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EXECUTIVE SUMMARY

Hanchet, S. M.; Francis, M. P.; Horn, P. L. (2001). Age and growth of John dory (*Zeus faber*). ***New Zealand Fisheries Assessment Report 2001/10.*** **25 p.**

The aim of the current work was to describe and validate age and growth of John dory using zone counts and marginal increment analysis of whole otoliths, and analysis of length frequency data using MULTIFAN.

Otoliths were difficult to interpret, but patterns of opaque and translucent bands were generally visible. Fish were aged by counting the number of opaque bands, and validation of this ageing method was achieved by showing that one translucent band was formed annually. Von Bertalanffy growth curve parameters were calculated, separately by sex, for fish sampled in QMA 1, and were found to fit the raw data well. Validation by following strong year classes between years was inconclusive, probably because the otoliths available came from surveys of different areas.

The length frequency analysis (MULTIFAN) gave similar interpretations of the early age and growth of John dory. Both methods suggest that fish grow rapidly to about 20 cm by age 1 and about 30 cm by age 2. This interpretation is borne out by examination of the length-frequency data, which show the clear progression of the first two length modes, and the intervening "gap" over time. After age 2 the growth curves for the two sexes began to diverge. Male growth slowed down considerably after age 2 and fish reached a maximum age of 9 and an estimated L_∞ of about 40 cm. Females grew slightly larger than males, reaching an estimated L_∞ of about 46 cm and a maximum age of 9.

The calculated growth curves were comparable to those reported for Hauraki Gulf fish, but differed markedly from those for John dory from Australia. We believe that these differences arose from different methods of otolith interpretation, rather than real differences in growth.

Using a maximum age of 9 years, and assuming that in an unexploited population 1% of the John dory would reach that age, the instantaneous natural mortality (*M*) is estimated to be 0.51. However the population we sampled has been moderately exploited for a long time, and the proportion reaching 9 years may be closer to 5%, suggesting an *M* of 0.33. Uncertainties about the degree of exploitation, and the true maximum age of John dory, make it impossible to estimate *M* precisely; the most plausible range is 0.35–0.5. It is recommended that population models applied previously to John dory stocks be re-run using this new range of *M*.

1. INTRODUCTION

John dory are an important inshore commercial species with annual landings of 800–900 t over the past decade (Annala et al. 2000). Although it is a cosmopolitan species, little has been published on its age, and there are no validated ageing studies. Hore (1982) read a large sample of whole otoliths from fish collected throughout the year from the Hauraki Gulf. He noted the presence of a number of false rings or checks which made the interpretation of the otoliths difficult. He was able to validate the first ring by following the progression of the first mode in the length frequency data. He considered that the older ages were validated using marginal increment analysis. However, the marginal increment analysis was far from conclusive and individual samples had very wide error bars, confirming his observations that ageing was difficult. Smith & Stewart (1994) aged John dory from Australia using whole otoliths. They considered that small John dory were difficult to age due to the large number of fine increments, but that the increment pattern was clearer in larger fish. They estimated a maximum age of 12 years. Other studies have estimated growth curves for northern hemisphere populations of John dory from length frequency data using ELEFAN or MULTIFAN (Righini & Voliani 1996, A. Silva, IPIMAR, Portugal, pers. comm.).

A Ministry of Fisheries research project (INS9701) was initiated in 1997 to determine age and growth of John dory (Objective 4) and to model the John dory stocks (JDO 1 and 2) around the North Island (Objective 1). Results of the preliminary ageing work were reported by Hanchet & Francis (1998). Ageing of John dory was attempted using whole otoliths, otolith thin sections, spine sections, otolith weights, and length frequency analysis (using MULTIFAN). Determination of ages from the otoliths and spines was difficult because of the many fine increments present and the lack of distinct winter checks (particularly in the younger fish). Repeatability between readers and methods was poor and depended on the subjective grouping of the finer increments. Different ageing methods gave different interpretations of the growth rates and longevity of John dory. Otolith thin sections suggested a slow growth rate, with fish taking 8 years to reach 30 cm, and a maximum age of 16 years. In contrast, the MULTIFAN analysis suggested that John dory had an extremely fast early growth rate, reaching 20–25 cm total length after 1 year and 35–40 cm after 2 years, and attained a maximum age of 5 years. However, there was some concern over the results of the analysis because the length frequency data had been combined from all areas and years and both sexes, so this analysis was regarded as preliminary. Lengths at age based on modes in otolith weight data for younger fish agreed with those from the length frequency data, and when extrapolated suggested a maximum age of 8 years. Hanchet & Francis (1998) considered that the maximum age probably lay somewhere between 5 and 10 years.

The results of the modelling were reported by Horn et al. (1999). Essential requirements for modelling are knowledge of the growth of the species, and longevity (in particular for estimating natural mortality, M). Horn et al. (1999) assumed maximum ages of either 4 or 8 (with corresponding M estimates of 1.15 and 0.57, respectively), but the model results were sensitive to the value used, and they recommended that a study be carried out to validate age and growth of older John dory, and to estimate the maximum age.

The current report stems from an objective carried out under contract to MFish: "To develop a validated ageing methodology for John dory (MOF804G)". This involved three steps:
(i) collection of monthly samples of otoliths from the commercial fishery to analyse the seasonal changes in otolith margins;
(ii) analysis of length frequency data from the research database to validate early growth;
(iii) comparison of age frequency distributions from the 1997 and 1999 Hauraki Gulf trawl surveys to follow strong year classes.

2. METHODS

2.1 Otoliths

Otoliths (sagittae) of John dory were collected regularly over a 12-month period from commercial landings taken in QMA 1 (Table 1). Initially we had intended to collect samples from the west coast North Island fishery in QMA 9. However, it became apparent that a comprehensive set of samples would be more reliably collected from QMA 1. Total length (TL, rounded to the nearest centimetre below actual length) and sex were recorded for all fish from which otoliths were taken. Wherever possible, otoliths were selected to obtain at least 50 per sample from a wide size range of fish. Otoliths from two research trawl surveys conducted in the Hauraki Gulf (October–November 1997, voyage KAH9720) and the Bay of Plenty (February 1999, voyage KAH9902) were also examined.

All selected otoliths were examined whole and untreated. They were immersed in water, on a black background, illuminated by reflected light, and examined under a binocular microscope (x40). A pattern of dark (translucent) and white (opaque) zones was generally apparent on the dorsal lobe of each otolith. Subsequently in this paper, 'zone' refers to the paired structure of one opaque band inside one translucent band. The number of complete zones (i.e., zones with at least some translucent material outside them) was counted. Measurements from the nucleus to the most distant section of the first, second, and third opaque bands were recorded for some otoliths. Fish length and sex were unknown to the otolith reader.

To convert zone counts to estimates of age, it was necessary to validate the ageing method by determining when and how frequently the zones were laid down. To examine changes in otolith margin characteristics throughout the year, margins of otoliths from the validation samples in Table 1 were classified as either translucent or opaque, and the number of complete zones was counted. The month of collection was unknown to the otolith reader.

John dory probably spawn in the Hauraki Gulf from about December to April (Hore 1982), so a theoretical 'birthday' of 1 January was chosen. Von Bertalanffy growth curves were fitted to all the available age-length data from QMA 1 (east Northland, Hauraki Gulf, Bay of Plenty), using a non-linear least-squares regression procedure (SAS Institute 1988). Separate equations were derived for each sex.

The rate of instantaneous natural mortality (M) was estimated using the equation $M = -\log_e(p)/A$ where p is the proportion of the population that reaches A or older (Hoenig 1983). p values of 0.01 and 0.05 were used here.

Estimated age-frequency distributions from the two trawl surveys were inspected for progression between years of any particularly strong or weak year classes. Although both surveys were conducted in QMA 1, they were in different localities at different times of the year, i.e., Hauraki Gulf in October–November 1997, and Bay of Plenty in February 1999. For each survey, a length-frequency distribution (scaled to represent the population in the survey area) was constructed, and applied to an age-length key derived from the otolith data, to produce an age-frequency distribution.

2.2 Length-frequency analysis

John dory length-frequency distributions by sex were extracted from the MFish research trawl database for the following regions:

- All New Zealand (All NZ)
- Northeast coast North Island (NENI)
- West coast North Island (WCNI)

The All NZ data set comprised sexed length-frequency data from all trawl surveys on the research trawl database, grouped by month. Small 0+ John dory were not sexed in the March and April samples. For analysis, we added these fish to the length-frequency distributions of both males and females. Monthly data subsets containing fewer than 31 measured fish of a given sex were removed, leaving 9 monthly male samples and 8 monthly female samples (Appendices 1–2).

The NENI data set consisted of length-frequencies obtained from the following *Kaharoa* trawl surveys (Appendices 3–4):

- seven surveys of Hauraki Gulf in October–November between 1986 and 1997
- five surveys of Bay of Plenty in February–March between 1983 and 1999
- one survey of both Hauraki Gulf and Bay of Plenty in May–June 1987

Data from a number of other surveys, including all *Ikatere* surveys, were not used because John dory were not sexed. Length-frequencies from the Hauraki Gulf and Bay of Plenty were grouped together to provide seasonal contrast, as analysis of the All NZ data set revealed strong seasonal growth patterns. Length-frequency distributions of John dory in the Hauraki Gulf and Bay of Plenty were similar in the only survey that sampled both regions (Figure 1).

The WCNI data set consisted of length-frequencies obtained from seven *Kaharoa* trawl surveys of the west coast North Island in October–December between 1986 and 1996 (Appendices 5–6).

Von Bertalanffy growth curves were fitted to the length-frequency data sets using the MULTIFAN model (Fournier et al. 1990). MULTIFAN simultaneously analyses multiple length-frequency samples using a maximum likelihood method to estimate the proportions of fish in each age class, and the von Bertalanffy growth parameters. The main assumptions of the MULTIFAN model are:

- the lengths of the fish in each age class are normally distributed around their mean length;
- the mean lengths-at-age lie on or near a von Bertalanffy growth curve;
- the standard deviations of the actual lengths about the mean length-at-age are a simple function of the mean length-at-age (Fournier et al. 1990).

The von Bertalanffy parameters were estimated by conducting a systematic search across a matrix of plausible K values and age classes. Constraints were placed on the mean lengths of some age classes with distinct modal peaks to prevent MULTIFAN searching outside the realistic parameter range. Four separate models, based on different growth hypotheses, were fitted to each data set. The four models respectively had:

- constant length standard deviation for all age classes;
- variable length standard deviation for the different age classes;
- constant length standard deviation plus seasonal growth;
- variable length standard deviation plus seasonal growth.

The seasonal form of the von Bertalanffy equation is:

$$L_t = L_\infty(1 - e^{-K(t - t_0 + (\frac{\phi_1}{2\pi}\sin(2\pi((\frac{12t+1}{12}) - \phi_2))))})$$

where L_t is the length at time t, L_∞ is the maximum theoretical length, K is the von Bertalanffy growth constant, t_0 is the theoretical age at which length is zero, and ϕ_1 and ϕ_2 describe the amplitude and phase of the seasonal component, respectively. 0+ recruits first appeared in the trawl samples in March, and the theoretical birth date was defined as 1 January. The time of maximum growth is $12\phi_2 - 1$ months after 1 January.

The best fitting model for each data set was determined using likelihood ratio tests. Twice the increase in the maximum log-likelihood is distributed as a χ^2 distribution with degrees of freedom equal to the number of additional parameters. Tests among models were carried out with a significance level of 0.05. Following Fournier et al. (1990), a significance level of 0.10 was used for testing whether there was any gain in introducing an additional age class into the analyses.

3. RESULTS

3.1 Otoliths

3.1.1 Otolith interpretation

Otoliths of John dory are small, with three distinct lobes (two smaller ventral lobes and a larger dorsal lobe). Zonation patterns in the otoliths were often difficult to interpret. Zone counts were taken along the dorsal lobe, but increments were often apparent on the ventral lobes, and these were sometimes used to help interpret unclear patterns on the dorsal lobe.

The first translucent zone was often less distinct, and more diffuse, than the second, or subsequent translucent bands. Also, the first and second opaque bands often contained numerous fine increments. As the fish grew, and the otolith thickened, these fine increments became less apparent, as did the first translucent band. When the positions of the first and second translucent bands were uncertain (owing either to otolith thickening or to a profusion of fine increments), the mean radial measurements (Table 2) were used to try to determine their likely positions.

3.1.2 Marginal state

It was generally possible to determine whether an otolith margin was translucent or opaque, although some interpretations (particularly for some older fish) were difficult or impossible because of the narrowness of the margin, the indistinct nature of the zonation pattern, or the refractive effects of very thin edges. Percentages of otoliths with translucent margins are shown in Figure 2. Based on data from all age classes combined, it is apparent that translucent material is initially laid down about June, that most otoliths have a translucent margin throughout winter, and that most fish are laying down opaque material by November-December. This pattern is less clear when data are examined by age class, but a trend of a maximum proportion of translucent margins in winter, and a minimum proportion in summer, is still apparent. For older fish (i.e., those with five or more complete zones), the proportion of otoliths with translucent margins seldom drops below 50%, emphasising the marginal classification difficulties for this group. Overall, the data support the hypothesis that one opaque band and one translucent band (i.e., one complete zone) are laid down annually in the otoliths of John dory.

As the opaque part of a zone appears to be complete by early winter (1 June), fish are about 0.5 year old on completion of the first opaque band. Hence, the age of the fish was taken as the number of complete zones, less 0.5 year, plus a correction for the time elapsed between 1 June and the date of sampling.

3.1.3 Growth parameters

Von Bertalanffy growth curve parameters (with asymptotic 95% confidence intervals) calculated from all otolith readings of fish from QMA 1 (northeast North Island), separately by sex, are given in Table 3, and raw data are plotted in Figure 3. Time of sampling, and hence, part-year growth, is incorporated in this analysis. The calculated von Bertalanffy growth curve fits the otolith data well.

Female John dory grow significantly faster and reach a larger size than males. Both sexes had a maximum observed age of 9 years.

3.1.4 Comparison of year class strength from trawl surveys

Estimated numbers-at-age distributions from the two trawl surveys are presented in Table 4. The surveys were separated by 15 months. The Hauraki Gulf survey was 2 months before the John dory birthday, and the Bay of Plenty survey was just after it. The ages in Table 4 have been rounded to the nearest whole year, so fish classified as age 1 are actually 0.83 years old from Hauraki Gulf and 1.12 years old from Bay of Plenty. This has the effect of adjusting the surveys so they can be compared as if 1 year apart.

The Hauraki Gulf data appear relatively unreliable based on the high coefficients of variation (c.v.s) for most year classes. The number of aged fish is low, and a few changes in the ageing data could markedly change the calculated distribution, e.g., the age 6 males are represented by only three fish. Year class strengths are not consistent between sexes. The Bay of Plenty data appear more reliable; all age classes from 1 to 5 have c.v.s less than 0.4, and the mean weighted c.v. over all age classes is about 31%. Year class strengths are relatively consistent between sexes.

There are no clear progressions of strong or weak year classes between the two samples. The age 2 fish from the Bay of Plenty survey (spawned early 1997) appear to be a weak year class, but the same year class in the Hauraki Gulf survey (age 1) is not weak.

3.2 Length frequency analysis

Raw length frequency data from all trawl surveys (including all areas and years) are summed by sex in Figure 4. Fish are first caught in the surveys at about 10 cm in March. They reach a modal length of about 15 cm by September, and about 20 cm by December, when they are almost 1 year old. The mode can be followed through to about April after which it starts to merge with the main adult mode. Confirmation that this is a single year class is provided by the movement of the "hole" in the size distribution from about 15–20 cm in March to about 27 cm in September and to 32 cm in February. There were no systematic differences in the length of the first mode for males and females. For John dory over about 35 cm, females tended to be larger than males, and reached a greater maximum length (53 cm males and 60 cm females).

Parameter estimates and the number of distinguishable age classes determined from the MULTIFAN best-fit growth model are shown in Table 5. More age classes were distinguished using the All NZ data set than the NENI and WCNI data sets. This is attributable to the larger sample sizes and better seasonal coverage of the All NZ data. More age classes were distinguished for females than males.

Strong seasonal variation in growth was apparent for the All NZ and NENI data sets (Table 5, Figure 5). For WCNI, seasonal growth parameters did not significantly improve the fit; this was a result of the lack of seasonal contrast in the data set (all samples were collected in October–December) rather than a lack of seasonal variation in growth. The seasonal phase parameter was 0.26–0.34 (Table 5), indicating that maximum growth rates occurred around March.

The MULTIFAN growth curves were very similar for all three male data sets (Table 5, Figure 5). For females, growth appeared to be slightly faster in NENI than WCNI, though the differences may have been caused by the smaller sample sizes and lack of seasonal contrast in the WCNI data. Because of the minimal regional variation, the best estimates of growth for John dory are probably those obtained from the All NZ data, which comprise large samples collected in most months of the year.

In the All NZ data sets, male and female lengths were essentially identical over the age range 6 months to 2 years (length range about 20–35 cm), with male growth almost ceasing beyond 2 years (Figure 5). Divergence of the male and female curves at ages less than 6 months reflects the paucity of sexed 0+ fish in the January–September samples (see Figure 4).

3.3 Natural mortality

Using a maximum age of 9 years, and assuming that in an unexploited population 1% of the John dory would reach that age, the instantaneous natural mortality (*M*) is estimated to be 0.51. However, the population we sampled has been moderately exploited for a long time, and the proportion reaching 9 years may be closer to 5% (Annala et al. 2000), suggesting an *M* of 0.33. Uncertainties about the degree of exploitation, and the true maximum age of John dory, make it impossible to estimate *M* precisely, but the most plausible range is 0.35–0.5.

4. DISCUSSION

We consider that John dory otoliths are generally difficult to read, in line with the observations of other authors (Hore 1982, Stewart & Smith 1994, Hanchet & Francis 1998). This is because of the large number of fine increments present in the younger fish, and, at times, the difficulty in identifying the first few translucent bands in the older fish. However, the otoliths generally exhibited a pattern of zones each comprising one opaque and one translucent band, and the fish were aged from counts of the number of complete zones. Validation of this ageing method was achieved in general by showing that, for all fish combined, one translucent band was formed annually. It was not possible to validate the method for every year class individually because of insufficient sample sizes. Possible validation by following strong year classes between years was inconclusive, possibly because the otoliths available came from different geographic areas.

The two ageing methods used in this paper gave similar interpretations of the early age and growth of John dory (Figure 6). Both methods suggest that fish have a fast early growth rate, reaching about 20 cm by age 1 and about 30 cm by age 2. This interpretation is borne out by examination of the length-frequency data, which show the clear progression of the first two length modes, and the intervening "gap" throughout the year (see Figure 4). However, after age 2 the growth curves for the two sexes and methods diverge. Both methods suggest that male growth slows considerably after age 2, and produced similar L_∞ estimates of about 40 cm. However, the maximum age was 6 years from MULTIFAN but 9 years from the otoliths. Both methods suggest females grew larger than males after age 2, but resulted in different L_∞ estimates of 46 cm using otoliths and 55 cm using MULTIFAN.

MULTIFAN tends to underestimate the number of age classes present in data sets that have a unimodal grouping of multiple age classes of older fish, and overestimate the length-at-age of the older age classes (Francis & Francis 1992). This probably explains the large difference in maximum age between the two methods, and also the difference in the growth curves between the males. The reason for the large difference in female L_∞ between the two methods is more difficult to explain. The larger L_∞ in the MULTIFAN curve appears to be due to the presence of larger fish in March and April (Appendix 1), which would have increased the mean length of the largest age class for that run. The April samples were collected mainly from the east coast North Island and west coast South Island, and the larger fish recorded here may be due to area-specific differences in growth and maximum lengths. The L_∞ for females for the NENI data set was 49 cm, which is closer to the 46 cm obtained from the otolith ageing (Table 5). Thus the best growth curves for John dory are those based on length at age data, as described by the parameters in Table 3 (current study).

The growth curves and maximum ages determined in the current study are similar to those reported by Hore (1982) for Hauraki Gulf fish (see Table 3 and Figure 3). However, the New Zealand growth curves differ markedly from that presented by Smith & Stewart (1994) for John dory from Australia. In particular, the Australian interpretation has the fish growing at a relatively slow rate over their entire life, rather than having an initial period of very rapid growth. It is believed that the differences between studies are likely to be caused by different methods of otolith interpretation, rather than real differences in growth rates. This comparison serves to highlight the difficulties present in accurately ageing this species.

The age-frequency distributions for the two trawl surveys indicate that a sample of about 250 otoliths is probably necessary to obtain estimates of numbers-at-age with sufficient precision, i.e., a mean weighted c.v. over all age classes of less than 30%. The apparent difference between surveys in the strength of the 1997 year class raises the question of possible stock differences between the Hauraki Gulf and the Bay of Plenty. However, because of the differences in timing of the surveys, and the low precision of the derived age-frequency distributions, any such conclusion would be very tentative.

Horn et al. (1999) applied population models to four John dory stocks in QMAs 1, 2, 8, and 9. The models used M estimates of 1.15 and 0.57, based on assumed maximum ages of 4 and 8 years respectively, and an assumption that the stocks had not been heavily exploited (i.e., $p = 0.01$). The present study shows that John dory live to at least 9 years. Furthermore, some John dory stocks may have been moderately exploited. A more plausible range of M is therefore 0.35–0.5. Because Horn et al.'s population models were sensitive to the value of M used, we recommend they are re-run using this new range of M.

5. ACKNOWLEDGMENTS

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Table 1: Details of otolith samples examined to determine marginal state, and to provide data to calculate growth parameters. Sources: TS, trawl survey; MS, market sampling. *n*, sample size of marginal state data; *N*, number of successfully aged fish.

Date	Area	Source	*n*	*N*
26 Mar 1999	East Northland	MS	44	45
5 May 1999	Hauraki Gulf	MS	37	38
3 Jun 1999	Bay of Plenty	MS	45	50
2 Jul 1999	Bay of Plenty	MS	36	41
2 Aug 1999	Hauraki Gulf	MS	37	45
7 Sep 1999	QMA 1	MS	42	47
30 Sep 1999	East Northland	MS	47	47
9 Nov 1999	QMA 1	MS	22	23
14 Dec 1999	QMA 1	MS	47	49
7 Jan 2000	QMA 1	MS	41	44
3 Feb 2000	QMA 1	MS	42	46
27 Mar 2000	Bay of Plenty	MS	37	40
Oct–Nov 1997	Hauraki Gulf	TS	0	121
Feb 1999	Bay of Plenty	TS	0	225

Table 2: Mean radial measurements (mm) from the nucleus to the outer edges of the first three opaque zones, in the dorsal lobe of the otolith. *N*, sample size; s.d., standard deviation.

Zone	Radius	s.d.	*N*
1	0.84	0.07	113
2	1.05	0.08	111
3	1.21	0.08	53

Table 3: Von Bertalanffy parameters (with 95% confidence intervals), by sex, for John dory from QMA 1 (current study), and other published growth equations for John dory.

Sex	*n*	L_∞		*k*		t_0		Reference
Male	421	39.2	(38.5–40.0)	0.698	(0.610–0.787)	–0.20	(–0.36 to –0.05)	Current study
Female	440	46.0	(44.9–47.0)	0.571	(0.503–0.639)	–0.18	(–0.33 to –0.03)	Current study
Male		36.4		0.480		–0.25		Hore (1982)
Female		41.1		0.425		–0.22		Hore (1982)
Both		53.2		0.150		–1.00		Smith & Stewart (1994)

Table 4: Estimated numbers-at-age, by sex (with c.v.s), calculated from trawl surveys in the Hauraki Gulf (HGU) and the Bay of Plenty (BoP).

Sex	Age	HGU	c.v.	BoP	c.v.
Male	1	88 469	0.238	44 040	0.257
	2	36 802	0.418	19 326	0.222
	3	27 140	0.389	20 906	0.284
	4	34 463	0.695	17 892	0.301
	5	22 686	0.643	8 670	0.398
	6	43 958	0.623	7 004	0.506
	7	1 989	0.599	3 911	0.625
	8	0	0.000	3 789	0.671
	9	0	0.000	1 886	0.770
Female	1	72 908	0.380	52 407	0.190
	2	43 291	0.437	7 097	0.400
	3	61 634	0.234	18 817	0.313
	4	43 906	0.259	13 514	0.299
	5	17 496	0.429	9 681	0.355
	6	482	0.553	9 635	0.673
	7	3 944	0.833	1 659	0.853
	8	0	0.000	2 784	0.733
	9	0	0.000	2 245	0.575
Measured males		170		207	
Measured females		211		172	
Aged males		62		114	
Aged females		59		111	
No. of shots with JDO		44		52	
Mean weighted c.v.		39.5		30.6	

Table 5: Von Bertalanffy growth parameter estimates for the best-fit MULTIFAN models. t_0 is expressed in years relative to 1 January, the theoretical birthday. Amplitude and phase are the seasonal growth parameters.

			Von Bertalanffy growth parameters				
Region	Sex	Ages	K (yr^{-1})	L_∞ (cm)	t_0 (yr)	Amplitude ϕ_1	Phase ϕ_2 (yr)
All NZ	F	6	0.49	54.6	-0.23	0.80	0.26
NENI	F	4	0.84	49.0	0.09	0.95	0.32
WCNI	F	4	0.77	47.7	0.09	–	–
All NZ	M	5	1.04	41.0	0.08	0.71	0.34
NENI	M	4	1.15	40.4	0.13	0.95	0.31
WCNI	M	3	0.91	44.0	0.10	–	–

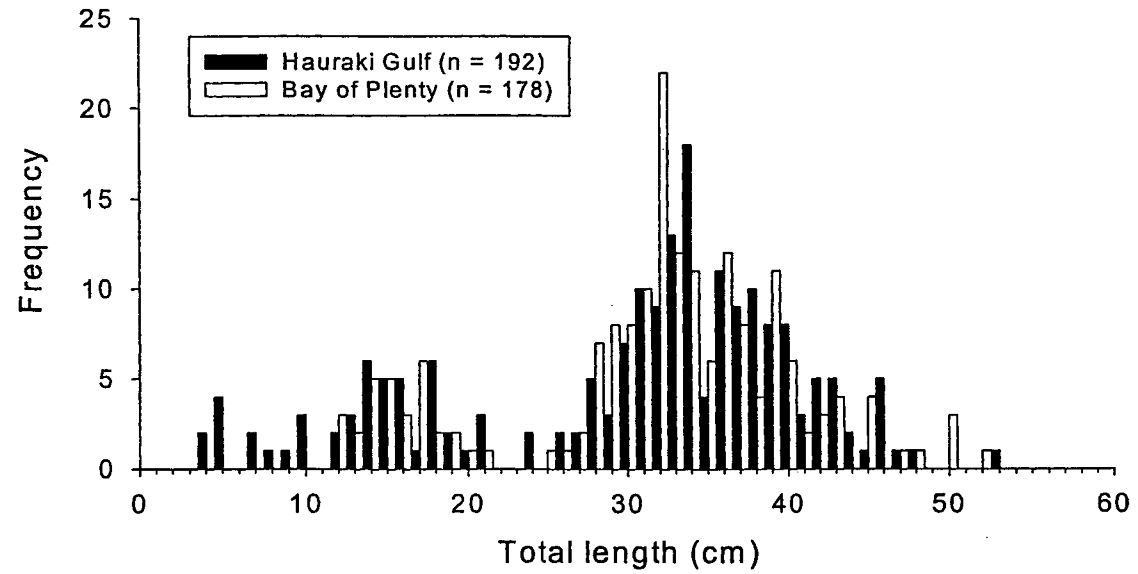


Figure 1: Comparison of length-frequency distributions of John dory collected from the Hauraki Gulf and Bay of Plenty during *Kaharoa* voyage KAH8711 in May 1987.

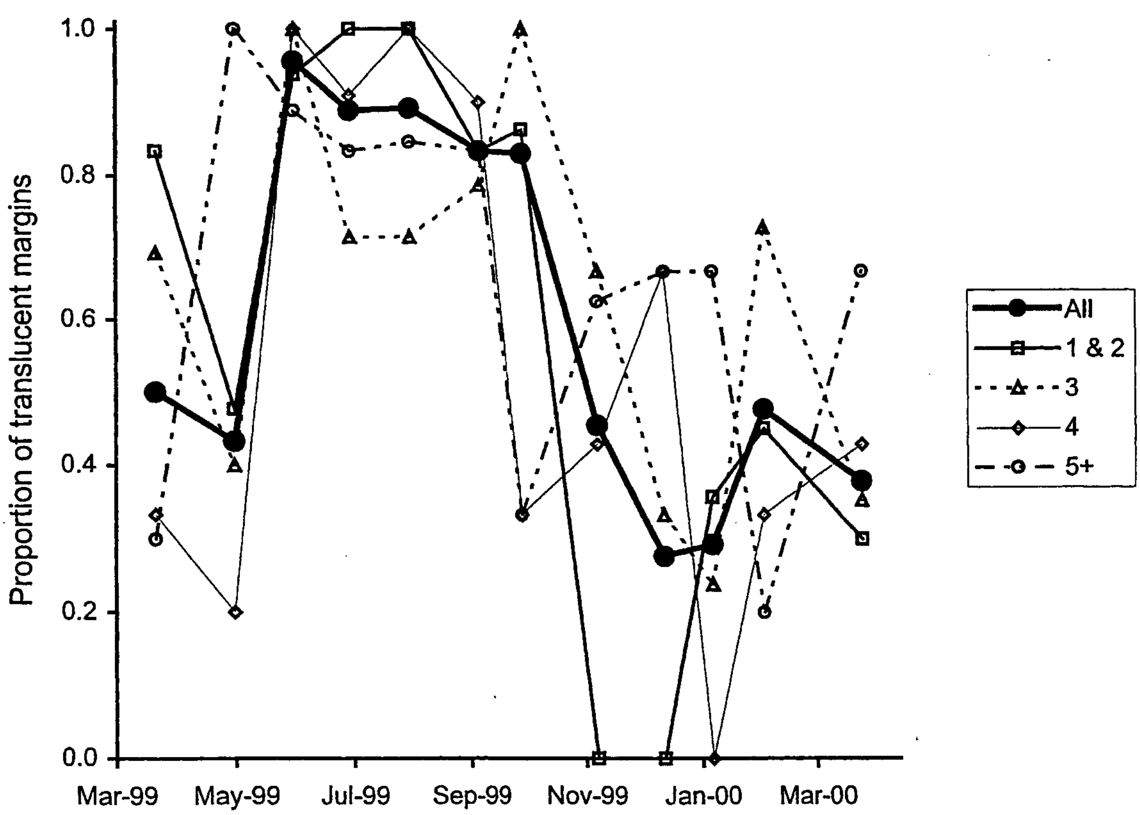


Figure 2: Seasonal change in the proportion of John dory otoliths with a translucent margin. For details of area and sample size, see Table 1. Proportions are plotted for all data combined, and for four age groupings separately.

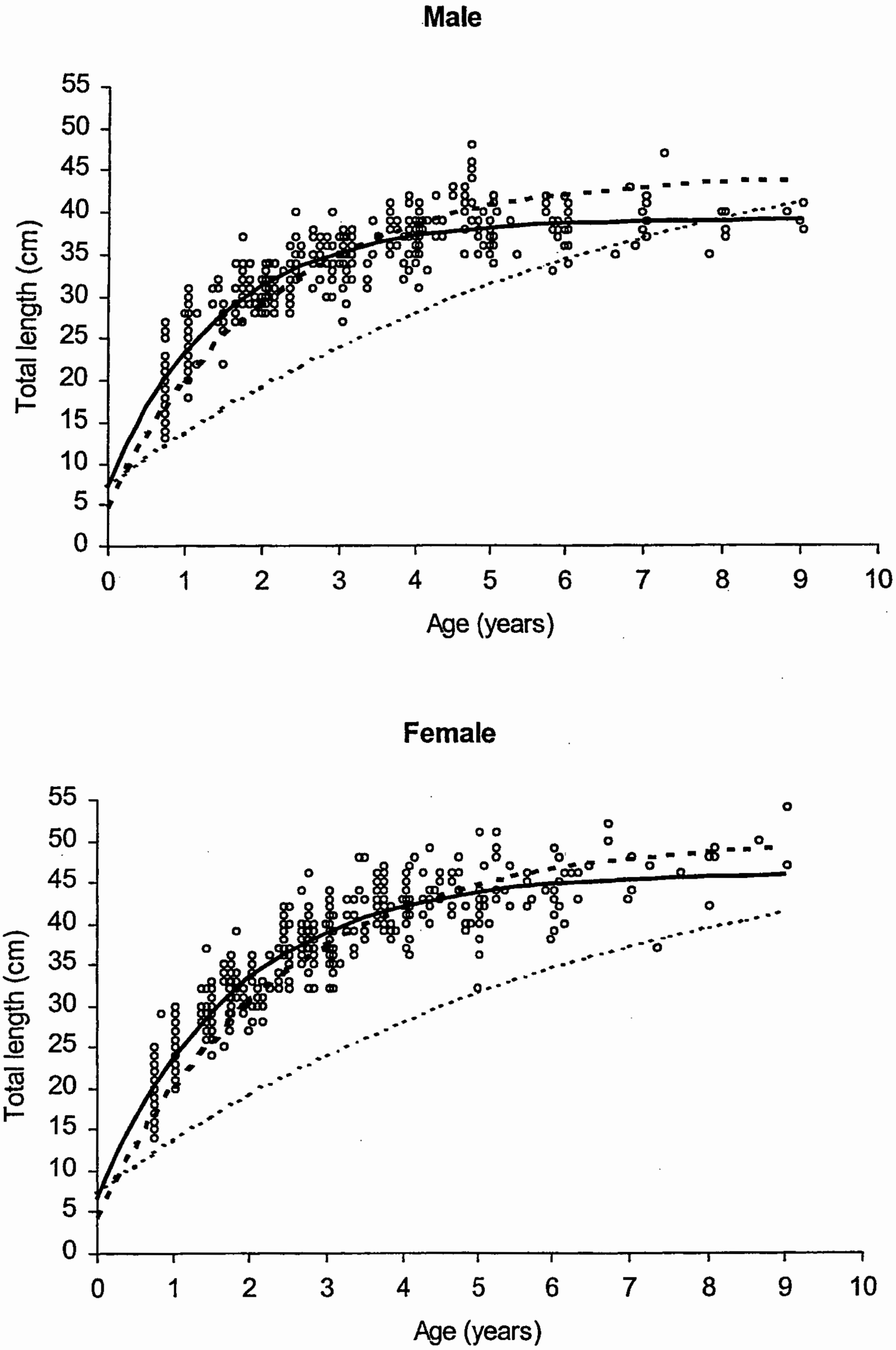


Figure 3: Raw age-length data and von Bertalanffy curves, by sex, for John dory from off northeast North Island (QMA 1). Derivation of von Bertalanffy curves are: thick solid line, current study using otolith data only; thick dashed line, from Hore (1982); thin dashed line, from Smith & Stewart (1994).

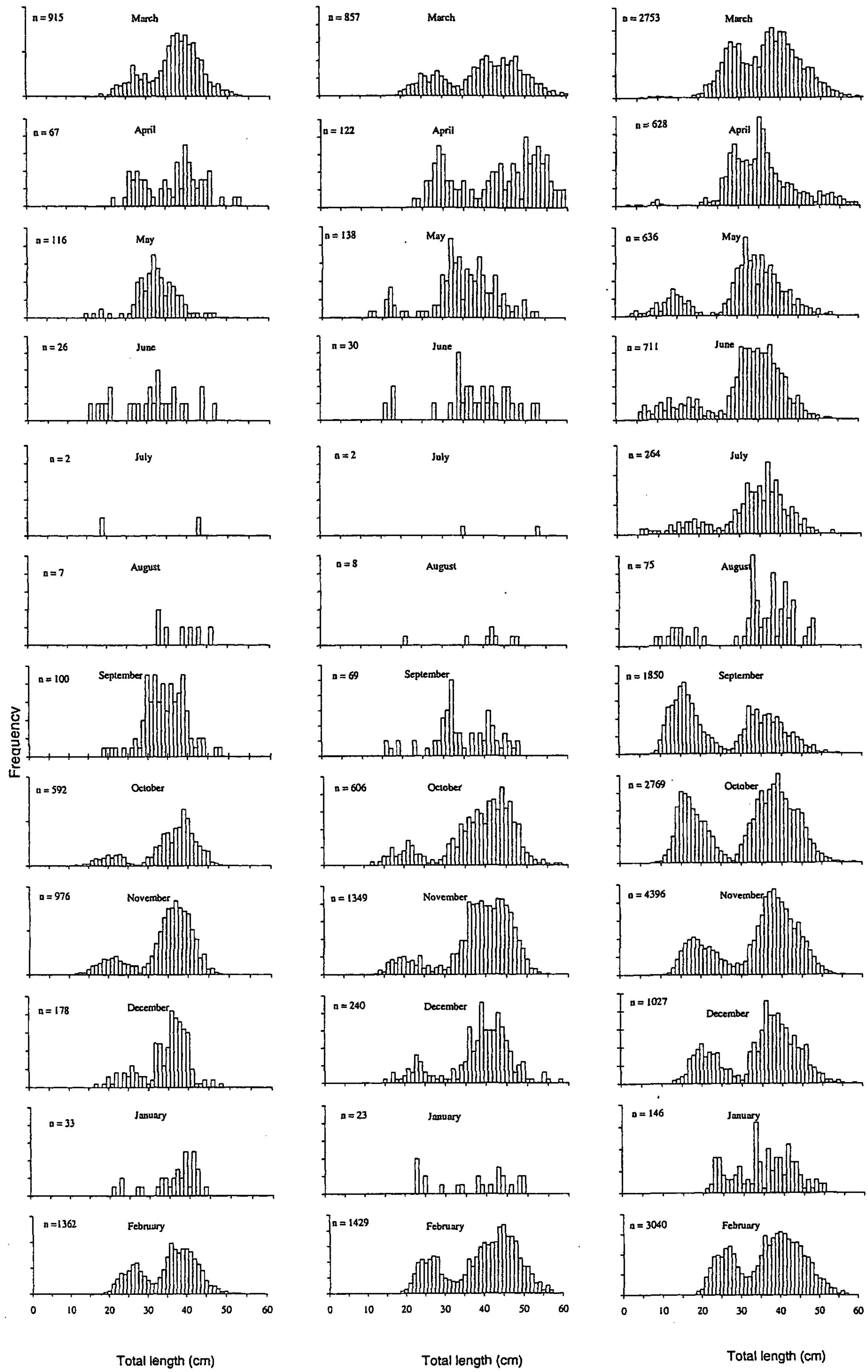


Figure 4: Length frequency distribution of male, female and total John dory from the trawl survey database by month for all areas and years combined.

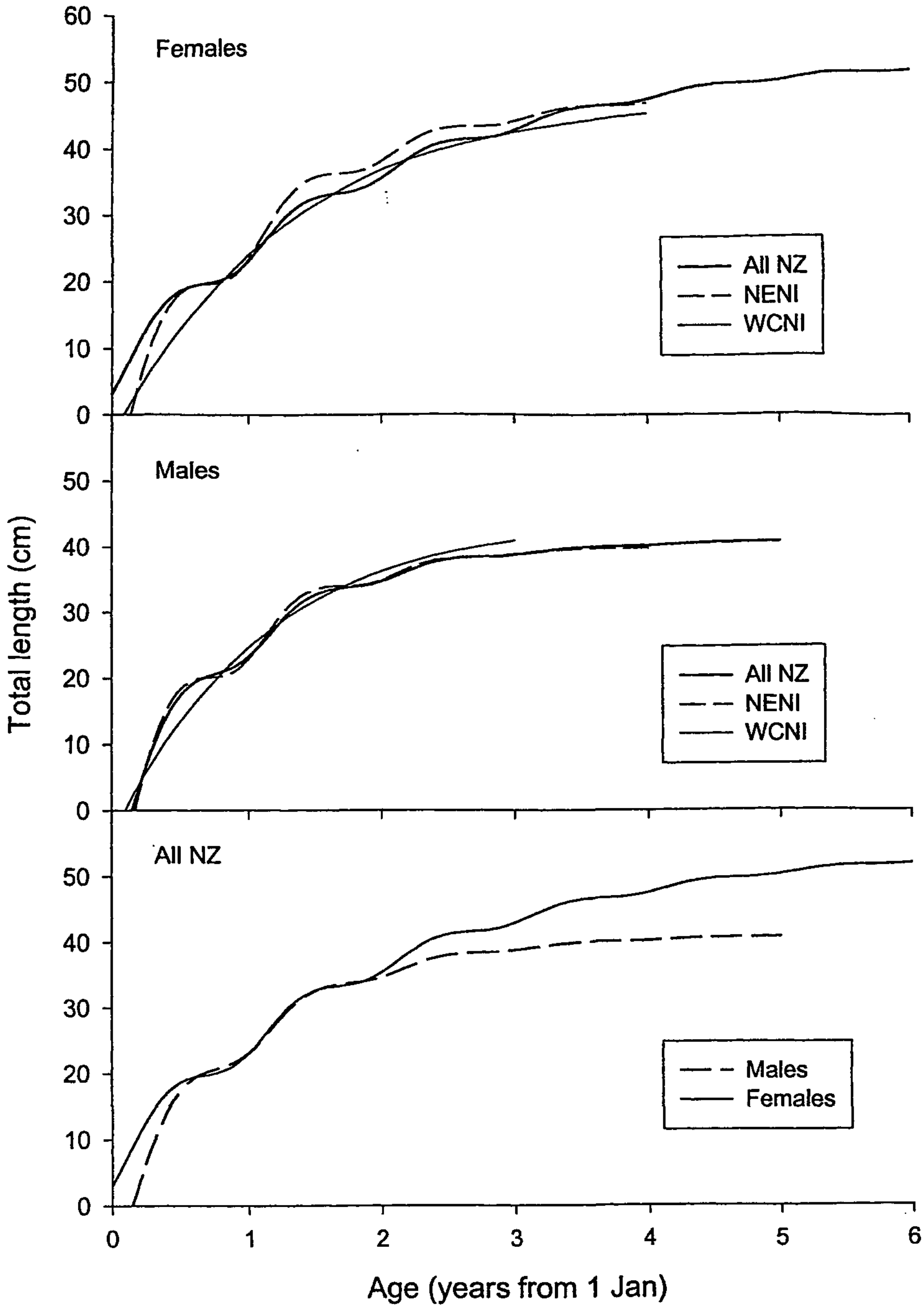


Figure 5: Von Bertalanffy growth curves from best-fit MULTIFAN models applied to the All New Zealand, northeast North Island (NENI) and west coast North Island (WCNI) length-frequency data sets. The age axis has its origin at the theoretical birth date (1 January).

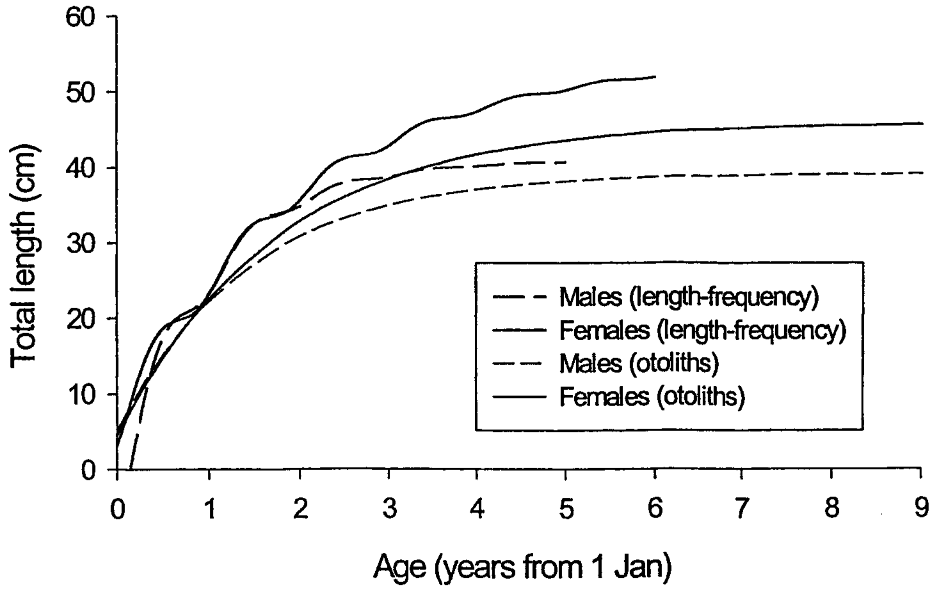
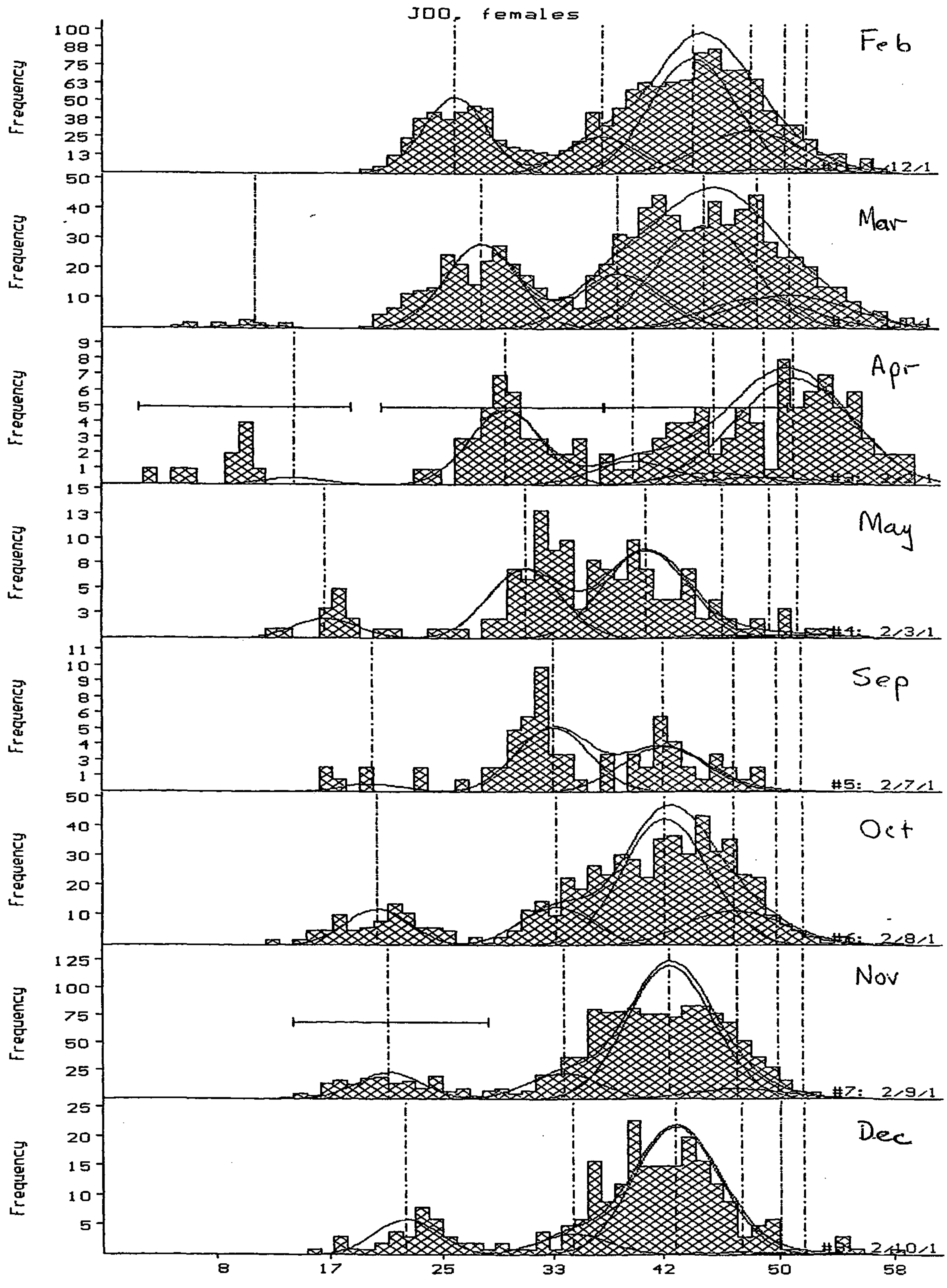
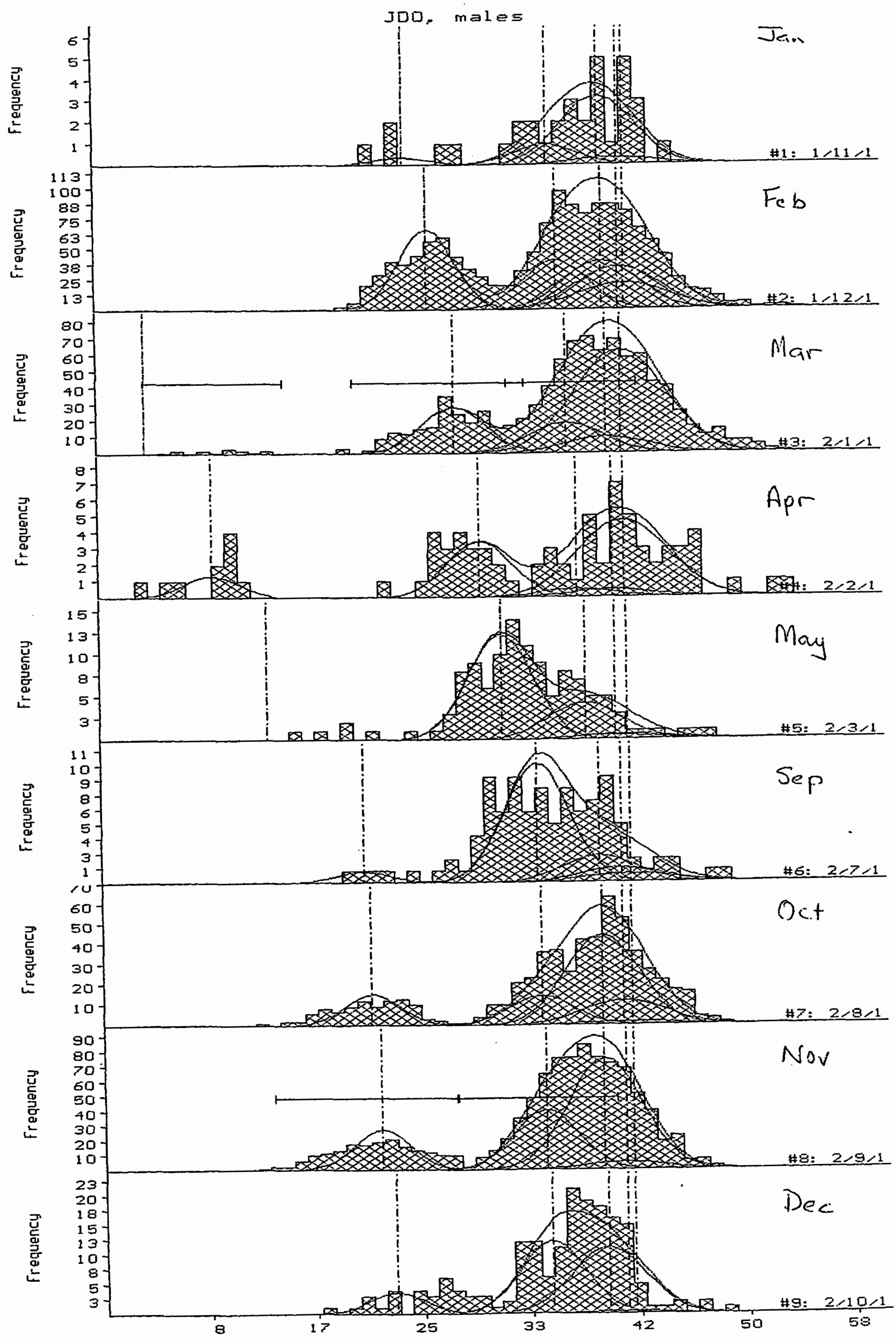


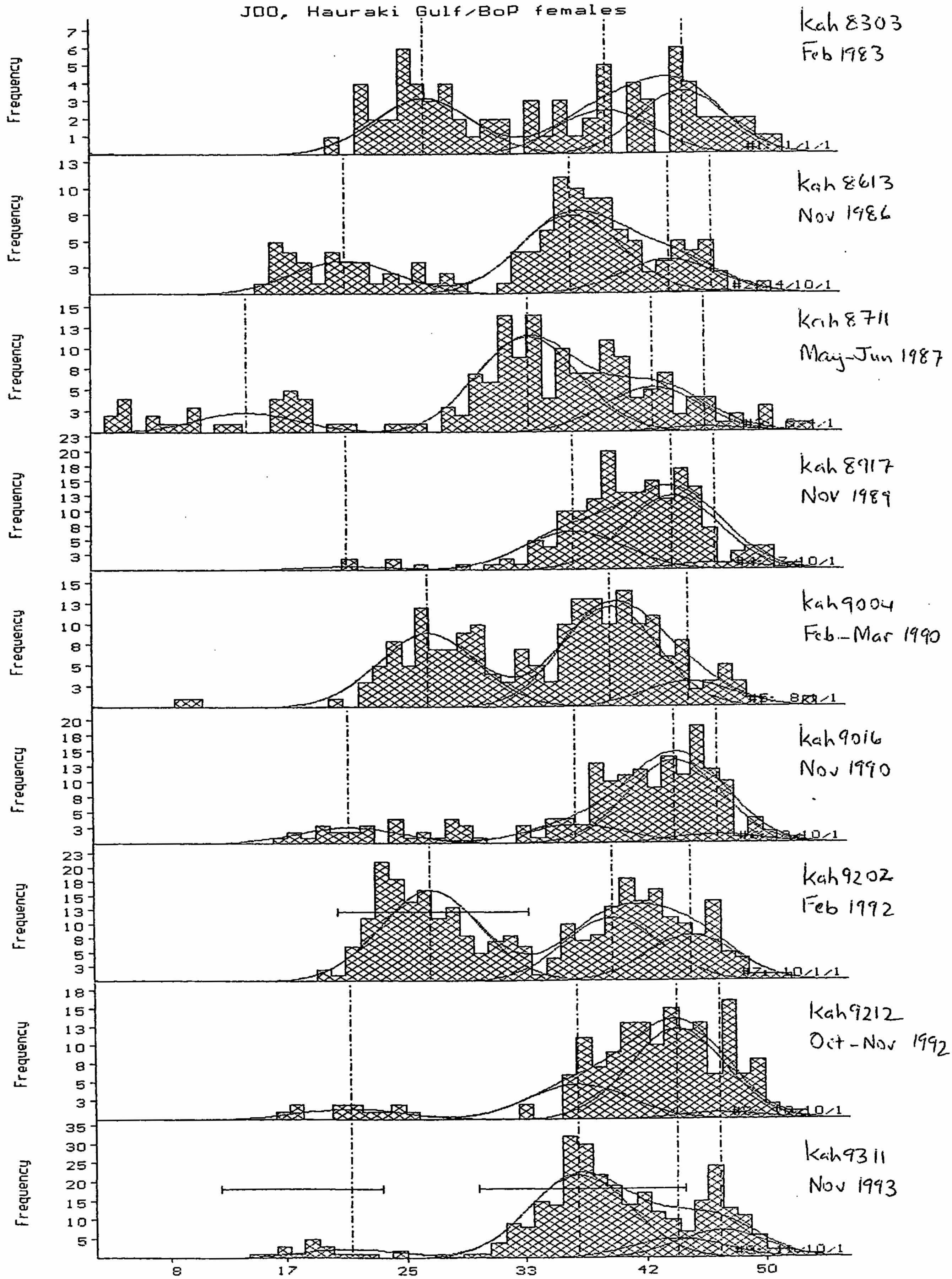
Figure 6: Comparison of MULTIFAN (All NZ length-frequency) and length-at-age (otoliths) Von Bertalanffy growth curves for John dory.



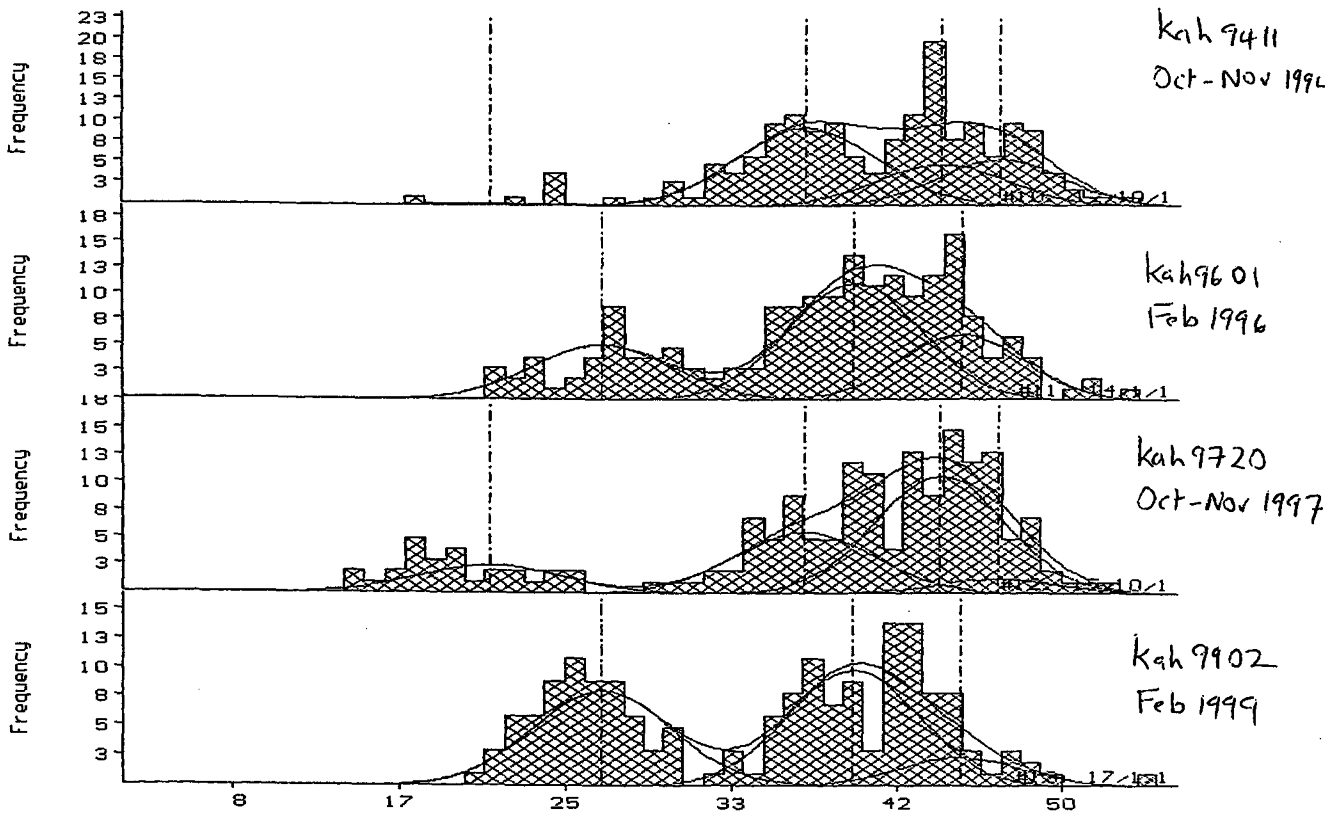
Appendix 1: Length-frequency distributions of female John dory for the All New Zealand data set showing the fit of the best MULTIFAN growth model to the overall data (uppermost smooth curve) and the individual age classes. Length histograms are arranged in chronological order. Vertical dash-dot lines indicate the mean lengths of each age class, and horizontal bars show the constraints placed on the mean lengths of selected age classes during model fitting.



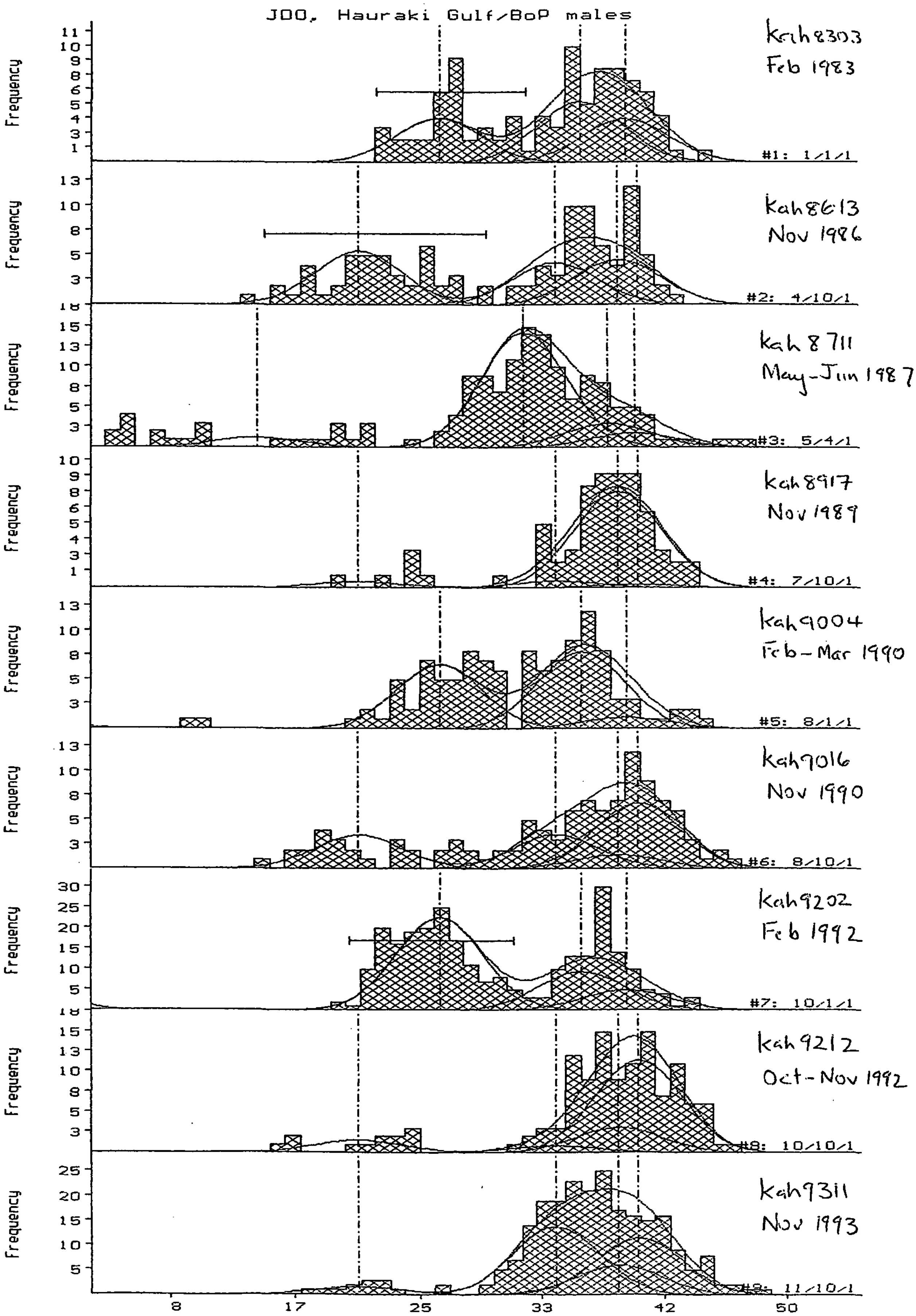
Appendix 2: Length-frequency distributions and best-fit MULTIFAN model for male John dory for the All New Zealand data set.



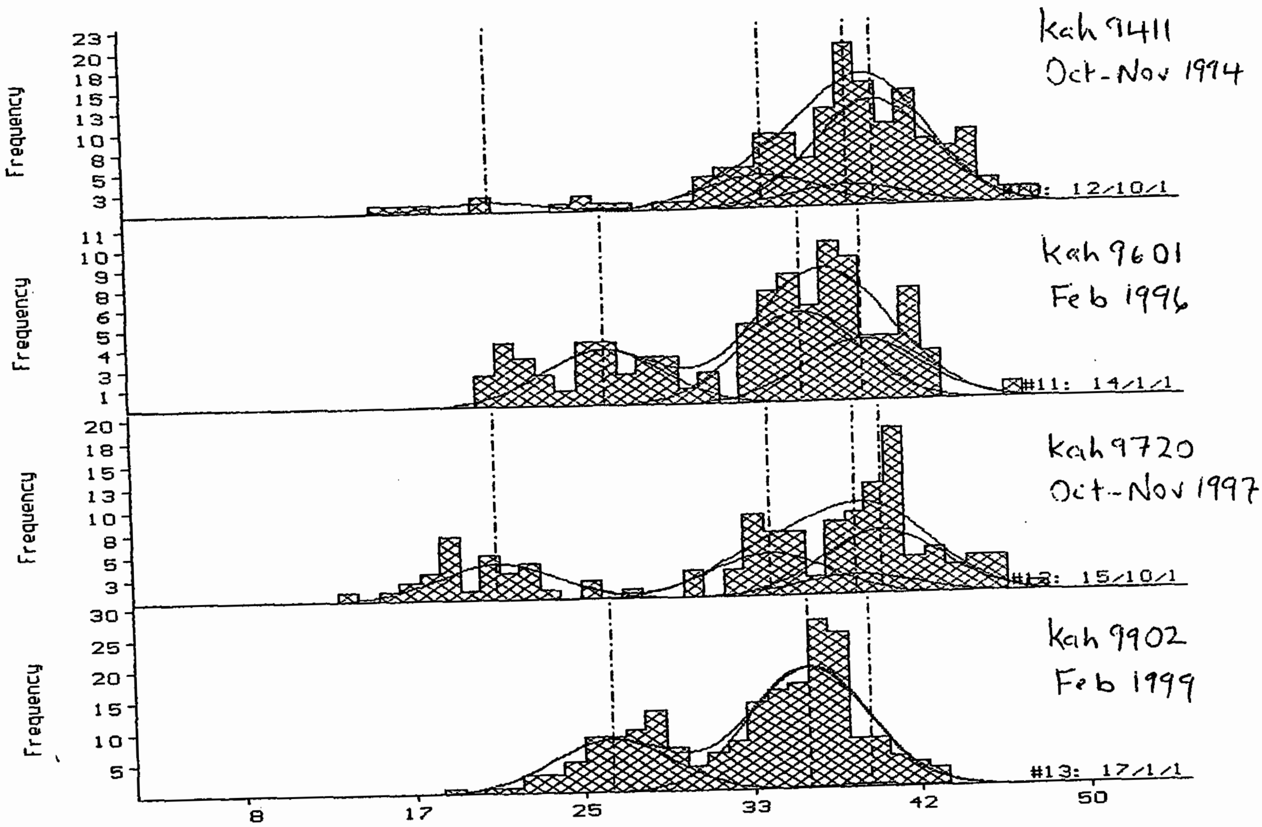
Appendix 3: Length-frequency distributions and best-fit MULTIFAN model for female John dory for the north-east North Island data set.



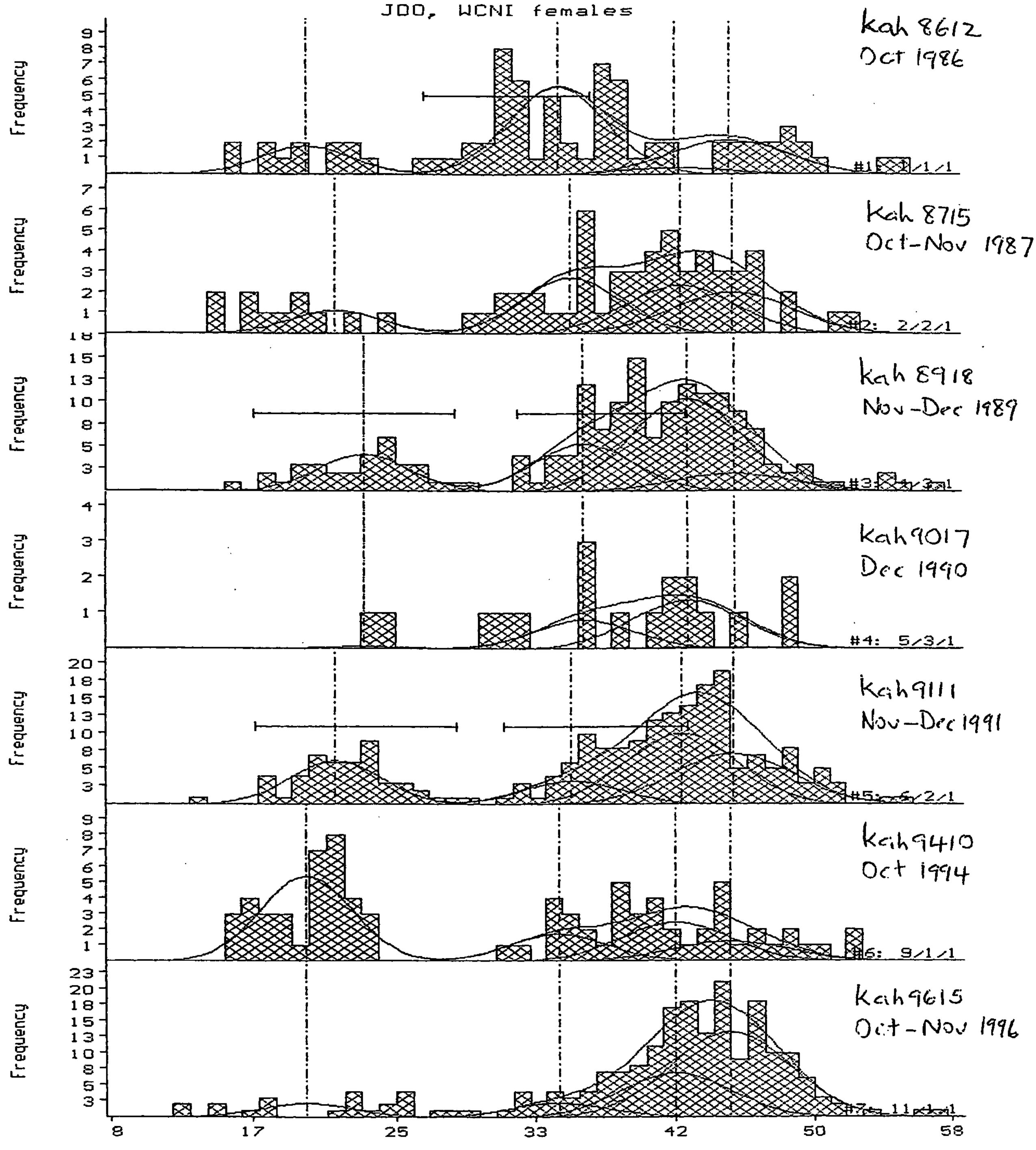
Appendix 3 (continued)



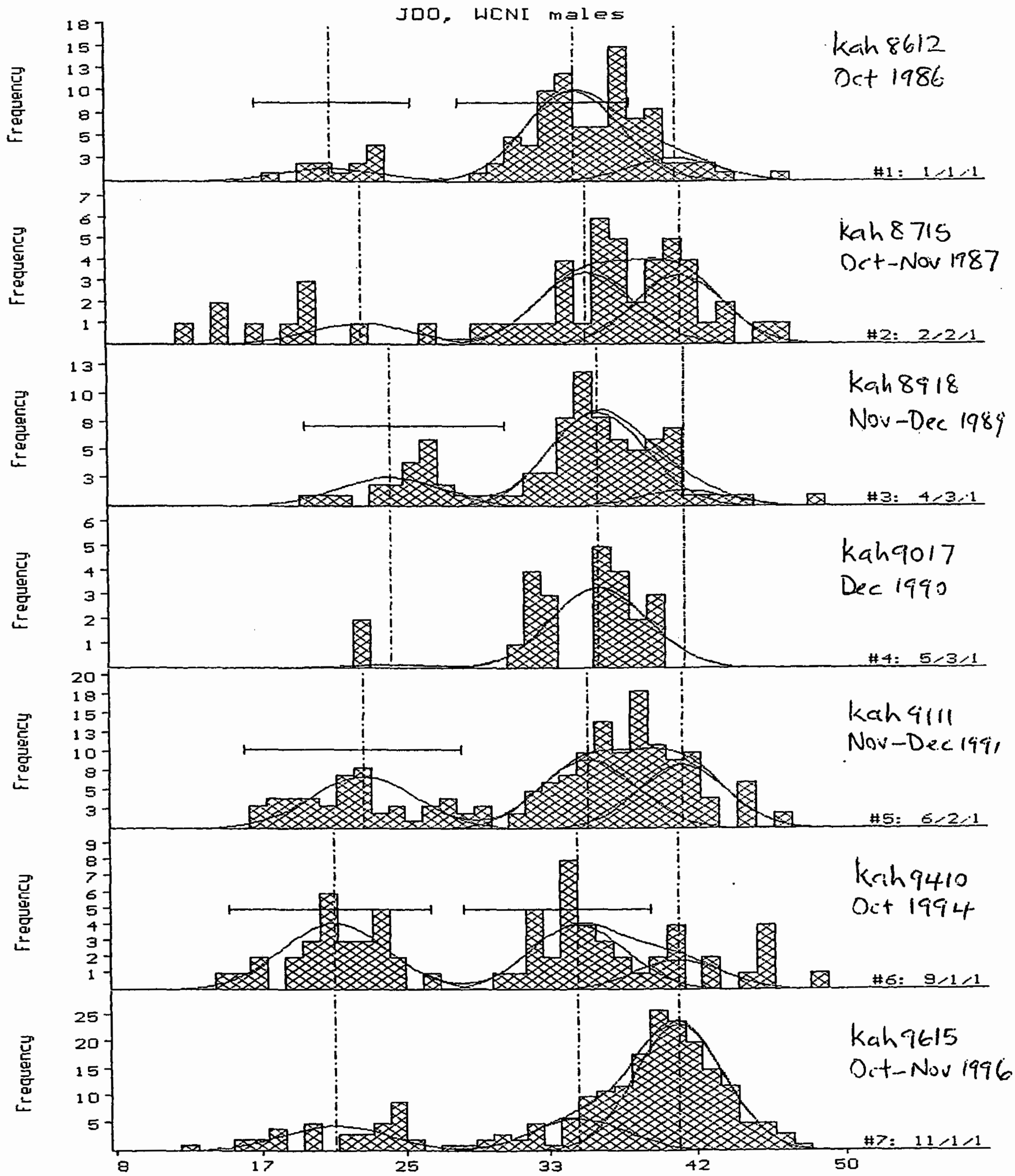
Appendix 4: Length-frequency distributions and best-fit MULTIFAN model for male John dory for the north-east North Island data set.



Appendix 4 (continued)



Appendix 5: Length-frequency distributions and best-fit MULTIFAN model for female John dory for the west coast North Island data set.



Appendix 6: Length-frequency distributions and best-fit MULTIFAN model for male John dory for the west coast North Island data set.