUE analysis

Purse-seine data were extracted from the relevant MFish CELR database for the period 1991–99. Only records where blue mackerel was the specified target were used. The data was groomed and replicate records removed. The unit of CPUE was set as the total catch of EMA per day fished, and individual data records were combined where appropriate. There were no zero catches. A total of 716 records was available. Data fields included fishing year, month, fishing area (008 or 009), net length, vessel, and sea temperature (as measured by the fishing vessel).

A CPUE index of log (tonnes per day) was used for the analysis. Using logged values results in a multiplicative model, where the effect of each variable is to multiply the expected CPUE by a factor whose value depends on the value of the variable.

The form of the model was:

$$\log_e(\mathrm{CPUE}_t) = M + Y_{it} + A_{jt} + B_{kt} + C_{lt} + \ldots\ldots + \varepsilon_t$$

or equivalently

$$\mathrm{CPUE}_t = \exp(M) * \exp(Y_{it}) * \exp(A_{jt}) * \exp(B_{kt}) * \exp(C_{lt}) + \ldots.. + \varepsilon_t$$

where		
where	CPUE_t	is the catch per unit effort for a particular day,
	M	is an overall mean for log (CPUE_t),
	Y_{it}	is the effect on log(CPUE_t) of day *t* being in the *i*th year

A_jt	is the effect of variable A having value j
B_{kt}	is the effect of variable B having value k
C_{lt}	is the effect of variable C having value l
ε_t	is the error in log($CPUE_t$), with zero mean and independently normally distributed

CPUE values were regressed against each of the possible predictor variables to determine which explained the greatest amount of variability in the CPUE. The best variable was then included in the model, and the model rerun with this variable plus each of the additional variables in turn to find the next most predictive variable. This stepwise regression procedure continued until adding an additional variable added less than 1% to the overall estimated R^2 value.

Variables in a regression model can take two forms: either categorical, in which they take on particular discrete values with no inherent ordering, or continuous, allowing them to take the value of any real number. The year of the set is a categorical variable. Therefore the regression coefficient for each of the years can vary independently. The regression coefficients represent the change in CPUE over time. A possible index of abundance can be estimated from the year coefficients (Doonan 1991) by

$$\hat{Y} = \exp(\hat{Y}_i - \hat{Y}_{base})$$

where $\hat{Y}_i$ is the regression coefficient for year i

$\hat{Y}_{base}$ is the regression coefficient for the base year to compare against

The variance of this estimate is

$$\sigma^2 = Var(\hat{Y}_i) + Var(\hat{Y}_{base}) - 2Cov(\hat{Y}_i, \hat{Y}_{base})$$

If all other effects on the CPUE have been incorporated as variables, differences in the year effects may be attributable solely to changes in abundance, and can be viewed as an index of abundance.

3.2.1 CPUE results

Results of the stepwise regression are given in Table 2. Month explained the greatest proportion of the variation. This agrees with the strongly seasonal catch patterns of this fishery (July–December). This was followed by fishing year, and then by vessel and water temperature, with each of these accounting for only a small proportion of the variance. The overall variance explained by the regression was 13.75%. No trend with time (fishing year) was apparent for the CPUE series (Table 3).

Table 2: Results of stepwise regression analysis. Variables are given in the order in which they were selected into the linear model (of catch per day) and the model R^2 at each step.

Variable	Model R^2
Month	0.0815
Fishing year	0.1030
Vessel	0.1224
Water temperature	0.1375

Table 3: Fishing year indices, standard errors, and sample sizes.

Fishing year	Index	S.e	Records
1991 (base)	1.000	0.000	39
1992	0.391	0.752	142
1993	0.706	1.642	128
1994	0.917	2.243	61
1995	0.120	0.269	106
1996	0.395	1.317	42
1997	0.599	1.416	82
1998	0.328	0.994	68
1999	0.345	1.105	48

3.3 Otolith ageing and growth estimation

Otoliths collected between September and November 1997 were available from the Bay of Plenty commercial purse-seine fishery. This set contained fish of 33 to 52 cm fork length (FL). Juvenile blue mackerel were collected during a trawl survey off the west coast of the North Island in November 1999 (KAH9915; Morrison & Parkinson 2001), to provide smaller fish. Otoliths were also retrieved from an archival collection, to provide additional juvenile samples, and to allow for the estimation of maximum age in the stock, from a time when fishing pressure was presumably light (early 1980s) (otoliths from research voyages KAH8202 and KAH8203, Hauraki Gulf; KAH8303, Bay of Plenty).

During preparation, up to five otoliths were embedded in blocks of clear epoxy resin (Araldite K142) and cured at 50 °C overnight. Once hardened, a 1 mm thick transverse section was cut from each block, through the *primordia*, using a Struers Accutom-2 high speed saw. The thin section was ground and polished on one side and mounted (polished surface down) on a glass slide using quick setting epoxy resin (5-minute Araldite). The upper surface of each slide was ground on a Struers Planopol-2 grinder with a series of progressively finer carborundum papers (400, 800, and 1200 grit) to a thickness of about 350 μm (where increment clarity and resolution were optimal for this species). An aqueous suspension of alumina powder (Linde A) was used for the final polish.

Thin sections were read with a bright field stereomicroscope (x100). A pattern of hyaline (light) and opaque (dark) zones was evident. The number of complete opaque zones (i.e., opaque zones with hyaline material outside them) was counted to obtain an age estimate. Fish length and sex were always unknown to otolith readers.

Before ageing estimation, a sub-sample covering the total size range of fish was assessed to formulate a standardised reading procedure. Once the readers were confident with their interpretation of these otoliths, the entire sample was aged.

Counting growth rings in otoliths is subjective; different readers may produce different results for the same otolith. To assess "between-reader" variability, two readers independently read all otoliths. Both readers assigned each otolith a zone count, and used a readability value to indicate the degree of confidence they had in the zone count. The readability scale used was:

1 = zones very clear (the reader had a high level of confidence in their band count)

2 = zones relatively clear (the reader may be up to 1 band out)

3 = zones average in clarity (the reader may be up to 2 bands out)

4 = zones relatively unclear (the reader was not confident in band count, possibly more than 2 bands out)

5 = zones unreadable

When there was disagreement between the two reader's first age estimates, otoliths were re-examined jointly, using a microscope and image enhancing software. Consensus on the zone count was reached or the otolith was discarded from the analysis.

In young fish (under 6 years) the distance from the last visible opaque zone to the otolith edge was classed as either narrow, medium, or wide. This was based on the relative distance between the two outermost opaque zones. This variable was used in the conversion of zone counts to estimated ages.

Blue mackerel otoliths are small, thin, and curved distally. The purse-seine otolith collection had been used previously for whole otolith reading, and the otoliths were initially stored dry in paper envelopes. This resulted in many of the otoliths being broken, usually through the primordium. Broken otoliths were often difficult to interpret, particularly if fractured through the nuclear region from where the thin sections were taken. Interpretation was further hindered as the otoliths had been subsequently attached to moulded plastic trays using dichloroethane. This practice appeared to reduce the contrast between opaque and hyaline bands, especially towards the margins of the sections.

In finished preparations false checks were often evident. This made it difficult to determine 'annual' bands. This problem was minimal in fish older than age 6 because bands were more regular in the outer margins, enabling a clearer interpretation of the earlier years to be obtained.

To convert zone counts in otoliths to estimates of age it was necessary to know:

(i) when spawning occurs

(ii) when the formation of the opaque zone in the otolith is completed

(iii) when sampling was conducted

Blue mackerel have an annual reproductive cycle with a summer spawning season (Stevens et al. 1984; Stewart et al. 1999). By convention, a "birthday" of 1 January was used for all the fish examined in this study.

Using oxytetracycline markers, Stewart et al. (1999) have shown that opaque bands are formed annually during winter but do not become visible until spring or early summer. They noted that an association was present between the growth rate of the otolith and the detection of the opaque zone, with the zone becoming apparent earlier in faster growing fish. These relationships between growth rate and the probability of correctly assigning an age class have important implications for ageing blue mackerel, and so it was necessary to determine marginal width accurately. Stewartet al.'s findings were used as the basis of the conversion from zone counts to estimated ages.

The information on time of spawning, time of zone formation, and sampling time was used to obtain an estimated age from otolith zone counts. For example, an otolith sampledon 1 November, with a single opaque zone and a wide marginal hyaline zone would be allocated an age of 1 year and 10 months (1.8 years). The wide marginal hyaline zone indicated that the opaque zone formed in the second winter was not yet apparent. If the marginal hyaline zone was narrow or of medium thickness the otolith would have been attributed an age of 0.8 months.

Von Bertalanffy growth curves were fitted to the age-length data using a non-linear least-squares regression procedure (Ralston & Jennrich 1978). All otolith readings of sufficient quality were used in these estimates (purse-seine, archival and west coast North Island juveniles combined). Separate equations, and mean lengths at age were calculated for each sex and for males and females combined.

Estimates of instantaneous natural mortality (M) were calculated for both male and female fish using the method of Hoenig (1983). M was derived from the equation:

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

where

p = proportion of the population reaching age A (or older) in an unexploited stock (set at 0.01 for this study)

A = the maximum age reached by 1% of an unfished population (Sparre et al. 1989).

3.3.1 Ageing and growth results

Growth curve parameters are given in Table 4. Individual fish ages, mean length-at-age, and fitted von Bertalanffy curves are plotted in Figures 4–7. These estimates are based on all otolith data combined (purse-seine, archival, and west coast North Island juveniles).

Table 4: Von Bertalanffy growth parameters for blue mackerel (all otolith data combined)

	Males and (unsexed)	Females and (unsexed)	Combined
L_∞	48.77	51.11	50.02
K	0.25	0.21	0.23
T_0	-0.89	-1.06	-1.01
Age range	0.2–21.9	0.2–23.9	0.2–23.9
N	177 (77)	171 (77)	425

Male blue mackerel reached a maximum age of 21+ years. Females were aged to a maximum of 23+ years. Von Bertalanffy curves for male and female fish were very similar, with females having a marginally greater L_∞, and a correspondingly lower value for k. Male and female fish had rapid growth for the first 4–5 years, but growth was negligible after about 12 years. The otoliths aged suggest a value of A of about 21 years for males and 23 years for females, giving estimates for M of 0.22 and 0.20 respectively. These samples were not from virgin populations, so M may be overestimated.

3.4 Estimation of age structure of commercial catch

Shed sampling data was available from commercial catches taken in the Tauranga based purse-seine fishery. An age-length key was constructed from the otolith data (Appendix 2), and applied to the scaled length frequency distribution from the catch sampling (Figure 8), to provide an estimate of age structure for the fished blue mackerel population. The age structure of the fished population was composed mainly of fish 4–12 years old, with a tail of older fish up to 19 years in age (Figure 9). No fish less than 4 years old were caught for females, and less than 3 years old for males.

4. DISCUSSION

This report summarises the main data sources available for blue mackerel that might be suitable for use in a stock assessment model. However, neither of the two time series available (aerial sightings and purse-seine catch/effort) displayed any decline in abundance through time; many of the aerial sightings indices actually showed a statistically significant increase. In the absence of other auxiliary data, a lack of decline in these indices precludes their use in a stock reduction analysis.

The time series indices of relative abundance from aerial sightings data presented here indicated an increasing trend in the abundance of blue mackerel in east Northland and QMA 1, but a flat series in the Bay of Plenty. This is similar to the results of Bradford & Taylor (1995), who found an increase in median tonnage from the late 1980s to 1992, although the time series they used was not as long. It has been suggested that the large peak in the aerial sightings index for east Northland and QMA 1 in 1991 might be a result of a change in flying patterns in response to a low abundance of skipjack tuna (Tom Birdsall, Sanford Ltd, pers. comm.). This could provide useful insight into the cause of a markedly different year index data-point (that significantly affected many of the regression fits), but it was not within the scope of the present study to investigate this suggestion further. Removal of the 1991 point increased the significance of the regression by reducing the standard error of the fits, but also reduced the slopes.

The CPUE analysis did not contain any temporal trend. In addition, using catch effort data from the purse-seine fishery resulted in the violation of a number of conditions that should be met for use of such data. Not the least of these was that due to the visual targeting of schools using spotter planes, the gears may be effectively 'saturated' i.e., search time is minimal, while catch is maximal. Changes in availability of other target pelagic species (e.g., skipjack and kawahai) may also have strongly affect patterns of fishing, along with changes in what the market required in terms of demand and fish sizes. Such factors are ignored in the CPUE analysis, but may have had as great, or greater, an influence on catches as did actual fish abundance.

The ageing data presented in this report are the first for New Zealand blue mackerel stocks. Blue mackerel were found to grow rapidly in their first 4 to 5 years of life, with growth then slowing down. After age 12 growth was negligible. Estimates of growth for males and females were very similar. Comparison with work done for the same species in southeastern Australia (Stevens et al. 1984) found good agreement between the two studies. Fish from Australia were also fast growing for the first 5 to 6 years, with a slowing of growth beyond this point. Estimates of Von Bertalanffy growth parameters from the Australian study were L_{∞}, 44.1 cm; k, 0.24; t_0, -1.79 years, with fish being aged from 1 to 9 years old (c.f. 50.0, 0.23, -1.01, ages 0.2–23.9 for this study). These findings suggest that the growth rates of New Zealand and Australian fish are similar, but that New Zealand fish grow larger and live longer. However, it appears that the fish aged by Stevens et al. (1984) were collected by trawling (versus purse-seining in this study); differences in the vulnerability of different size/age classes to different catching methods cannot be discounted.

The relatively large negative value for t_0 in the present study might be explained by 1. all samples being collected with large mesh gears, resulting in a sampling bias towards larger individuals in any year class (over the range of incomplete retention by the gear), and a concurrent bias towards negative values of T_0, and/or 2. given a suspected broad summer spawning pattern, an inaccuracy in the assumed 1 January birth date for many fish. Neither potential effect can be quantified in the present study.

In conclusion, the available data is not sufficient for a formal stock assessment for this species. Other approaches will need to be developed to allow for a more quantitative approach to managing this fishery.

5. ACKNOWLEDGMENTS

We are grateful for the provision of the shed sampling data, with associated otolith collection, from Adam Langley, Tom Birdsall, and Martin deBeer, courtesy of Sanfords Ltd. Malcolm Francis provided invaluable comments on a draft. Thanks also to Karen Field for assistance with the CPUE analysis, and Bernadette McVey for extraction of the catch and effort data. Mike Beardsell provided appreciated editorial input. This project was finded through MFish project EMA9801.

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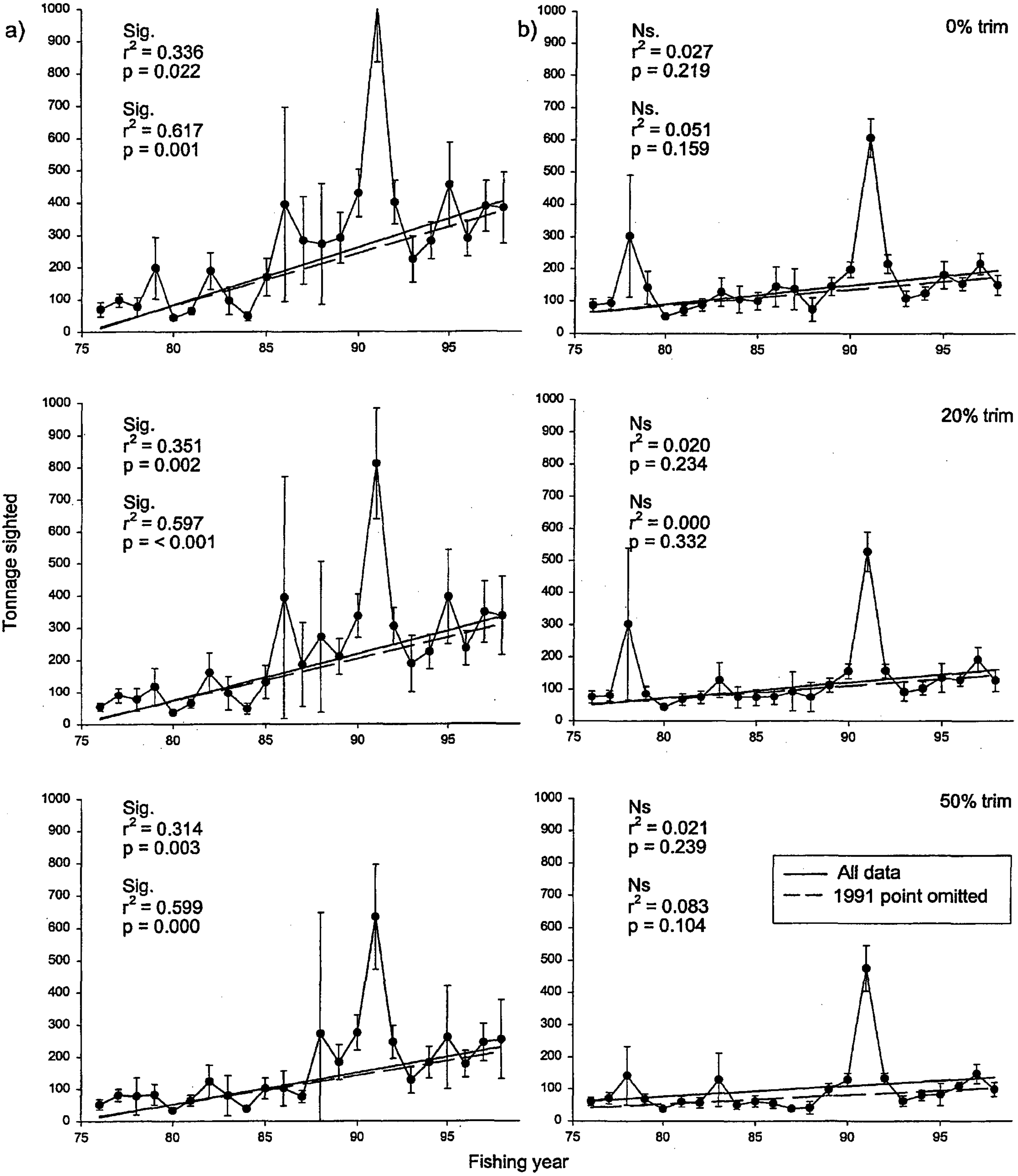

Figure 1: Mean annual tonnage indices sighted in east Northland per a) first 1 hour of flying time and, b) per hour for the first 2 hours of flying time. Error bars are 1 standard error. Trim values are 0, 20 and 50%. The significance level was set at 0.05. Regressions were calculated for all data, and with the 1991 data omitted. All regressions are shown (Sig, significant; Ns, not-significant); for each graph the upper values are for all data, the lower values for the data with the 1991 point excluded.

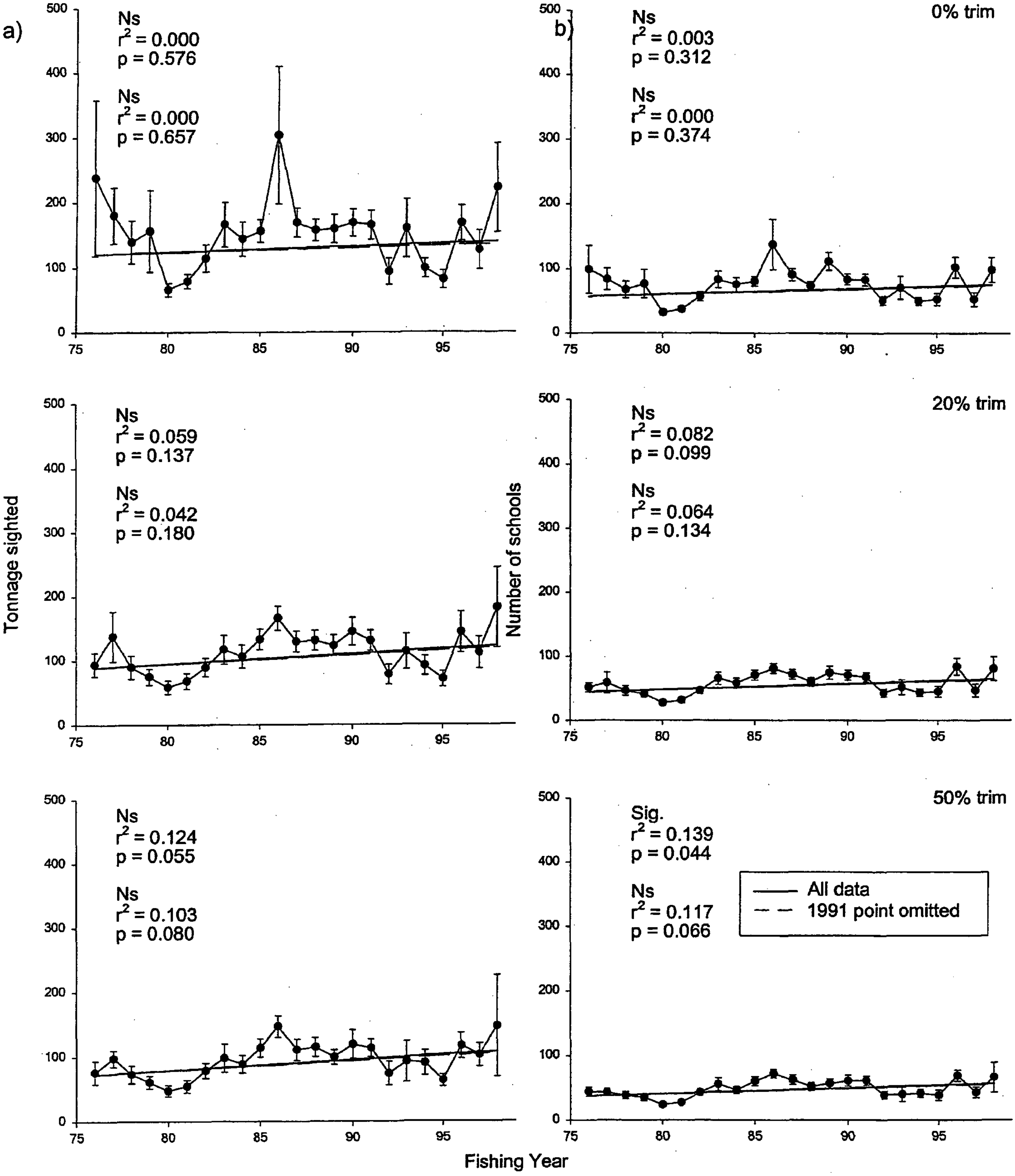

Figure 2: Mean annual tonnage indices sighted in Bay of Plenty per a) 1 hour of flying time and b) per 2 hours of flying time. Error bars are 1 standard error. Trim values are 0, 20, and 50%. The significance level was set at 0.05. Regressions were calculated for all data, and with the 1991 data omitted. All regressions are shown (Sig, significant; Ns, not significant); for each graph the upper values are for all data, the lower values for the data with the 1991 point ommited.

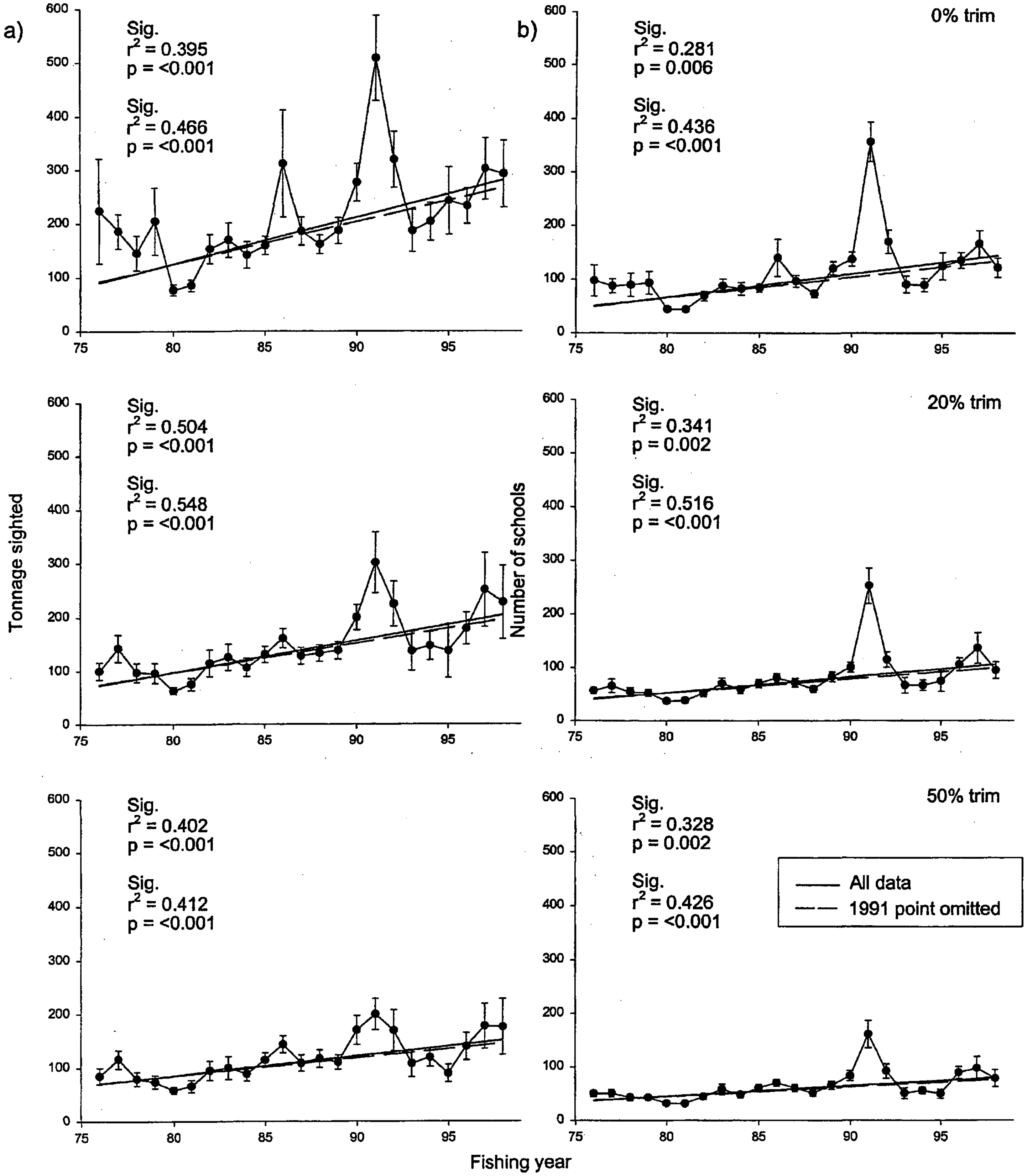

Figure 3: Mean annual tonnage indices sighted in QMA 1 per a) first 1 hour of flying time and b) per hour for the first 2 hours of flying time. Error bars are 1 standard error. Trim values are 0, 20, and 50%. The significance level was set at 0.05. Regressions were calculated for all data, and with the 1991 data omitted. All regressions are shown (Sig, significant; Ns, not significant); for each graph the upper values are for all data, the lower values for the data with the 1991 point excluded.

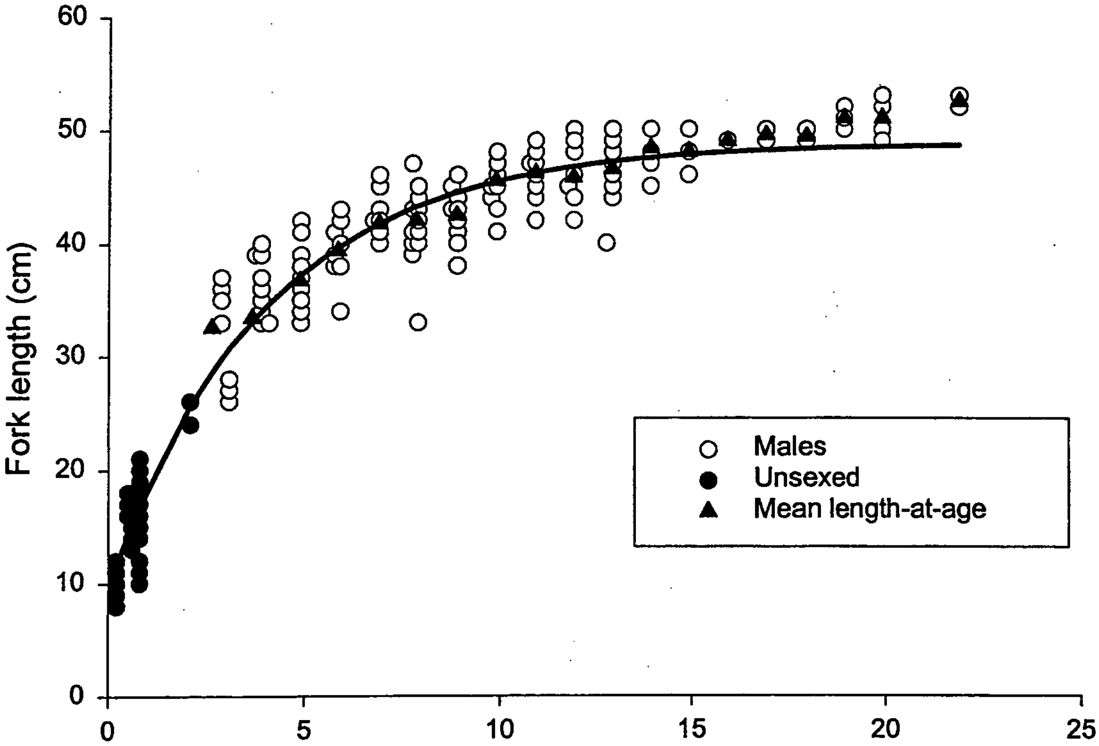

Figure 4: Individual age-length estimates, mean length-at-age, and von Bertalanffy curves for males and unsexed blue mackerel. All data from purse-seine, archival, and juvenile west coast North Island collections are included.

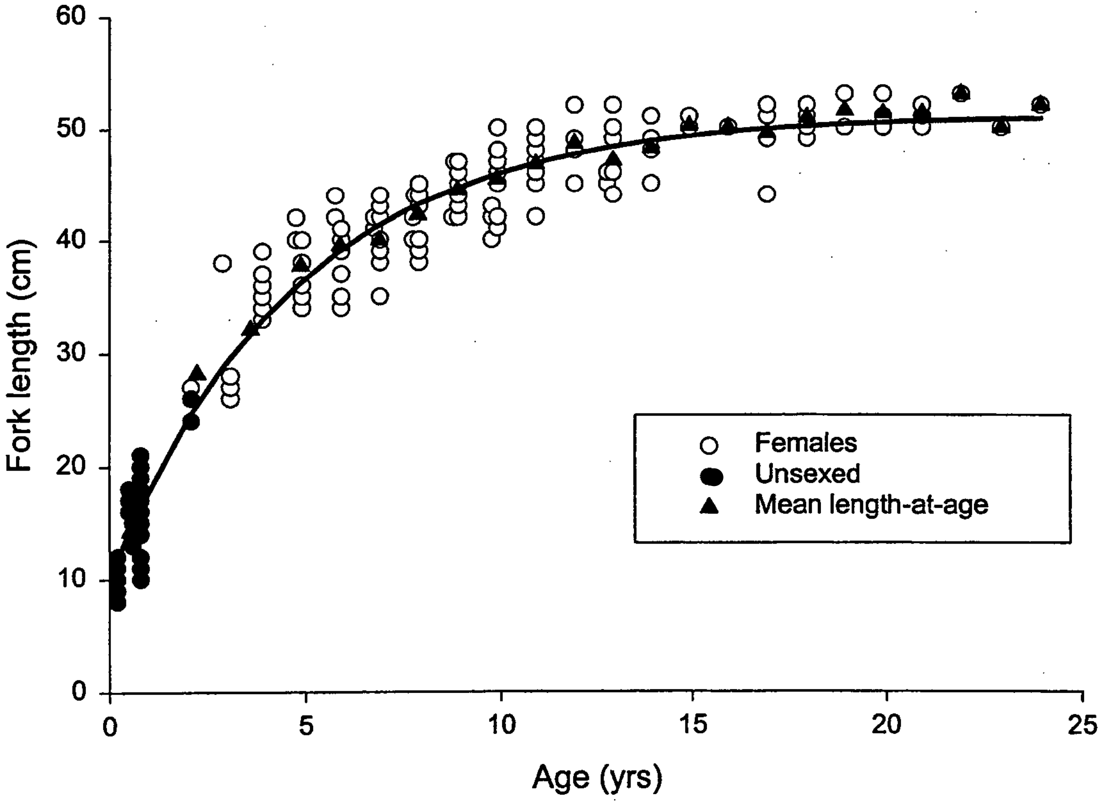

Figure 5: Individual age-length estimates, mean length-at-age, and von Bertalanffy curves for female and unsexed blue mackerel. All data from purse-seine, archival, and juvenile west coast North Island collections are included.

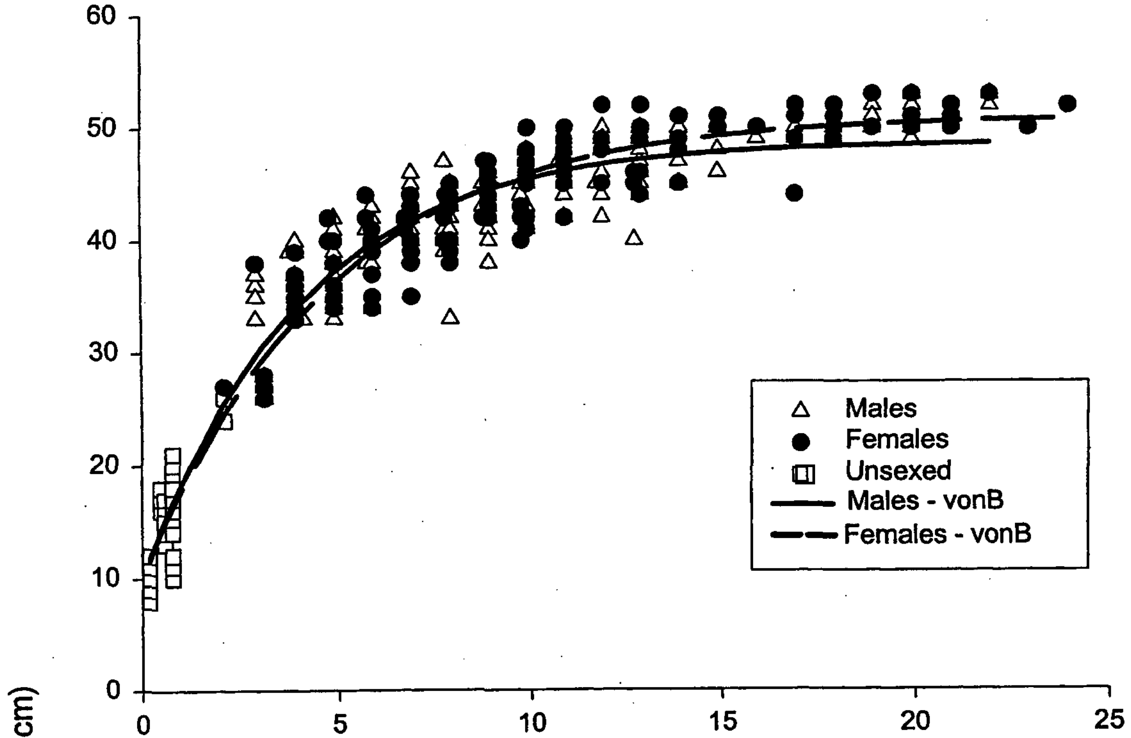

Figure 6: Individual age-length estimates, and von Bertalanffy curves for male, female and unsexed blue mackerel. All data from purse seine, archival, and juvenile west coast north island collections are included.

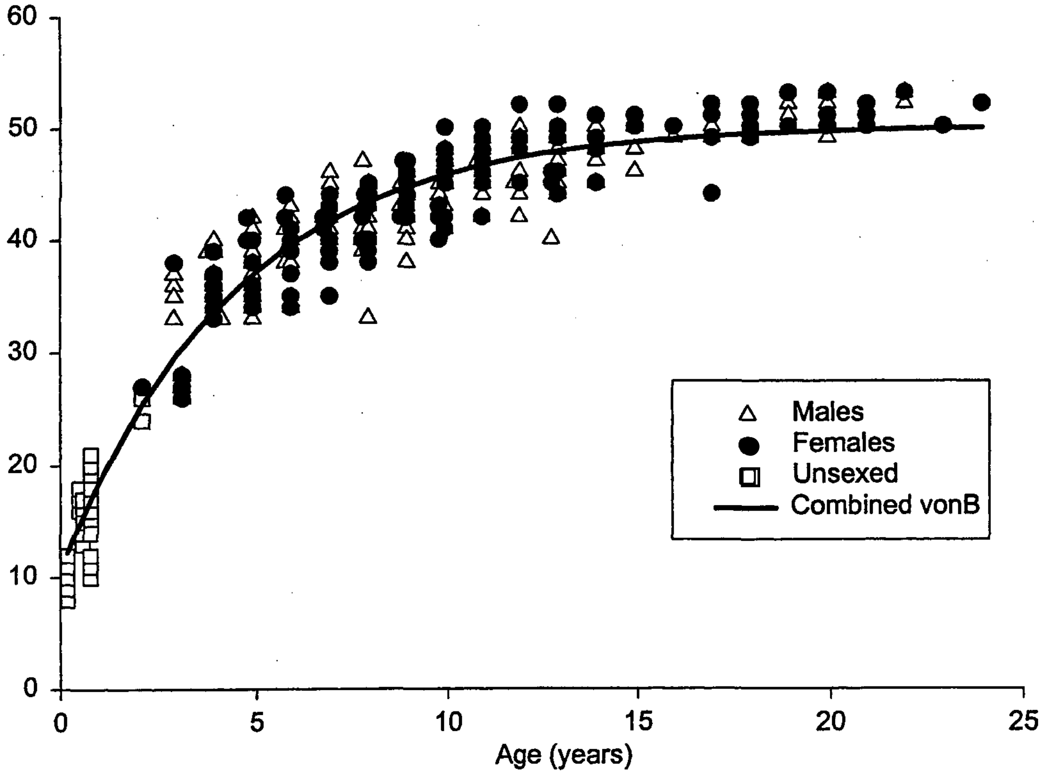

Figure 7: Individual age-length estimates, and von Bertalanffy curve for all fish combined. All data from purse-seine, archival, and juvenile west coast North Island collections are included.

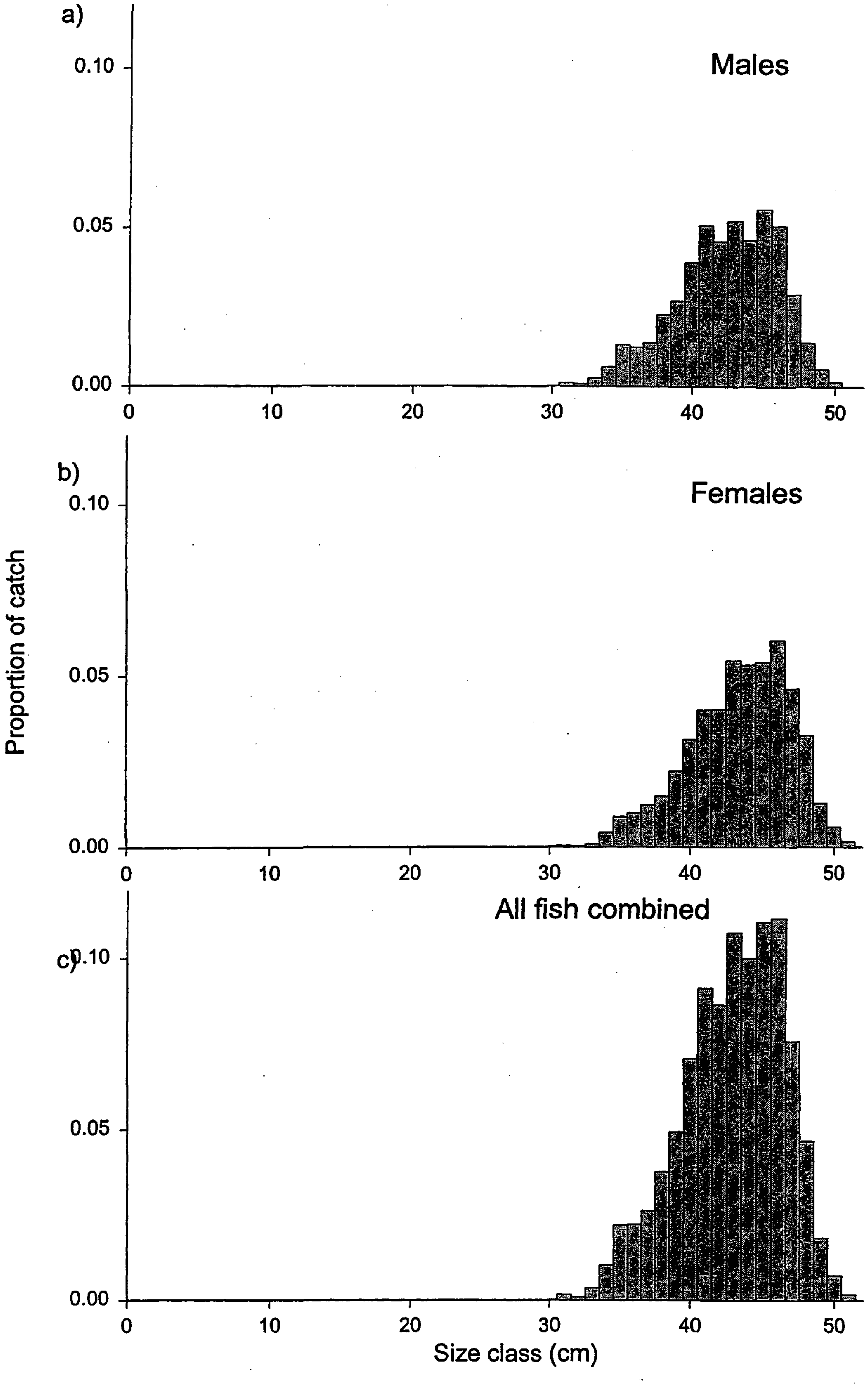

Figure 8: Scaled length frequencies for the commercial catch from purse-seine (from Sanfords Ltd catch sampling). a, proportion of males; b, proportion of females; c, total proportions, both sexes combined.

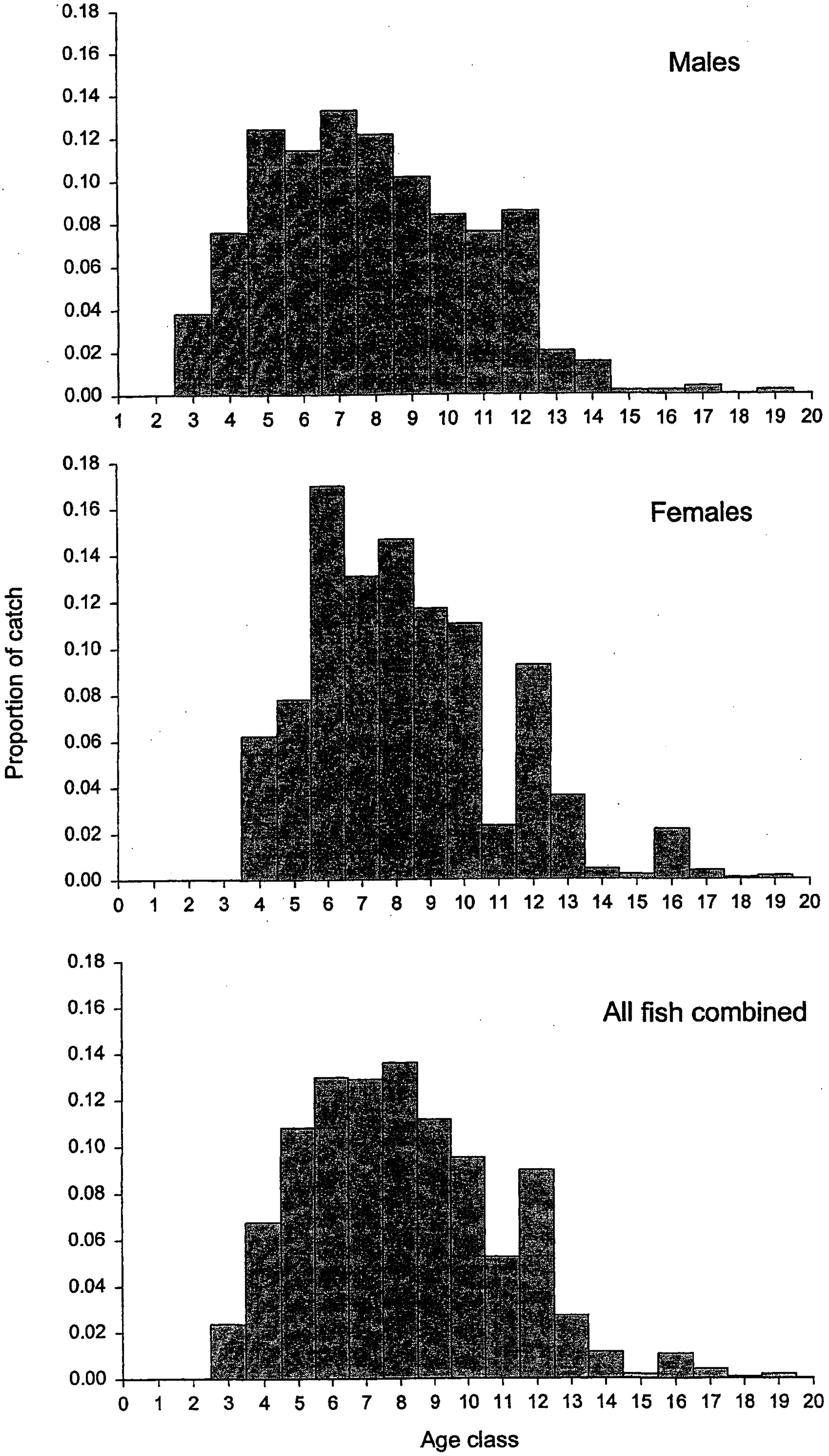

Figure 9: Age structure for the purse-seine fished population, for males, females, and all fish combined.

Appendix 1: Symmetrically trimmed means

The (α, β) trimmed mean (T) of x with distribution F is defined by

$$T_{\alpha,\beta}(F) = \int_{F^{-1}(\alpha)}^{F^{-1}(1-\beta)} \frac{x dF(x)}{1-\alpha-\beta} \qquad (1)$$

which is a descriptive measure of location provided that $\alpha = \beta$, when it is called the 2β trimmed mean, or the symmetrically trimmed mean (Staudte & Sheather 1990). Staudte & Sheather (1990) list four important properties of trimmed means.

1. They are robust to outliers, up to $100\beta\%$ on each side.
2. They have very strong nonparametric efficiency; namely, their asymptotic efficiency relative to the untrimmed mean never drops below $(1 - 2\beta)^2$.
3. They are simple to calculate, and their standard errors are easily estimated from the 2β-Winsorized[•] sample.
4. When the data are normally distributed, there is strong evidence that the distribution of the standardised trimmed mean has an approximate Student's t distribution with known degrees of freedom: hence robust confidence intervals of known coverage probability may be constructed for normal means, even when the sample is small.

The standard error is given by

$$\hat{\mathrm{SE}}[T_{2\beta}(F_n)] = \frac{1}{(1-2\beta)} \frac{s^2_{W_{2\beta}}}{\sqrt{n}} \qquad (2)$$

where $s^2_{W_{2\beta}}$ is the sample variance of the 2β Winsorised sample. That is, let $m = [n\beta]$, and define

$$Y_{(i)} = \begin{cases} X_{(m+1)}, i \le m \\ X_{(i)}, \quad m < i \le n-m \\ X_{(n-m)}, n-m < i \end{cases} \qquad (3)$$

Then the sample variance of the 2β trimmed mean is defined as

$$s^2_{W_{2\beta}} = \frac{1}{n-1} \sum_{i=1}^{n} (Y_i - \bar{Y})^2 . \qquad (4)$$

[•] The Winsorised sample is where each observation below the first quartile is replaced with the value of the first quartile, each observation above the third quartile is replaced with the value of the third quartile, and all other observations remain unchanged.

Appendix 2: Blue mackerel age-length key. Note that otoliths were read both from the purse-seine collection, and other unrelated sources

Males

Length (cm)																		Age class		No. aged
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
28	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
33	0.50	0.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
34	0.25	0.50	0.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
35	0.20	0.60	0.20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5
36	0.25	0.50	0.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
37	0.40	0.20	0.40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5
38	-	0.50	0.25	0.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
39	0.17	0.17	0.50	-	0.17	-	-	-	-		-	-	-	-	-	-	-	-	-	6
40	-	-	-	0.40	0.40	-	-	-	-	0.20	-	-	-	-	-	-	-	-	-	5
41	-	-	0.13	0.38	0.13	0.25	0.13	-	-	-	-	-	-	-	-	-	-	-	-	8
42	-	-	0.38	0.13	0.13	0.13	-	0.13	0.13	-	-	-	-	-	-	-	-	-	-	8
43	-	-	0.10	0.10	0.30	0.50	-	-	-	-	-	-	-	-	-	-	-	-	-	10
44	-	-	-	-	0.20	0.10	0.20	0.10	0.30	0.10	-	-	-	-	-	-	-	-	-	10
45	-	-	-	*0.08*	*0.08*	*0.08*	*0.17*	*0.25*	*0.08*	*0.17*	*0.08*	-	-	-	-	-	-	-	-	*12*
46	-	-	-	-	-	0.11	0.33	0.11	0.22	0.11	-	0.11	-	-	-	-	-	-	-	9
47	-	-	-	-	0.11	-	0.22	0.22	-	0.33	0.11	-	-	-	-	-	-	-	-	9
48	-	-	-	-	-	-	0.11	0.33	0.11	0.22	0.11	0.11	-	-	-	-	-	-	-	9
49	-	-	-	-	-	-	-	-	-	0.29	-	-	0.14	0.14	0.29		0.14	-	-	7
50	-	-	-	-	-	-	-	-	0.10	0.10	0.30	0.10	-	0.10	0.10	0.10	0.10	-	-	10
52	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.33	0.33	-	0.33	3
53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.50	-	0.50	2
Total																				133

Females

Length (cm)																					Age class		No. Aged
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
27	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
33	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
34	-	-	0.75	0.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
35	-	-	0.4	0.4	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5
36	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
38	0.25	-	0.25	-	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
39		-	0.14	0.29	0.57	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7
40		-	0.2	0.4	-	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5
41		-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
42		-	-	0.2	0.3	-	0.2	0.2	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	10
43		-	-	-	0.17	0.5	0.33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
44		-	-	0.13	-	0.25	0.25	-	-	-	0.25	-	-	-	0.13		-	-	-	-	-	-	8
45		-	-	-	-	0.2	0.1	0.2	0.2	0.1	0.1	0.1	-	-	-	-	-	-	-	-	-	-	10
46		-	-	-	-	-	0.25	0.13	0.25	-	0.38	-	-	-	-	-	-	-	-	-	-	-	8
47		-	-	-	-	-	0.25	0.5	0.25	-	-	-	-	-	-	-	-	-	-	-	-	-	8
48		-	-	-	-	-	-	0.22	0.33	0.11	-	0.33	-	-	-	-	-	-	-	-	-	-	9
49		-	-	-	-	-	-	-	0.09	0.18	0.27	0.09	-	-	0.27	0.09	-	-	-	-	-	-	11
50		-	-	-	-	-	-	0.06	0.06	-	0.06	-	0.35	0.18	-	0.06	0.06	0.06	0.06	-	0.06	-	17
51		-	-	-	-	-	-	-	-	-	-	0.1	0.1	-	0.3	0.2	-	0.2	0.1	-	-	-	10
52		-	-	-	-	-	-	-	-	*0.09*	*0.09*	-	-	-	*0.09*	*0.27*	-	-	*0.18*	-	-	*0.27*	*11*
53		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.25	0.25	-	0.5	-	-	4
Total																							142

Appendix 2: continued

All fish

Length (cm)	Age class																								No. aged
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
8	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
9	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
10	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
11	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7
12	0.33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
13	-	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
14	-	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7
15	-	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
16	-	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
17	-	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
18	-	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
19	-	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4
20	-	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
21	-	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
24	-	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
26	-	-	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
27	-	-	0.50	0.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
28	-	-	-	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
33	-	-	-	0.33	0.67	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
34	-	-	-	0.13	0.63	0.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
35	-	-	-	0.10	0.50	0.30	0.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
36	-	-	-	0.20	0.60	0.20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5
37	-	-	-	0.40	0.20	0.40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5
38	-	-	0.13	-	0.38	0.13	0.38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8
39	-	-	-	0.08	0.15	0.38	0.31	0.08		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13
40	-	-	-	-	0.10	0.20	0.20	0.40	-	-	-	-	0.10	-	-	-	-	-	-	-	-	-	-	-	10
41	-	-	-	-	-	0.10	0.50	0.10	0.20	0.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10
42	-	-	-	-	-	0.28	0.22	0.06	0.17	0.11	0.11	0.06	-		-	-	-	-	-	-	-	-	-	-	18
43	-	-	-	-	-	0.06	0.13	0.38	0.44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16
44	-	-	-	-	-	0.06		0.22	0.17	0.11	0.06	0.17	0.17	-	-	-	0.06	-	-	-	-	-	-	-	18
45	-	-	-	-	-	-	-	0.14	0.09	0.18	0.23	0.09	0.14	0.09	-	-	-	-	-	-	-	-	-	-	22
46	-	-	-	-	-	-	-		0.18	0.24	0.18	0.12	0.24	-	0.06	-	-	-	-	-	-	-	-	-	17
47	-	-	-	-	-	-	-	0.06	0.12	0.35	0.24	-	0.18	0.06	-	-	-	-	-	-	-	-	-	-	17
48	-	-	-	-	-	-	-	-	-	0.17	0.33	0.11	0.11	0.22	0.06	-	-	-	-	-	-	-	-	-	18
49	-	-	-	-	-	-	-	-	-	-	0.06	0.11	0.28	0.06	-	0.06	0.22	0.17	-	0.06	-	-	-	-	18
50	-	-	-	-	-	-	-	-	-	-	-	-	0.07	0.11	0.26	0.11	-	0.07	0.07	0.07	-	-	-	-	27
51	-	-	-	-	-	-	-	-	-	-	-	-	-	0.10	0.10	-	0.30	0.20	-	0.20	0.10	-	-	-	10
52	-	-	-	-	-	-	-	-	-	-	-	0.07	0.07	-	-	-	0.07	0.21	0.07	0.07	0.14	0.07	-	0.21	14
53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.17	0.33	-	0.50	-	-	6
Total																									347