**Ministry for Primary Industries**
Manatū Ahu Matua

# Age, growth, maturity and natural mortality of New Zealand kingfish (*Seriola lalandi lalandi*)

New Zealand Fisheries Assessment Report 2014/03

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# EXECUTIVE SUMMARY

Age estimates of New Zealand kingfish (*Seriola lalandi lalandi*) were derived from opaque-zone counts in sagittal otolith thin section preparations. There was some uncertainty as to the location of the first opaque zone, and further work is needed to establish this.

A short series of monthly length frequency samples taken from the east Northland coast showed a clear progression of modes consistent with growth. Otolith derived age estimates for fish in these samples suggests that the length samples comprised a single cohort of 1+ age fish. The results indicate that it is feasible to track a single age cohort of young kingfish in the wild at least over their assumed second year of life. The data indicated that young kingfish grow quickly during summer with the possibility that growth slows during colder months. Otolith material collected from these fish may be useful in determining the status of the first otolith band in further investigations.

von Bertalanffy growth estimates were derived from age and length samples taken by the eastern Bay of Plenty recreational charter boat fishery. A sample of 1352 kingfish was measured for length (range 55 – 147 cm); a sub-sample of 187 fish was subsequently aged and sexed (age range 4 – 23 years). Estimates of $K$ and $L_{inf}$ estimates were 0.13 and 142 cm respectively. These estimates are based on the assumption that the sampled catch was representative of the eastern Bay of Plenty adult kingfish population. The Kimura likelihood ratio test did not support the hypothesis that male and female growth curves are different.

von Bertalanffy growth parameters were independently derived from 351 recreational tag recoveries collected from the eastern North Island; the $K$ and $L_{inf}$ estimates were 0.13 and 142 cm respectively. These results are contingent on a different assumption to the age analysis, i.e. that tagging does not affect growth. The tagging derived growth curve was not statistically different from the age-length curve.

The age data suggested that kingfish were not fully recruited to the Bay of Plenty charter boat fishery until age seven. A catch curve analysis produced total mortality estimates of 0.29; this in conjunction with the observed maximum age, suggest that a "plausible" range for kingfish natural mortality is 0.20 to 0.25. Again the underlying assumption is that the recreation catch sample was representative of the eastern Bay of Plenty adult kingfish population.

A new Bayesian analysis of length and maturity data originally collected by Poortenaar et al. (2001) produced slightly different length-at-50%-maturity estimates ($L_{50}$) for kingfish to those originally published by Poortenaar et al. (2001) [*males:* 82.89 compared with 81.15 cm; *females:* 96.86 compared with 94.36 cm]. The differences between the two analyses were largely due to adopting the middle values of each 5 cm length bin in the current analysis rather than the lower interval value as would have been used by Poortenar et al. (2001).

# 1 INTRODUCTION

The yellow tailed kingfish (*Seriola lalandi*) is widely occurring in shallow coastal areas around the world (Nugroho et al. 2001). New Zealand and Australian kingfish are thought to belong to the same sub-species (*S. lalandi lalandi*) whereas kingfish in Japan are believed to constitute a separate sub-species (*S. lalandi aureovittata*). A recent genetic study found that there was no significant allele separation between Australian and New Zealand kingfish populations, whereas population samples from Japan were genetically distinct (Nugroho et al. 2001). The genetic similarity between Australian and New Zealand kingfish stocks is consistent with documented movements of tagged fish between the two countries (Walsh et al. 2003).

There have been a number of age and growth studies conducted on the various *Seriola* species throughout the world. Baxter (1960) estimated the ages of *S. lalandi dorsalis* using scale annuli and fitted a Von Bertalanffy growth model to the results. Growth rates were similar to growth increments established from a tagging experiment. Mitani & Sato (1959) examined scales, otoliths and vertebral centra in *S. quinqueradiata*, a closely related species to *S. lalandi* and concluded that vertebral centra were the best hard parts to use for age estimation. This was largely because they considered *Seriola* scales and otoliths difficult to read on account of their small size. Nishioka et al. (1985) detailed a method to make polyvinyl alcohol replicas of the vertebral centrum so that precise measurements of growth rings were possible. The frequency distributions of the rings were matched with length-frequency modes from a three-year catch sampling series and a good fit was achieved. Murayama (1992) compared growth curves for *S. quinqueradiata* from various regions within the Japan Sea derived from vertebral centrum ages. He found that growth rates varied with time and area and hypothesised that differences in temperature were responsible.

An age and growth study on *S. dumerili* by Thompson et al. (1999) in the Gulf of Mexico indicated sexual differences in growth in this species. Female *S. dumerili* were found to grow faster and attain a larger size than the males. Thompson et al. were able to validate the annual nature of otolith rings from oxyteracycline marks in otoliths obtained from previously injected recaptured tagged animals. It is not clear that the population sample the authors used to estimate growth was truly representative of mean length-at-age. The maximum age Thompson et al. observed was 15 years.

A study evaluating methods for estimating the ages of *S. lalandi lalandi* from New South Wales by Gillanders et al. (1999a) is most relevant to New Zealand populations. Gillanders et al. examined dorsal spines, otoliths, scales and vertebrae as potential kingfish ageing tools. They could identify growth zones in all four structures but concluded that dorsal spines were unsuitable for ageing because they thought it likely that earlier growth zones were lost with increasing age. From the marginal increment analysis it appeared that one zone is laid down each year in otoliths and scales. Exact agreement between each repeated reading was low (50–66%) although agreement within one zone was reasonable (92–96%). They found that scales provided the most precise age estimates. However, the scale and otolith readings diverged below age four, which suggests that there may have been a problem in the interpretation of young otoliths. They concluded that further work is necessary to determine the position of the first zone in order to validate their age estimates. They provide growth estimates for kingfish (both sexes combined) based on ageing 597 kingfish ranging from 32 to 109 cm in length. Gillanders et al. do not mention how these fish were collected. If there was any size selection in the way their sample was collected then the estimates of mean length-at-age may have been biased (Hoenig et al. 1994). The maximum age of *S. lalandi* in the Gillanders et al. sample was 10. Stewart et al. (2001) provide growth estimates based on a larger aged dataset containing representative ages out to 21 years.

Poortenaar et al. (2001) examined gonad material from 204 female and 195 male *S. lalandi lalandi* collected in New Zealand waters over the November-January spawning period. The smallest mature female in their sample was 78 cm; 50% female maturity occurred at 94 cm and 100% of females larger than 128 cm were mature. The smallest mature male was 75 cm; 50% maturity in males occurred at 81

cm and 100% of males above 93 cm were mature. Mature females were defined as having vitellogenic or more advanced ovaries. Mature males were defined as having partially spermiated or more advanced testes. An earlier study on New Zealand populations of *S. lalandi lalandi*, reported maturity in both sexes occurred between 58 and 67 cm FL, with all fish mature by 70 cm FL (McGregor, 1995).

Gillanders et al. (1999a,b) report that female *S. lalandi lalandi* from New South Wales first mature at 70 cm FL (3 years) with 50% attaining sexual maturity at 83 cm FL (4–5 years). Males first matured at about 30 cm FL (less than one year old) and 50% had attained maturity at 47 cm FL (less than one year old). The application of Gillanders et al. (1999b) age-growth models to New Zealand data (Poortenaar et al. 2001), suggests first maturity and 50% maturity at 4 and 7 years respectively for females and 4 and 5 years respectively for males. Differences in size and age of sexual maturity between N.S.W. and New Zealand populations may be due to different growing conditions e.g. warmer water temperatures in N.S.W. or to intrinsic population behavioural and physiological differences.

To date there are no published estimates of New Zealand kingfish growth rates based on the analysis of skeletal structures such as otoliths or vertebrae. Average annual growth of New Zealand kingfish has been estimated by applying length increment data from the gamefish tagging programme to a length-based maximum likelihood model (GROTAG, Francis 1988). Although measurement error was high, the tagging data suggests that kingfish is a fast growing species (Hartill & Davies 1999). Annual growth increments of 11.5 cm and 4.1 cm were estimated for 50 cm ($g_{50}$) and 100 cm ($g_{100}$) kingfish respectively.

In this report we present observations of juvenile kingfish growth in east Northland. We evaluate an otolith reading technique for New Zealand kingfish. Growth estimates derived from otolith samples and tagging data are presented along with estimates of natural mortality. A revised analysis of the length-at-maturity data collected by Poortenaar et al. (2001) is also included.

All length measurements quoted in this report are fork-lengths unless otherwise stated.

## 2 MONTHLY GROWTH OF JUVENILE KINGFISH AT A NORTHLAND FISH AGGREGATION DEVICE

### 2.1 Introduction

The aim of the study was to collect observational data representing kingfish growth over the first two years of life.

The implication of growth estimates derived by Gillanders et al. (1999a) is that juvenile *S. lalandi lalandi* are relatively fast growing. A series of length frequency samples collected from a discrete juvenile kingfish population (less than two years of age) over a period of 6–8 months would be expected to show clear modal progressions as the fish grow. It should therefore be possible to estimate the juvenile kingfish growth rates from monthly length-frequency samples.

In 1999 the Lion Foundation funded a project to investigate the range of species attracted to two Fish Aggregation Devices (FADs) located five nautical miles from the Poor Knights Islands, Northland, outside the marine reserve. This project was supported by the Whangarei Deep Sea Anglers Club and was undertaken by Blue Water Marine Research Ltd. During the period the FADs were in place two reasonably large schools of juvenile kingfish (initially more than 200 individuals) became resident.

Starting in March 1999 four observational dives were made on the FADs, four to six weeks apart. Juvenile kingfish were observed on every visit. At each successive visit, although the size of the kingfish school gradually reduced, the mean fish length was observed to increase.

### 2.2 Methods

Monthly samples of juvenile kingfish were captured by hook-and-line using a variety of baits, lures and flies from Poor Knights Islands FADs and along the east Northland coast. Fork-length measurements were obtained from all sampled fish. Some fish were retained to provide otolith material (see Section 3).

### 2.3 Results

Sampling commenced on 18 February 2002 around the Poor Knights Islands FADs. Underwater visibility was good and at times several hundred small kingfish were seen. Although they became 'hook shy' and hard to catch, 34 juveniles were caught and measured.

A further sample of 31 fish was obtained at the FADs on 16th of April. Rough weather prevented a planned trip in mid-May, and a re-visit on the 30th of May discovered that both FADs outside the Poor Knights Islands had been lost, possibly during an earlier storm event.

Reports of large numbers of juvenile kingfish inhabiting headland areas north of Whangarei led to a relocation of fishing effort. On the 7th of June a sample of 10 juvenile kingfish was obtained from a reef area off the Tutukaka coast at Ngunguru and from a depth of 10–30 metres.

Revisiting the Ngunguru site on the 25th of July obtained a sample of 31 juvenile kingfish.

The sample length distributions are consistent with the growth of a single cohort over the 23 week sampling interval (Figure 1; Appendix 2).
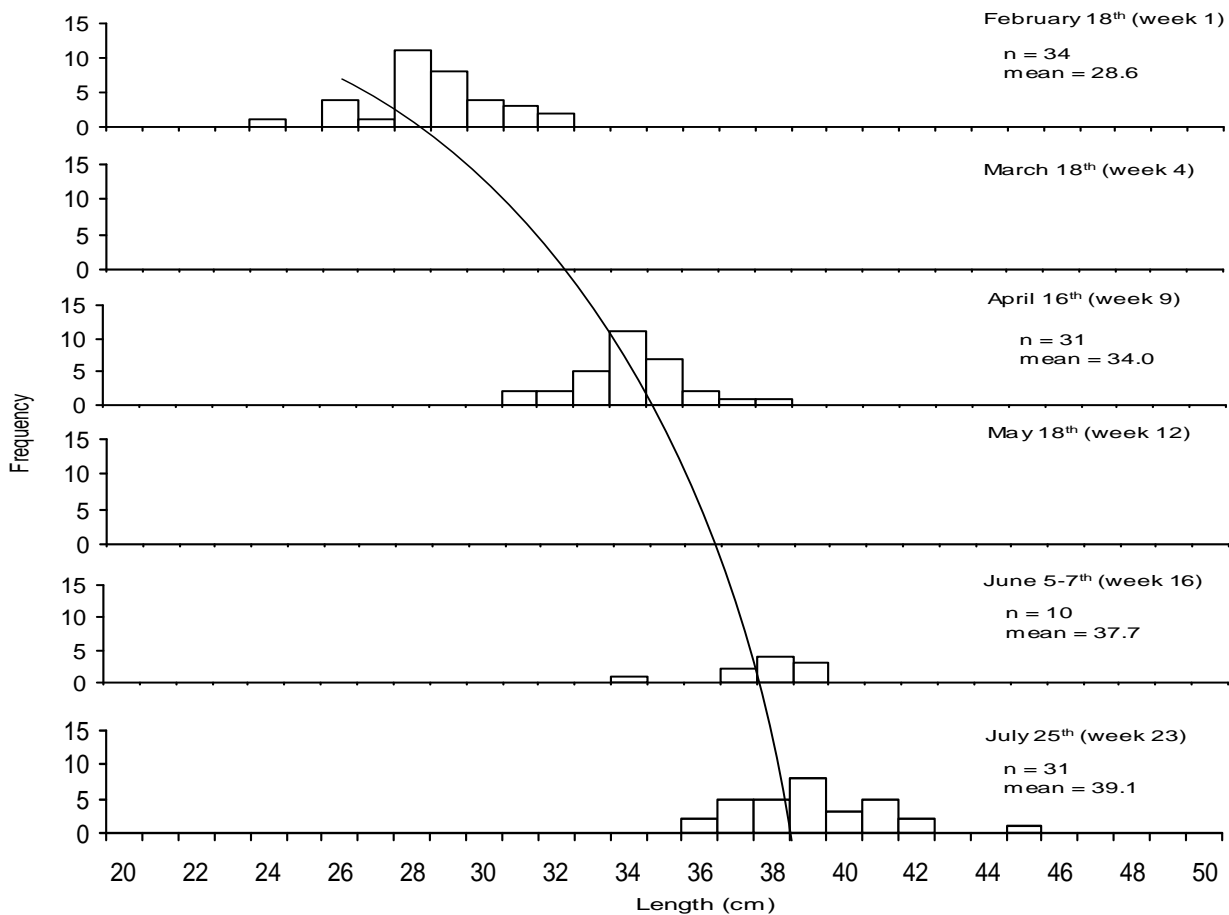
**Figure 1:** **Progression of length frequency modes for juvenile kingfish caught at Poor Knights Islands FADs and Tutukaka coast between 19/02/02 and 25/06/02.**

## 2.4 Discussion

We assume that the kingfish sampled at the Poor Knights and east Northland coast settled from the plankton at approximately the same time. Given the pelagic nature of juvenile kingfish we think it reasonable to assume that there is a high degree of mixing of these animals over the Tutukaka/Whangarei/Poor Knights Islands area and that the fish sampled were part of a single cohort.

Length-at-maturity information collected by Poortenaar et al. (2001) indicates that spawning in kingfish occurs mostly between the months November to January. Based on growth rates achieved under aquaculture (NIWA unpublished aquaculture data) it is highly unlikely the fish observed at the Poor Knights Islands FADs in February 2002 were less than 6 months old. The age of these fish based on otolith annuli was 1+ (Section 3). Furthermore, the hypothesis that the fish were 2+ or greater is also inconsistent with growth rates achieved in farmed kingfish (NIWA unpublished aquaculture data) and the Australian wild-stock growth estimates (Gillanders et al. 1999a; Stewart et al. 2001). It is

therefore reasonable to assume that the modal increases in the monthly length samples represent the growth of kingfish in their second year of life.

The data suggests that juvenile growth is seasonal; relatively fast during summer, slowing in winter (Figure 1).

# 3    OTOLITH THIN SECTIONS

## 3.1    Introduction

The aim of this section was to assess the precision of otolith zone counts for New Zealand *S. lalandi lalandi* . The work represents the first thorough review of New Zealand *S. lalandi lalandi* ageing methods.

## 3.2    Methods

A sample of 80 otoliths was obtained from kingfish covering the length range 25 to 128 cm. The fish were collected from east Northland (juvenile samples only 25–40 cm) and the eastern Bay of Plenty (predominately adult 65–128 cm).

Sagittal otoliths were dissected from the skull and air-dried. Each otolith was examined with transmitted light under a stereomicroscope, and a dorso-ventral sectioning line was marked through the nucleus on the lateral face with a fine marker pen. Otoliths were embedded in a resin mould using Araldite K142 clear epoxy resin and sectioned transversely to a thickness of approximately 0.5 mm, using a Struers Accutom-2 precision wafering saw fitted with two diamond-edged blades. Each thin section was glued to a microscope slide before being sequentially ground and polished until alternating opaque and translucent zones became clearly discernable under the stereomicroscope. Final opaque zone counting was done under a compound microscope at 80–100x magnification using transmitted white light.

The readability of each otolith was scored on a scale of 1 (excellent) to 5 (very uncertain). No otoliths were rejected as being unreadable. To assess within- and between-reader comparability, complete opaque (dark) growth zones were counted by Reader 1 (twice) and Reader 2 (once). To estimate reader precision, we calculated the average percent error (APE) and a coefficient of variation (CV) (Beamish & Fournier 1981; Chang 1982):

$$APE_j = 100 \times \frac{1}{R} \sum_{i=1}^{R} \frac{\left| x_{ij} - x_j \right|}{x_j}$$

$$CV_j = 100 \times \frac{\sqrt{\sum_{i=1}^{R} \frac{\left( x_{ij} - x_j \right)^2}{R-1}}}{x_j}$$

where $x_{ij}$ is the $i$th age determination of the $j$th fish, $x_j$ is the mean age of the $j$th fish, and R is the number of times each fish is aged. When $APE_j$ and $CV_j$ are averaged across many fish, they become an index of average percent error (IAPE) and the mean CV respectively. The mean CV is numerically 1.414 times greater than the IAPE. To assess between-reader bias, we plotted age-bias graphs (Campana et al. 1995).

## 3.3    Results

Within and between-reader comparisons were made for 80 otolith sections. The two counts of Reader 1 showed good precision: IAPE = 3.3% and mean c.v. = 4.6%. Campana (2001) reported that a mean c.v. for otolith annual zone counts of around 5% is considered acceptable for fishes of moderate longevity and reading complexity. There was a slight bias between the two readings of Reader 1, with his second count tending to be slightly larger on average: all second counts were either the same as (54%) or one zone greater than (46%) his first counts, with the greater counts tending to be among the older fish.

A comparison of the second reading of Reader 1 with the single reading of Reader 2 showed a clear and consistent difference: Reader 1 counted one more zone on average across the full age range than did Reader 2 (Figure 2). Twenty-six of the 80 otoliths were difficult to age (readability 4 or 5). Inspection of the readability scores showed that all but one of the outliers lying more than two zones from the fitted regression line in Figure 2 had readability scores of 4 or 5. For the 54 otoliths with readability scores of 1–3, the two readers agreed exactly on 3 (6%), within one zone on 41 (76%) and within two zones on 51 (94%).

The two readers jointly compared their counting techniques to identify the source of the between-reader ageing bias. The bias arose from different interpretations of the position of the first annual zone: Reader 1 included the distal margin of the opaque otolith core in his count, whereas Reader 2 began counting from the first zone outside the core (Figure 3). If the two readers had both used the same criterion for determining the first zone, they would have had 76% exact agreement and 94% within one zone.
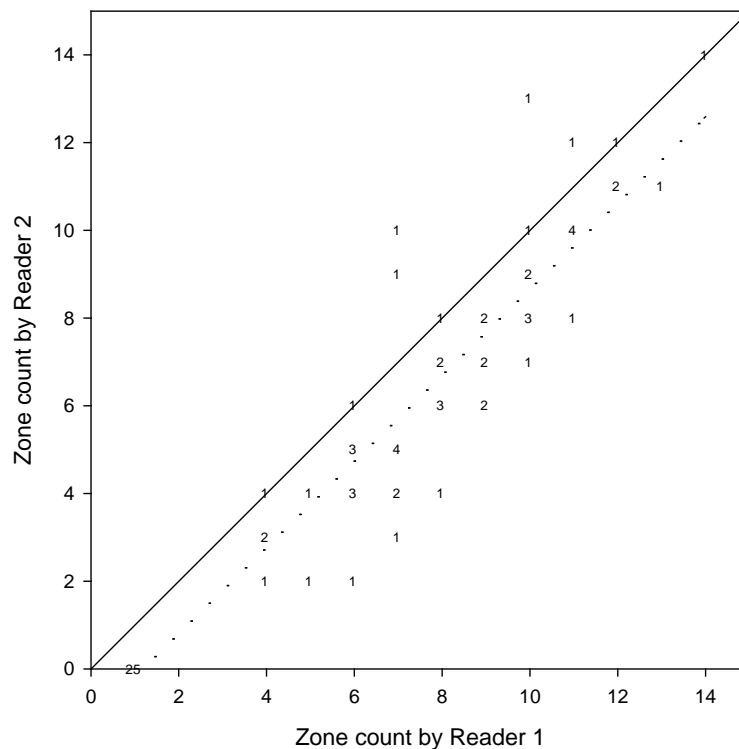


**Figure 2:    Comparison of opaque zone counts between the second count of Reader 1 and the only count of Reader 2 ($N = 80$). The solid line is the 1:1 equivalence line, and the dashed line is a linear regression fitted to the data. Numbers represent count frequencies. Means and standard errors are not presented because of the small sample sizes in most zone groups.**
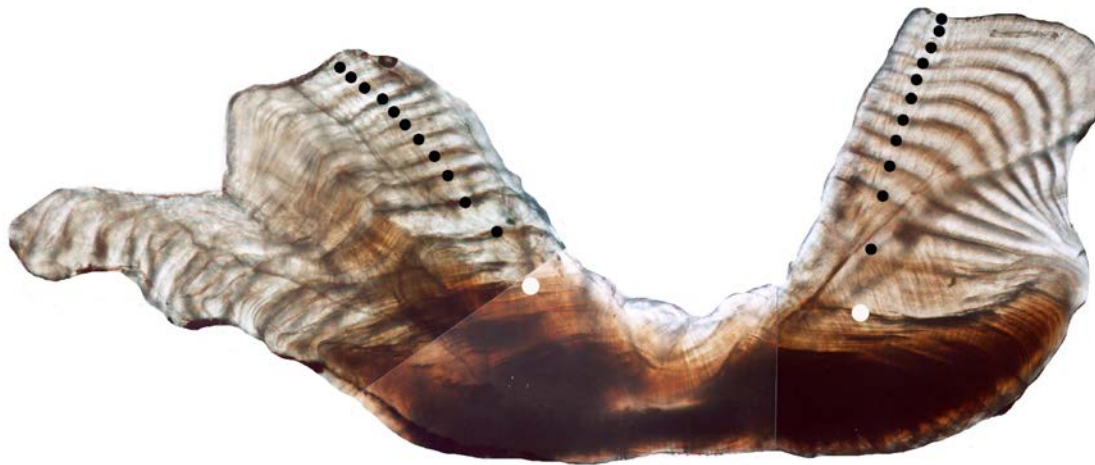
**Figure 3:** Thin transverse section of a sagittal otolith from a 92 cm FL kingfish (otolith K7–3, readability score 1) showing growth zones. Black dots indicate opaque zones counted by both readers, and white dots indicate an additional zone counted by Reader 1. Zone counts were 12 (Reader 1) and 11 (Reader 2).

## 3.4 Discussion

After allowing for the first-zone discrepancy between readers, our results were more precise than those reported by Gillanders et al. (1999a) on kingfish scales, otoliths and vertebrae. Depending upon the structure, Gillanders et al. reported the level of reader agreement as 50–66%, with 92–96% agreement within one zone; for whole otolith ages, they obtained a mean c.v. of 12% (compared with our mean c.v. of 4.6%). Conversely, Stewart et al. (2001) working with thin otolith sections achieved higher precision than we did (86% reader concurrence and 100% concurrence within one zone, and a mean c.v. of 3%).

If it is assumed that the juvenile fish sampled at the Poor Knights under Section 2 were age 1 and above then based on the otolith ring structures observed in these fish the Reader 1 interpretation is the correct one. For the purposes of the growth analyses that follow counts made by Reader 2 were incremented by 1 to make them consistent with Reader 1. However we believe the status of the first annual zone is yet to be proven. For subsequent analyses in this report ring counts have been assumed to represent actual ages at the time the otoliths were collected (October 2002 – February 2003).

No attempt was made in the current study to validate the annual deposition of otolith zones. Marginal increment analyses conducted by Gillanders et al. (1999a) on whole otoliths of fish aged 2–4 years suggested that one zone is laid down per year in August–September, although their data covered only eight months of the year. Stewart et al. (2001) believed that identification of the first annual zone was still problematic, and we concur. Consequently, validation of the timing of first zone formation, and the periodicity of zone formation in older kingfish, are still required.

# 4 ESTIMATION OF GROWTH, MAXIMUM AGE AND NATURAL MORTALITY IN KINGFISH CAUGHT BY WESTERN BAY OF PLENTY RECREATIONAL CHARTER BOATS

## 4.1 Introduction

The aim of this study was to estimate the "true" proportional age frequency composition of the eastern Bay of Plenty adult kingfish population, the purpose being to:
a.      estimate a total mortality rate for the fully recruited adult population (Z);
b.      derive estimates of mean length-at-age and from these data, and, in conjunction with juvenile growth data, to estimate von Bertalanffy growth parameters.

To meet these objectives it was necessary that the method chosen to provide kingfish length and age samples was uniformly selective of older fish; (Hoenig et al. 1994). Fishing methods taking reasonable numbers of kingfish in the eastern Bay of Plenty included purse seine, trawl, setnet and recreational line (Walsh et al. 2003). Recreational line was chosen for sampling as it was believed that its selectivity characteristics were closest to uniform.

## 4.2 Methods

From October 2002 to February 2003, 12 Whakatane charter boat (WCB) fleet skippers provided length measurements and otolith samples (as whole heads) from kingfish caught by client recreational anglers. WCB skippers were provided with measuring boards and recording forms and given training on the correct methods for collecting and recording data. Skippers were requested to record the length and sex of all kingfish caught on each charter trip. However sex was often not recorded because fishers were either not able to determine the sex or were unwilling to cut open their catch to do so. All fish providing otoliths for ageing were sexed. The length frequency data was converted to sex and age through the application of a sex-age key. The proposed key design called for the collection of 600 kingfish otolith pairs, covering the full length frequency range. As it transpired it was necessary to supplement the WCB otolith sample with otoliths collected from the local commercial trawl fishery; the assumption being that the WCB and commercial samples came from the same regional kingfish population. The assumption underlying the use of the key was that the distribution of sex and age within each length bin sample was equivalent to that in the eastern Bay of Plenty population. Otoliths were prepared and interpreted using the methodologies described in Section 3.

A critical requirement was that the final combined sample length frequency was similar to the "true" adult kingfish population length structure. The collected data was stratified for the purpose of identifying and removing length information not uniformly representative of the adult population.  The WCB skippers identified three factors that, in their opinion, could influence the size of kingfish caught by client anglers:

1.      *Fishing ground:* Inshore/White Island/Ranfurly bank;
2.      *Angler Experience* (relates to the likelihood that a fisher will catch a large kingfish): Very Experienced/Experienced/Novice;
3.      *Weather*: Excellent/Average/Poor.

Paired length frequency comparisons between the above factor-categories were made using a Kolmogorov-Smirnov (KS) randomisation test (Appendix 1). Factor categories that did not contain a full range of length classes and were found to be statistically dissimilar to those that did would be dropped from the final combined length frequency sample.

Once derived, the final length frequency sample was filtered through the age-length-sex key to generate proportional age-frequency histograms by sex. Total mortality estimates (Z) were derived from the generated age distribution using the Chapman & Robson (1960) estimator and catch curve analysis (Haddon 2001).

A natural mortality (M) estimate was calculated using the Hoenig (1983) log(100) ratio formula. The Hoenig estimate assumes that the oldest observed age represents 1% of the recruited population.

The von Bertalanffy growth model was fitted to the WCB age frequency data using Maximum Likelihood assuming lognormal error about mean-length-at-age. A MCMC process was used to derive Bayesian posteriors on all parameters and mean-length-at-age estimates. No priors were specified on the estimated parameters as they were assumed to come from uniform distributions. A variant of the likelihood ratio test as described by Kimura (1980) was used to test the null hypothesis that the specification of separate growth parameters for male and female kingfish is unwarranted.

## 4.3    Results

### 4.3.1    Length frequency analysis

Length measurements were obtained from 1352 kingfish. The numbers of kingfish measured by area, angler-experience and weather factors are given in Table 1.

**Table 1:    Number of kingfish measured by area, angler-experience and weather.**

| Area | Weather | Angler | | | |
| | | V Exp. | Exp. | Novice | Total |
|---|---|---|---|---|---|
| Ranfurly | Excellent | 45 | 20 | | 65 |
| | Average | 95 | 72 | 2 | 169 |
| | Poor | | 64 | 29 | 93 |
| Ranfurly Total | | 140 | 156 | 31 | 327 |
| White | Excellent | 89 | 228 | 80 | 397 |
| | Average | 27 | 267 | 107 | 401 |
| | Poor | | 24 | 91 | 115 |
| White Total | | 116 | 519 | 278 | 913 |
| Inshore | Excellent | | 1 | 2 | 3 |
| | Average | | 1 | 59 | 60 |
| | Poor | | 30 | 19 | 49 |
| Inshore Total | | | 32 | 80 | 112 |
| Total | | 256 | 707 | 389 | 1352 |

The length composition of the inshore samples contained fewer larger fish, whereas the length compositions of the Ranfurly and White samples were similar (Figure 4). The KS bootstraps results confirmed the Ranfurly and White samples as similar at the 5% level (P < 0.059), whereas the Inshore and combined Ranfurly/White length distributions were statistically dissimilar (P <0.001). The reason for the lack of larger kingfish in the inshore samples is unknown, it cannot be assumed that large kingfish are absent from these areas. We excluded the Inshore length samples on the grounds that they did not contain a full size range.

Inshore



Ranfurly Bank



White Island
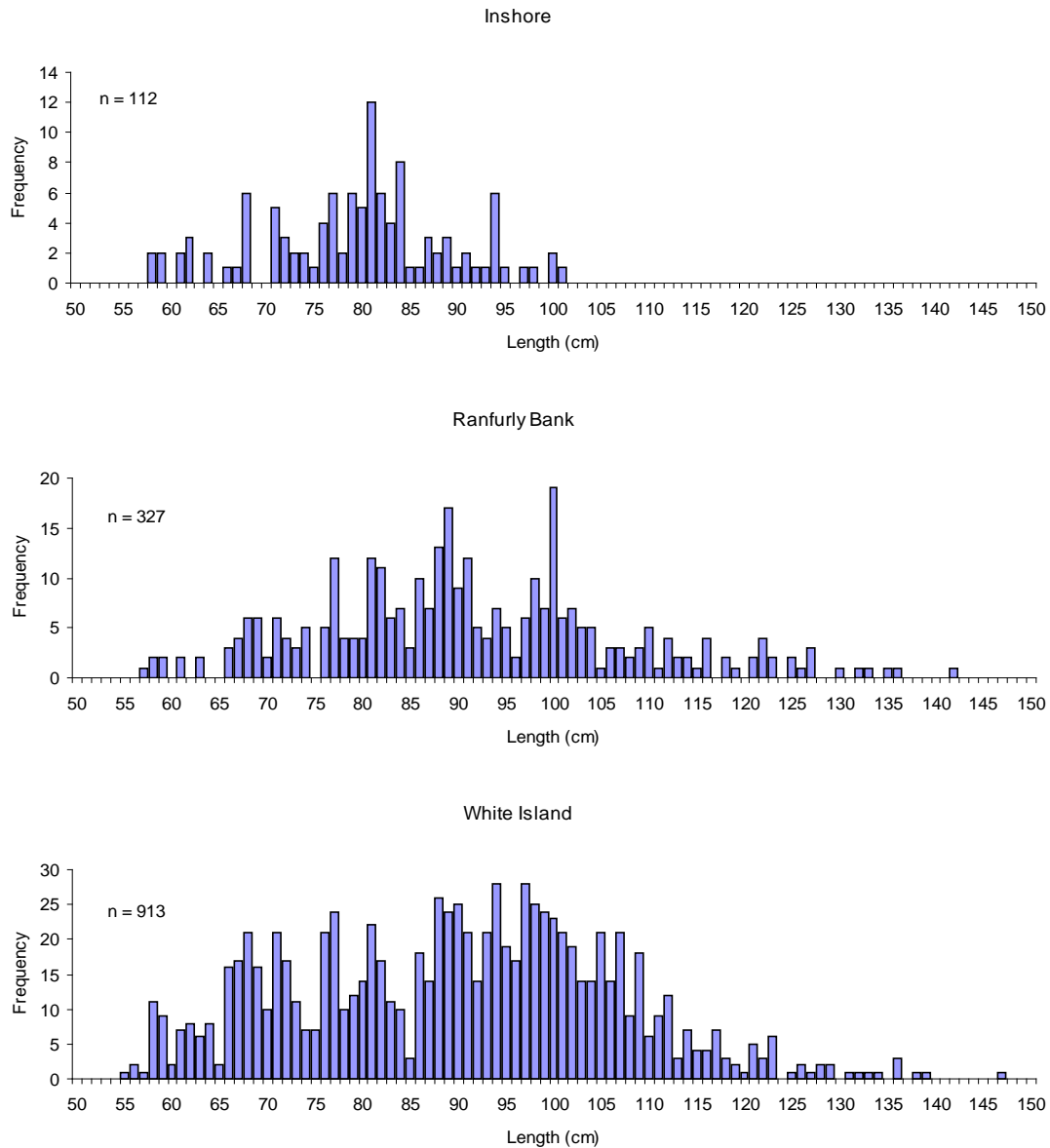


**Figure 4:** **Sampled kingfish length-frequencies by 'area'.**

The 'very-experienced' and 'experienced' angler-experience categories had similar length compositions; there were fewer larger fish in the 'novice' category (Figure 5). This again was supported by the KS bootstrap tests; the 'very-experienced' and 'experienced' angler-experience distributions were not statistically dissimilar at the 5% level ($P < 0.092$) whereas the 'novice' category differed statistically from the other categories combined ($P < 0.016$). We therefore excluded the length data from 'novice' experience-anglers on the grounds as above that their data did not contain a full size range.
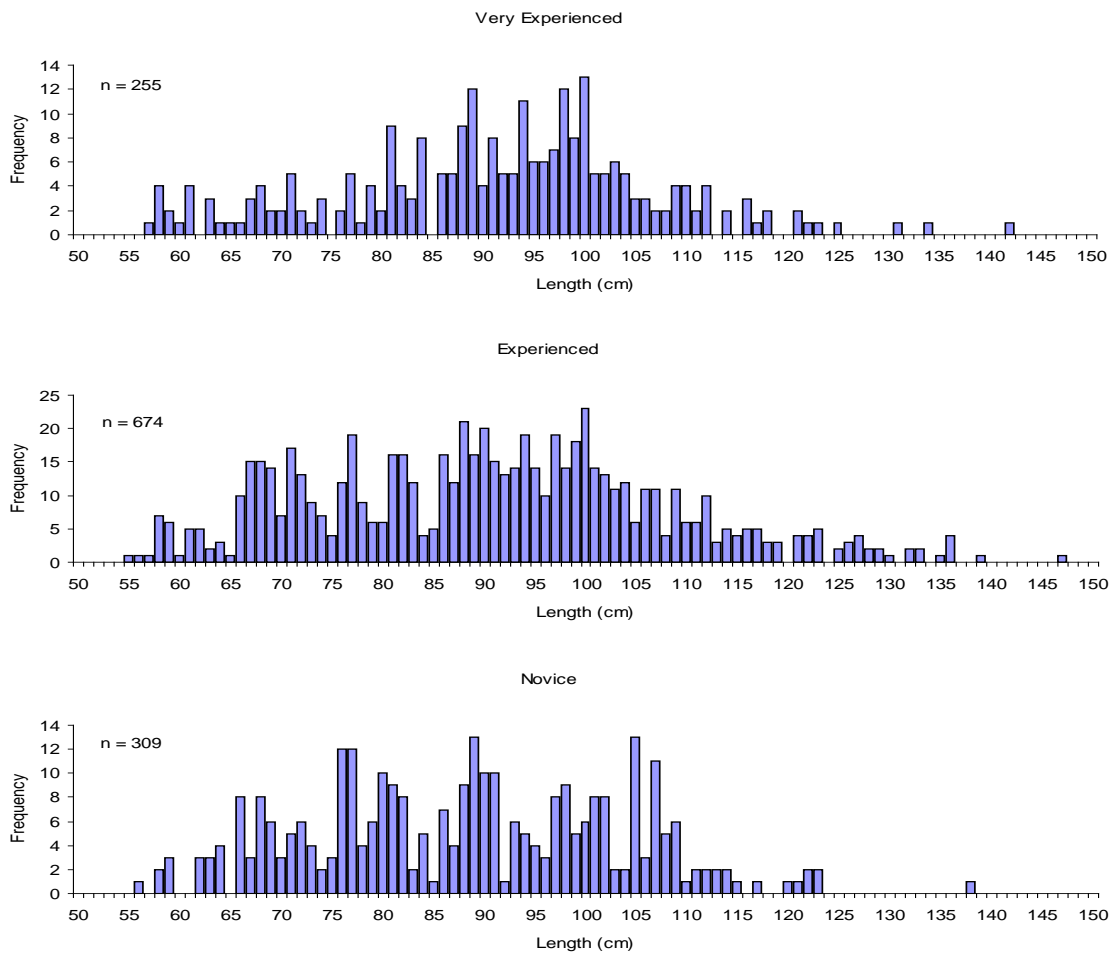
**Figure 5:** **Sampled kingfish length-frequencies in relation to 'angler-experience'.**

All three paired KS compositions of 'weather' were statistically different (Excellent/Average P < 0.009; Excellent/Poor P < 0.009; Average/Poor P < 0.009). Given that the length ranges of the three weather category distributions were similar (Figure 6) we concluded that there were no grounds *a posteriori* to reject or accept any specific set on the basis of it being more or less representative of the total kingfish population; the length data collected under all weather states were therefore combined (Figure 7). This distribution was assumed to represent the right-hand tail of the adult kingfish population in the eastern Bay of Plenty.
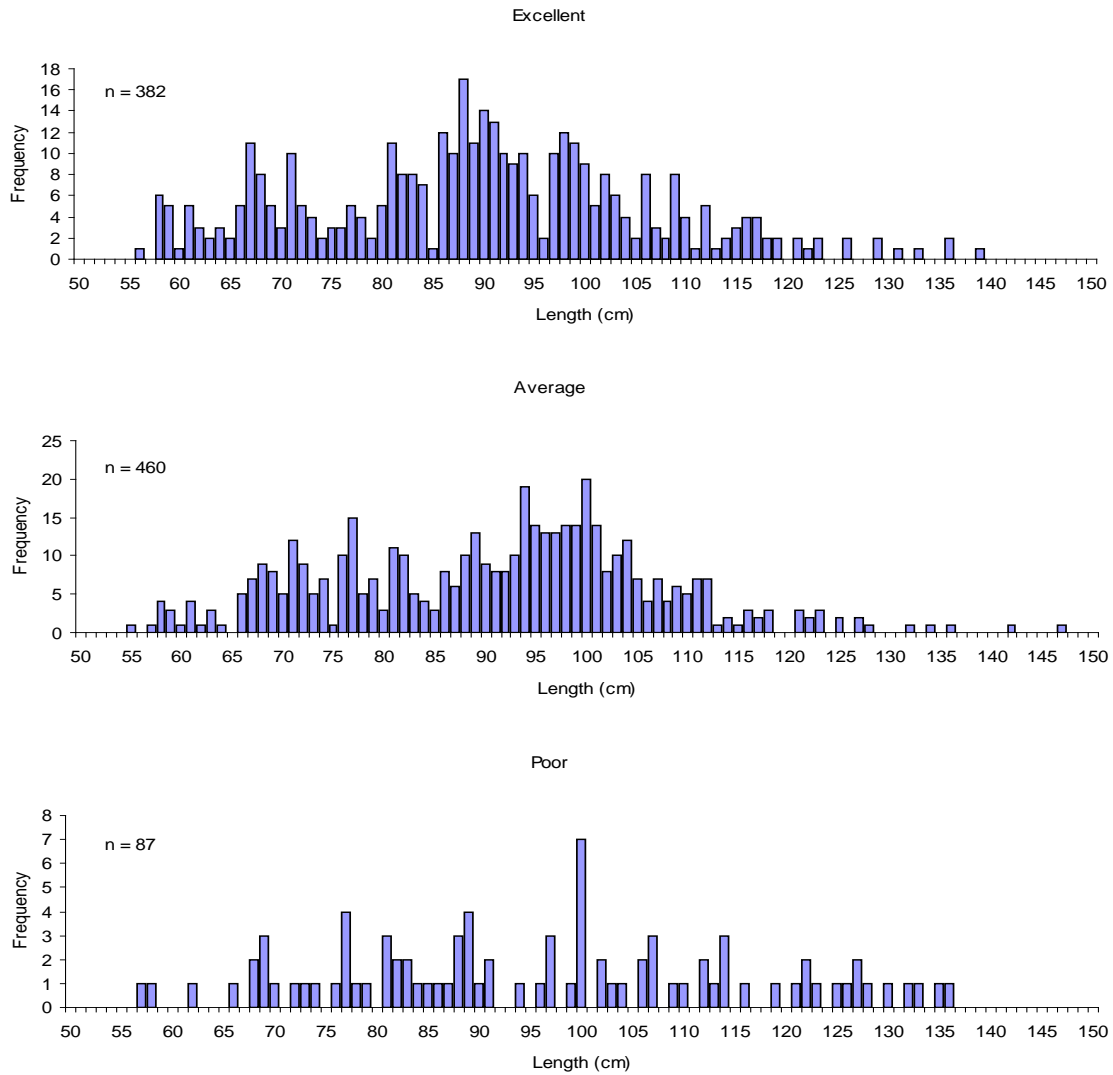
**Figure 6:** **Sampled kingfish length-frequencies in relation to 'weather condition'.**
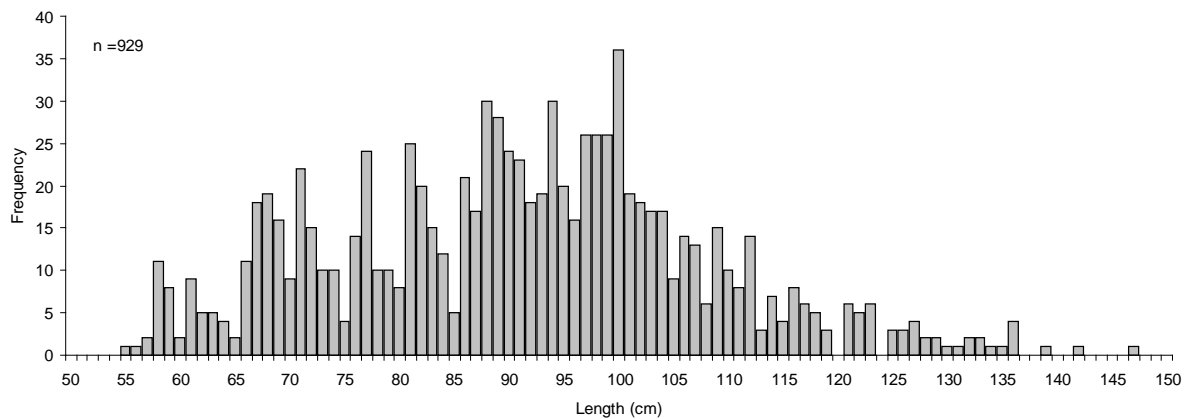


**Figure 7:** **Final combined WCB length distribution assumed to represent the right-hand tail of the adult kingfish population in the eastern Bay of Plenty.**

## 4.3.2 Age-frequency analysis

The final age-length-sex key was comprised of 111 female and 76 male kingfish (Figure 8). The age range of the female key was 4 to 22 years; the length range was 64 to 136 cm (Figure 8; Appendix 3). The age range of the male key was 4 to 23 years; the length range was 65 to 136 cm (Figure 8; Appendix 4).
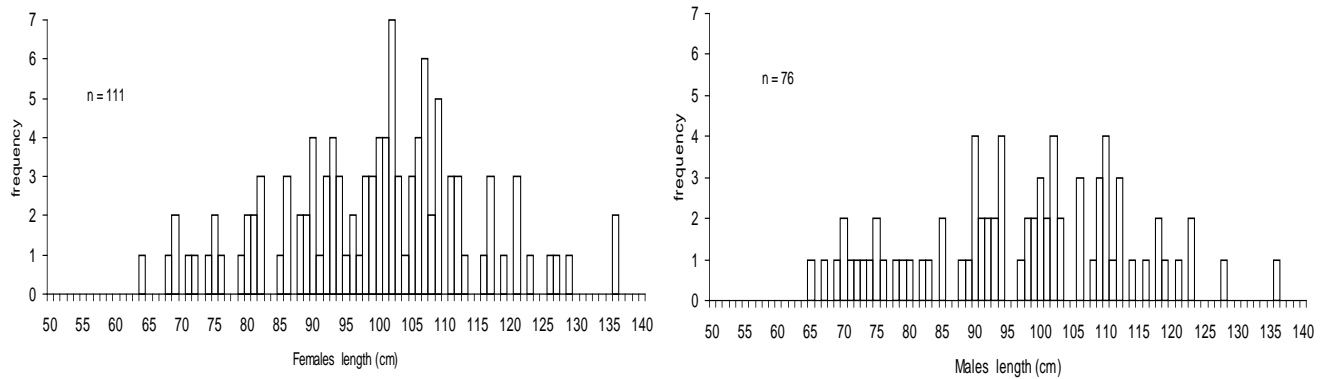


**Figure 8:** **Length frequency of unprojected age data by sex.**

The male and female age distributions were rescaled by projecting the WCB length data through the sex-age key (Figure 9).
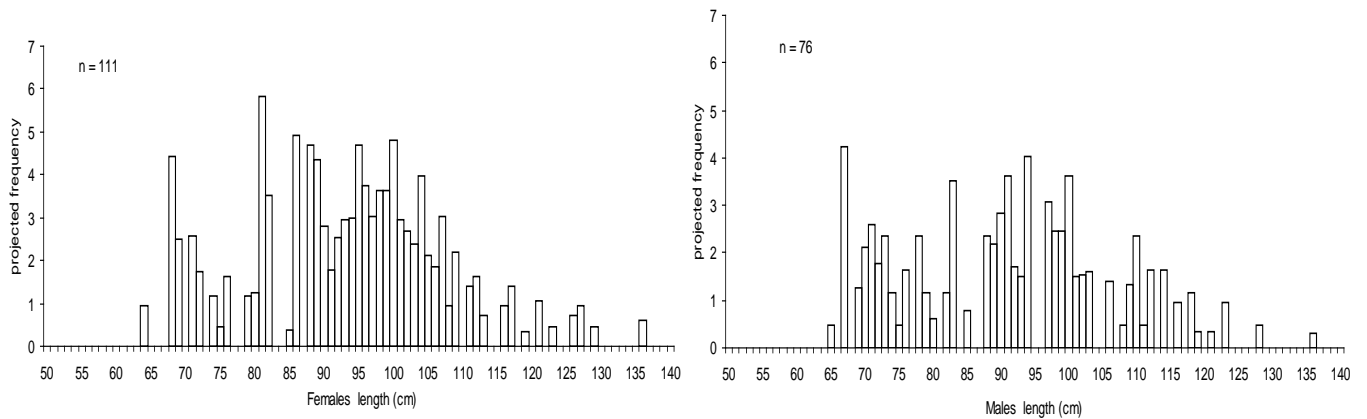


**Figure 9:** **Length composition of otolith age-sex sample after projection through the WCB proportional length frequency vector.**

### 4.3.3  Total mortality and natural mortality estimates

The male and female projected age distributions (Figure 9) were combined and the frequencies logged to create a combined-sex catch-curve (Figure 10). The curve shape suggests that the five, six and seven year old cohorts were unlikely to be have been fully recruited in the WCB catches (Figure 10). Using the Chapman & Robson (1960) approach the total mortality estimate (Z) for cohorts 8 years and older was 0.293.
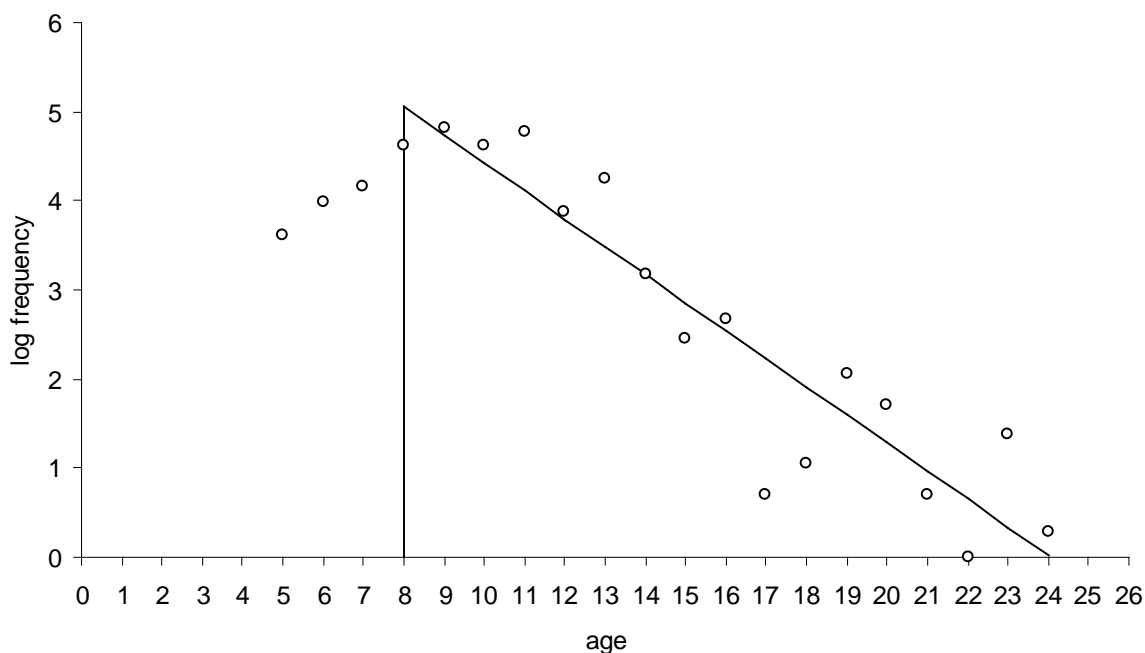


**Figure 10:  Catch curve based on the WCB age data (Chapman & Robson Z = 0.293 for 8+ cohorts based on a mean recruited age of 10.94 years).**

The Hoenig (1983) ratio for a maximum observed age of 24 years equates to a natural mortality (M) rate of 0.19.

### 4.3.4  von Bertalanffy growth estimates

von Bertalanffy growth estimates were derived from the east Northland FAD juvenile length data (section 2) and WCB age data for age cohorts 8 and older. The Poor Knights Islands FAD kingfish were assumed to be one year of age. The sexes of the Poor Knights Islands FAD kingfish were unknown so all these data were combined with both male and female components of the WCB age data.

The von Bertalanffy growth curves suggest that male and female kingfish grow at different rates (Figure 11). However, this hypothesis was not supported by the Kimura (1982) likelihood ratio test. The Kimura test  failed to show that separately fitted male and female von Bertalanffy parameters were significantly different from the sex combined values ($L_{inf}$ d.f. 1 $\chi^2$ 0.765516 P< 0.3816; $K$ d.f. 1 $\chi^2$ 0.2855 P < 0.5931; $t0$  d.f. 1 $\chi^2$ 0.0060 P < 0.9394; coincident d.f. 3 $\chi^2$  4.2146 P< 0.2392). Fits to the combined sex data set and the derived parameters are given in Table 2, Figure 12; Appendix 5 along with Bayesian 95% confidence intervals on mean length-at-age curve plotted in Figure 12 and tabulated in Appendix 5.

**Table 2:** **Male, female and combined kingfish von Bertalanffy growth parameters with associated standard deviation derived from maximum likelihood fits to Poor Knights and WCB age data (4, 5, 6,7 y-old cohorts not included in fits).**

|          | $L_{inf}$ | $K$   | $t0$    |
|----------|-----------|-------|---------|
| Female   | 149.950   | 0.086 | -1.434  |
| Stdev    | 4.843     | 0.005 | 0.070   |
| c.v.     | 0.032     | 0.060 | 0.049   |
|          |           |       |         |
| Male     | 131.780   | 0.105 | -1.314  |
| Stdev    | 5.254     | 0.009 | 0.108   |
| c.v.     | 0.040     | 0.088 | 0.082   |
|          |           |       |         |
| Combined | 140.580   | 0.096 | -1.339  |
| Stdev    | 3.447     | 0.005 | 0.066   |
| c.v.     | 0.025     | 0.050 | 0.049   |
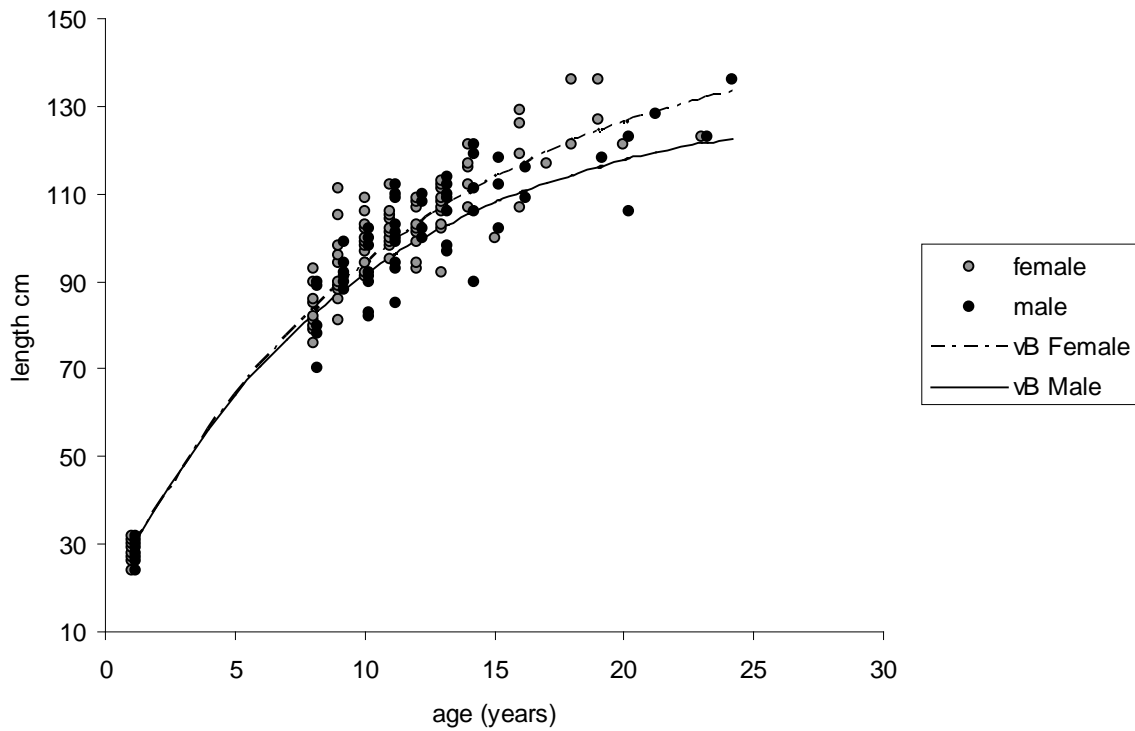


**Figure 11:** **Male and female von Bertalanffy growth curve fits to Poor Knights and WCB age data (4, 5, 6 7, 8 y-old cohorts not included in fits).**
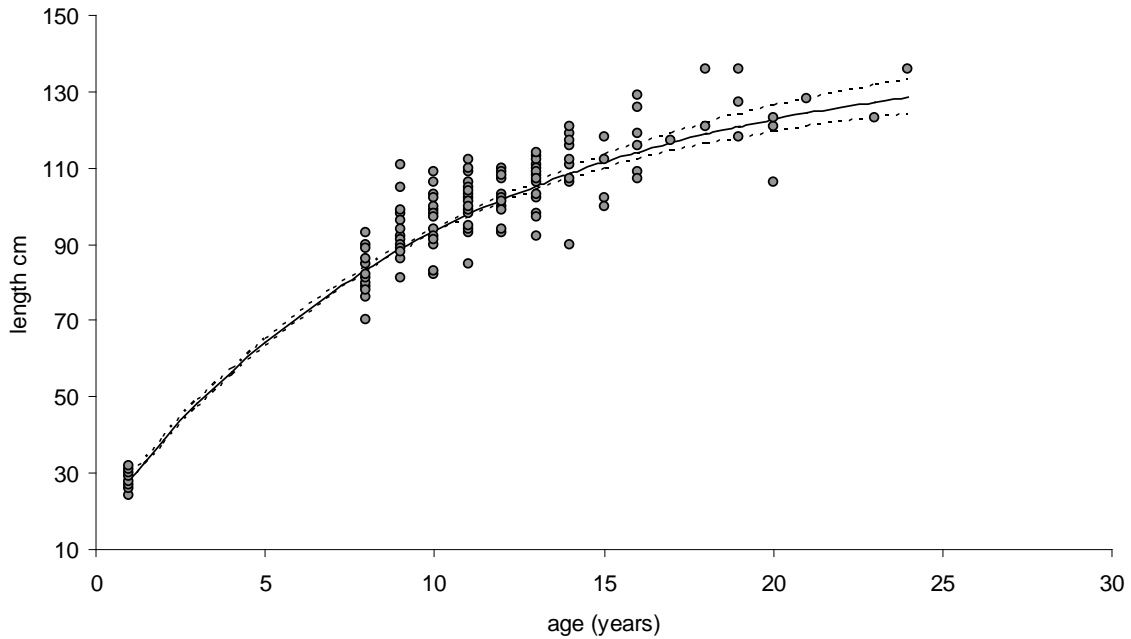
**Figure 12:** von Bertalanffy growth curve and Bayesian 95% confidence intervals fit to Poor Knights and WCB age data (4, 5, 6 7, 8 y-old cohorts not included in fits) both sexes combined.

## 4.4 Discussion

The validity of the total mortality (Z) and von Bertalanffy parameter estimates for eastern Bay of Plenty kingfish depends on the assumption that the WCB fishery was capable of catching a representative range of larger, older, fish (i.e. fish older than eight years of age). The WCB sample contained higher proportions of larger fish than were seen in the commercial length frequency data presented in Walsh et al. (2003). The WCB length frequency distribution was also markedly broader than Australian commercial catch sampling data (Stewart et al. 2001). Both of these observations suggest that the WCB data was likely to be representative of the underlying adult age and length structure. However, the rationale for excluding components of the length data was relatively subjective. If the inshore sample, which had proportionally more mid-sized fish, had been included the effect would have been to increase the steepness of the catch-curve (increase the estimate of Z) and increase the intrinsic rate-of-growth estimate (K); the maximum length estimate (Linf) would be likely to have been unaffected.

Fewer age samples were collected than were initially considered optimum for growth estimation (600). Age classes 8 through 14 were reasonably well represented in data whereas age classes 15 and above were represented by only one or two fish (Appendix 3; Appendix 4). The lack of data in the older age classes may mean that $L_{inf}$ was not well estimated. Estimates of *K,* these being determined more by the younger and faster-growing age classes, are more likely to be robust. The Kimura tests for sex-related differences in growth may have been influenced by the paucity of older-age observations and should be interpreted with caution.

The Chapman & Robson (1960) estimator and the 8+ catch curve regression results suggest that total mortality in eastern BOP kingfish was in the order of 0.30. The level of fishing mortality is not known, but current stock assessment information suggests that the east coast kingfish fishery (KIN 1) is unlikely to be heavily exploited (Annala 2003).

The validity of the Hoenig (1983) natural mortality estimate (0.19) rests on the assumption that fish older than the oldest fish observed (23 years) make up less than 1% of the adult population. The 23 y-old fish in the sample was 136 cm. Fish larger than 136 cm made up less than 1% of the WCB length

samples, their ages unknown. On the basis of its length (136 cm) the oldest observed fish's rarity is consistent with the Hoenig criteria. The otolith ageing precision results suggest that the true age of this fish is likely to be within two years of the estimated age, giving a likely upper bound of 0.18. The range of Gillanders et al.'s (2001) tagging-based estimate of natural mortality was 0.12 – 0.14. This range seems particularly low for a species that appears to have few individuals living longer than 20 years.

# 5 TAG BASED GROWTH ESTIMATES

## 5.1 Introduction

Tag-recapture programmes can provide growth increment data, as well as data on migration patterns and life history parameters. Since 1978, length data have been collected from recreational tagged and recaptured kingfish in Northland, Bay of Plenty and East Cape of New Zealand through the Ministry of Fisheries funded cooperative Gamefish Tagging Programme (GTP) which is ongoing.

The aim of this study was to derive von Bertalanffy growth parameter estimates using tag increment data from the Gamefish Tagging programme.

## 5.2 Methods

The Francis (1988) linear-increment growth model (GROTAG) was fitted to a 2004 extract from the GTP database, using a Maximum Likelihood estimator under assumed lognormal error about mean incremental growth. Data in the GTP database is classified as being of 'low', 'moderate' or 'high' reliability; being a reflection of the likely degree of accuracy. Only data classified as 'moderate' or 'high' reliability were used in the current GROTAG model fits (Table 3).

**Table 3:** **Number of tagged kingfish return observations from moderate to high reliability fishers by years-at-liberty.**

|  |  |  |  |  |  | Years at liberty |
|---|---|---|---|---|---|---|
| 0–1 | 1–2 | 2–3 | 3–4 | 4–5 | 5+ | Total |
| 226 | 66 | 28 | 17 | 5 | 9 | 351 |

A MCMC process was used to derive Bayesian posteriors on all parameters. Uniform priors were assumed on all estimated parameters. The GROTAG model parameters of interest were: $g50$ and $g100$ the mean annual growth increments at fish lengths of 50 and 100 cm; $u$ the bimodal seasonality amplitude parameter; $w$ the bimodal seasonality phase parameter. The von Bertalanffy growth parameters $K$ and $L_{inf}$ were derived algebraically from the GROTAG parameters. Hartill & Davies (1999) conducted a similar GROTAG analysis using a 1999 extract from the GTP database; their estimates were compared to the current estimates.

## 5.3   Results

The size-range of kingfish in the tagging extract was wide; the main mode in the data lay between 90 and 100 cm (Figure 13).
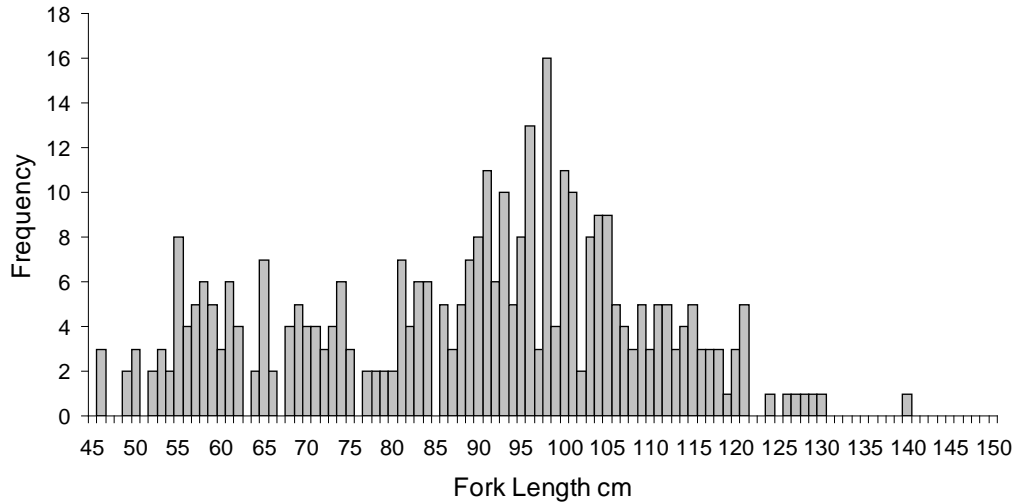


**Figure 13:   Length composition of tagging extract from the GTP database for moderate to high reliability fishers; n = 351 returns.**

The scatter plot of annual scaled increment data in Figure 14 shows both negative and positive incremental growth with the linear regression line through the data depicting an overall decrease in incremental growth with increasing length.
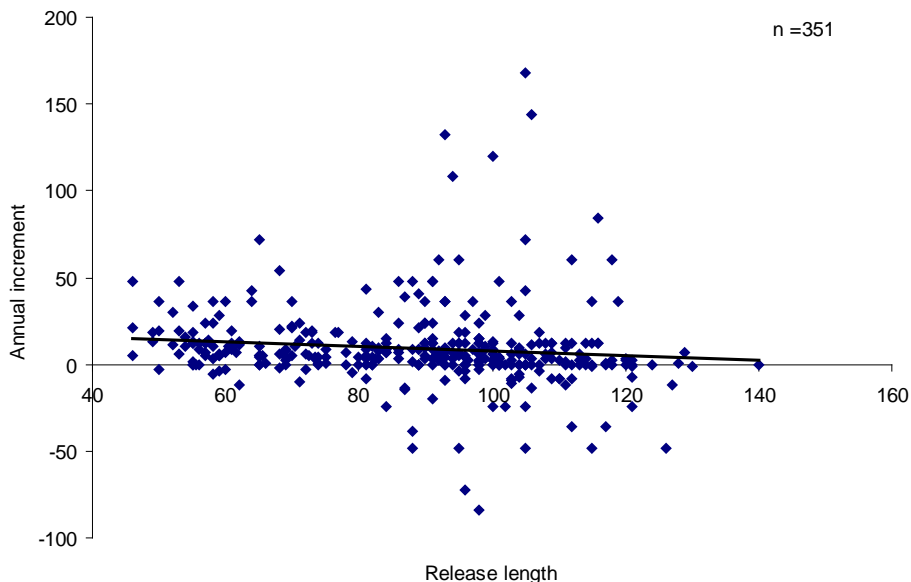


**Figure 14:   Scatterplot of kingfish annual length increments based on data from moderate to high reliability fishers. A linear regression line shows decreasing growth increments with length.**

The inclusion of the seasonal phase $w$ and amplitude $u$ parameters in the tagging estimator model significantly improved the likelihood fit to the tagging data ($\chi^2 = 7.313$; P< 0.0258; d.f. = 2). The revised tagging growth analysis produced a comparable estimate of $K$ to the Hartill and Davies (1999) analysis, but gave a higher estimate of $L_{inf}$ (Table 4). The seasonal phase parameter ($w$) estimate of 0.18 suggests February as being the month of maximum seasonal growth (Figure 15); which is consistent with that observed in juvenile kingfish at the Poor Knights FAD (Figure 1).

**Table 4:** **GROTAG parameters estimated from recreational tagging data in 2004 (n=351) and 1999 (n =214) (Hartill & Davies 1999).**

|  | 2004 | | 1999 | |
|---|---|---|---|---|
|  | Value | c.v. | Value | c.v. |
| g50 | 10.95 | 0.08 | 11.5 | 0.09 |
| g100 | 4.99 | 0.07 | 4.1 | 0.05 |
| u | 0.88 | 0.36 | - | - |
| w | 0.18 | 0.27 | - | - |
| K | 0.13 | 0.14 | 0.14 | - |
| Linf | 141.91 | 0.04 | 129.55 | - |
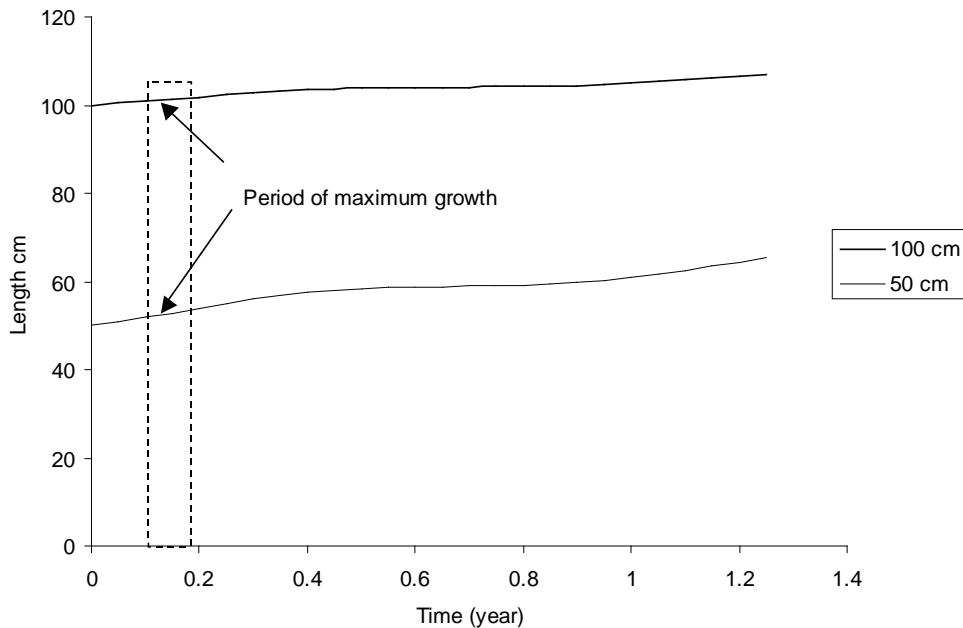


**Figure 15:** **Expected annual incremental growth of 50 and 100 cm kingfish as predicted by GROTAG incorporating seasonal growth.**

The estimated 2004 GROTAG curve and associated 95% Bayesian confidence intervals are given in Figure 16. The Hartill and Davies 1999 GROTAG tag curve and the WCB age-length model curve largely lie within the 95% confidence interval of the 2004 GROTAG curve (Figure 16).
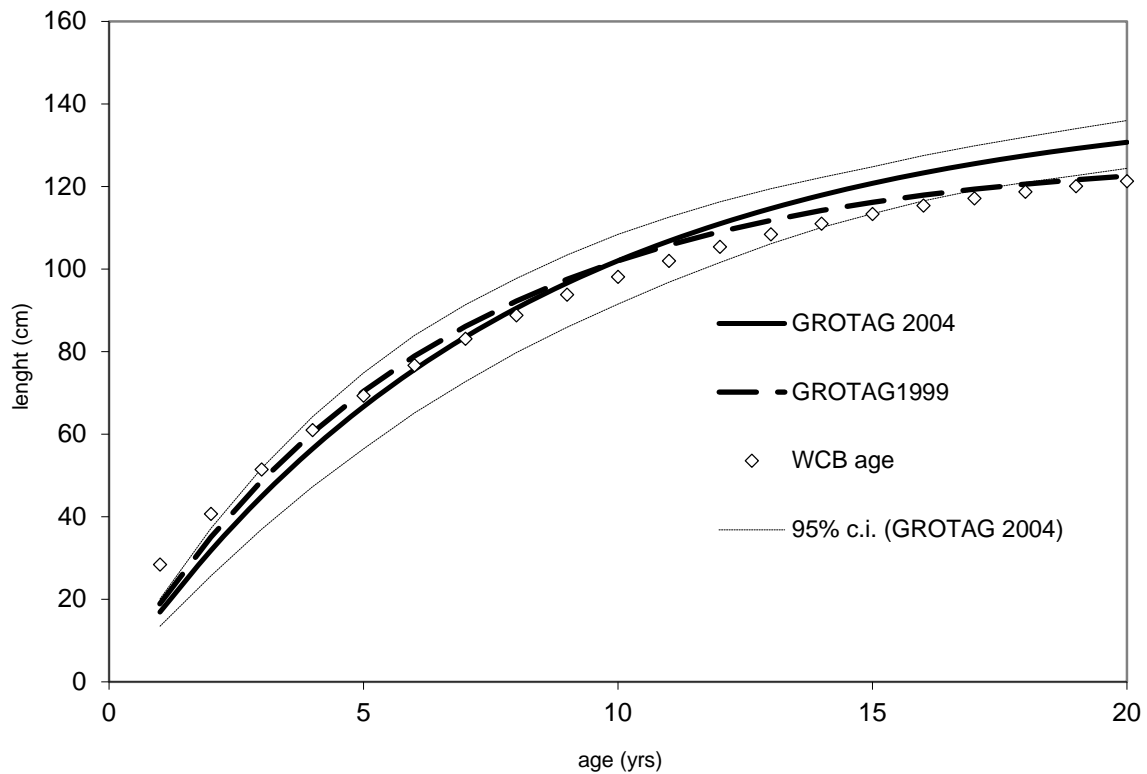
**Figure 16:** **Comparison of GROTAG 2004 (this study) and GROTAG 1999 (Hartill & Davies 1999) model curves and the WCB data von Bertalanffy growth model. Bayesian 95% confidence intervals are shown for the GROTAG 2004 growth curve.**

## 5.4 Discussion

The 2004 1999 GROTAG model curves and the growth curve fitted to the WCB data are not statistically dissimilar, i.e. all derived growth curves lay largely within the 95% confidence interval of the 2004 GROTAG curve. These results however are not consistent with GROTAG parameters obtained by Gillanders et al. (2001) derived from New South Wales recreational tagging data. Gillanders et al. (2001) annual increment estimates for 40 and 60 cm kingfish were 26.4 and 13.2 cm respectively; these equate to $K$ and $L_{inf}$ values of 1.07 and 80 cm. It is possible that south Australian kingfish grow faster than their New Zealand cousins but the Gillanders et al. (2001) implied estimate of $K$ seems too high to be credible. The majority of Gillanders et al. (2001) data came from kingfish under 80 cm. These are likely to have been younger and faster growing fish, and their growth estimates may have been biased. In an earlier report, Gillanders et al. (1999a) presented growth estimates derived from seasonal length information using the length analytical software MULTIFAN[TM] (Otter Research 1992). Their MULTIFAN derived estimates of $K$ and $L_{inf}$ were 0.18 and 125 cm; these are more consistent with our estimates.

# 6 REANALYSIS OF POORTENAAR ET AL (2001) SIZE AT MATURITY DATA

## 6.1 Introduction

Poortenaar et al. (2001) investigated patterns of kingfish gamete development, size at maturity and seasonal changes in gonad condition. Samples were collected from commercial and recreational fisheries along the west and east coasts of northern New Zealand between September 1998 and March 2000. Poortenaar et al. (2001) derived estimates of $L_{50}$ (the length at which 50% of fish are mature), by fitting a Weibull function to length and sexual maturity data collected during the summer spawning months. Their $L_{50}$ estimates were 81.15 cm for males (n =194) and 94.36 cm for females (n =205).

We reanalysed their data using Bayesian methods to calculate male and female $L_{50}$ estimates, and to derive 95% credibility intervals about these estimates.

## 6.2 Methods

Poortenaar et al. (2001) developed a macroscopic maturity index for kingfish comprising six stages for females and five for males (Appendix 6). Females with an index stage of three or greater were deemed to be mature. Males were classified as mature at stage two or greater. Changes in the monthly ratio of gonad weight to body weight (gonadosomatic index) were used to determine months of peak spawning. Only data collected in the peak spawning months (October – January) were used in the size at maturity analysis. Maturity ratios were calculated using 5 cm length bins. The length bins were assigned a value at the centre range of the bin for the purpose of fitting the model to the data (e.g. 90–95cm = 92.5; 95–100 cm =97.5). The data from the east and west coasts were combined as were data from the 1998 and 1999 summer spawning events.

The observed proportions of mature fish were fitted to an asymmetric Gompertz curve,

$$Y = a + b \exp\left[-\exp\left(-d\left(X - c\right)\right)\right]$$

where $X$ is the binned fork length in centimeters, $Y$ is the proportion of mature kingfish, and a, b, c, d are fitted regression coefficients. These coefficients have the following roles:
  a controls the lower asymptote (set to 0);
  b controls the upper asymptote (set to 1);
  c controls the maximum growth (estimated);
  d controls the growth rate (estimated).

The above equation can be rearranged to calculate the fork length at which 50% of the fish are mature, as follows:

$$L_{50} = c - \frac{1}{d} \ln\left( \ln\left| \frac{a - Y_{0.5}}{b} \right| \right)$$

The model was fitted to the data using a maximum likelihood method estimator under assumed lognormal error about numbers mature-at-length, using the auto-differentiation software AD Model Builder™ (Otter Research 2000). Uniform priors were assumed on all estimated parameters.

Confidence intervals for the $L_{50}$ parameters were generated from the posterior distributions using MCMC chains of length 100 000 where every tenth value was sampled. In addition a bootstrap approach was used where the data were randomly resampled with replacement, the model refitted and

a new estimate of $L_{50}$ was calculated for each resample. One thousand bootstrap estimates of $L_{50}$ were obtained for each sex.

## 6.3  Results

Poortenaar et al. (2001) data included observations from 268 female and 227 male kingfish. Gompertz model fits to the data are given in Figure 17. The estimated male $L_{50}$ value from the maximum likelihood fits under AD Model Builder™ was 83 cm (c.v. 0.002). The female $L_{50}$ value was 97 cm (c.v. 0.002).
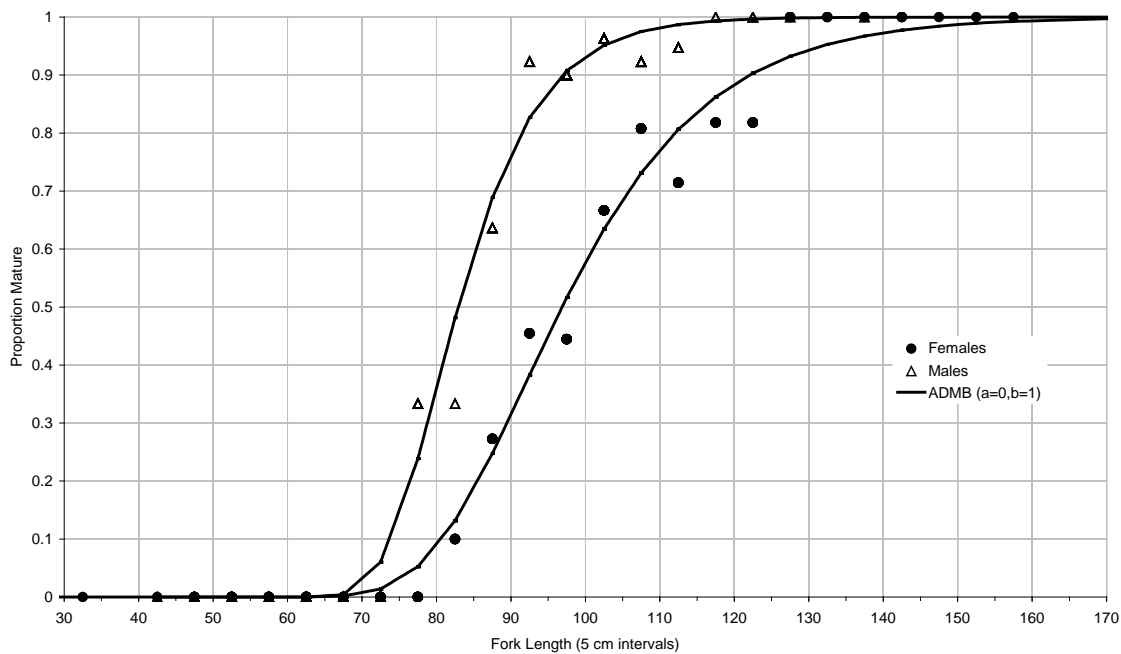


**Figure 17:  Fitted Gompertz curves for mature kingfish by 5 cm fork length intervals. Separate Gompertz models were fitted to the male and female data using maximum likelihood.**

$L_{50}$ 95% credibility intervals calculated from the MCMC model runs were 82.53–83.25 cm for males (Figure 18) and 96.46–97.27 cm for females (Figure 19). The estimated values of $L_{50}$ derived from the bootstraps were 83 for males and 97 for females. $L_{50}$ 95% confidence intervals as derived from 1000 bootstraps were 82.22–83.71 cm for males and 96.50–97.27 cm for females. The bootstrap results are similar to the MCMC results.
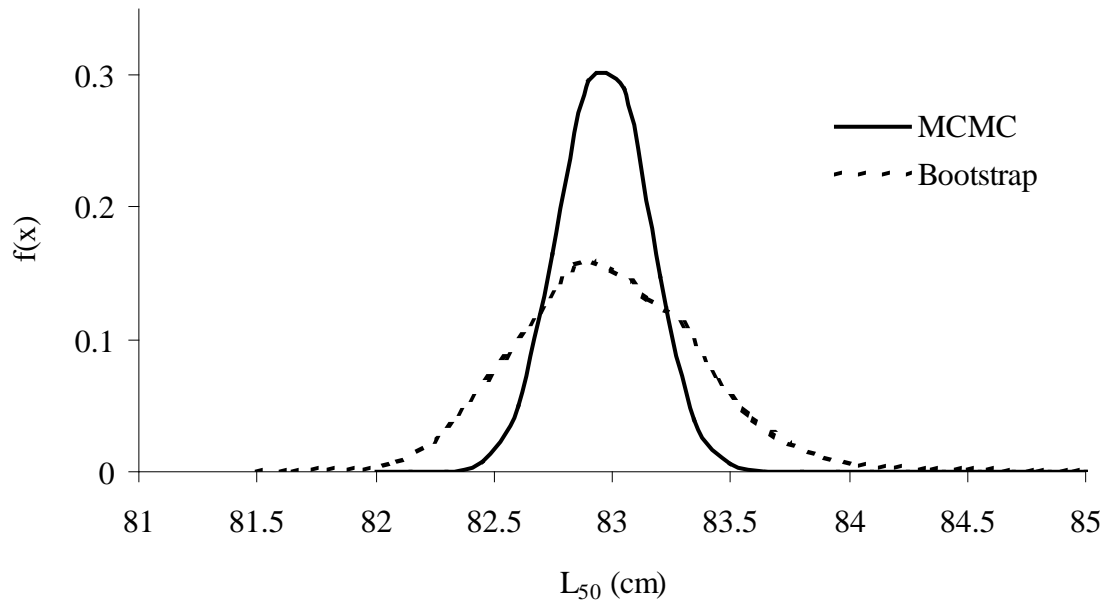
**Figure 18:** **Estimated Bayesian posterior distribution for male L$_{50}$ (solid line). The L$_{50}$ bootstrap distribution is provided for comparison (dashed line).**
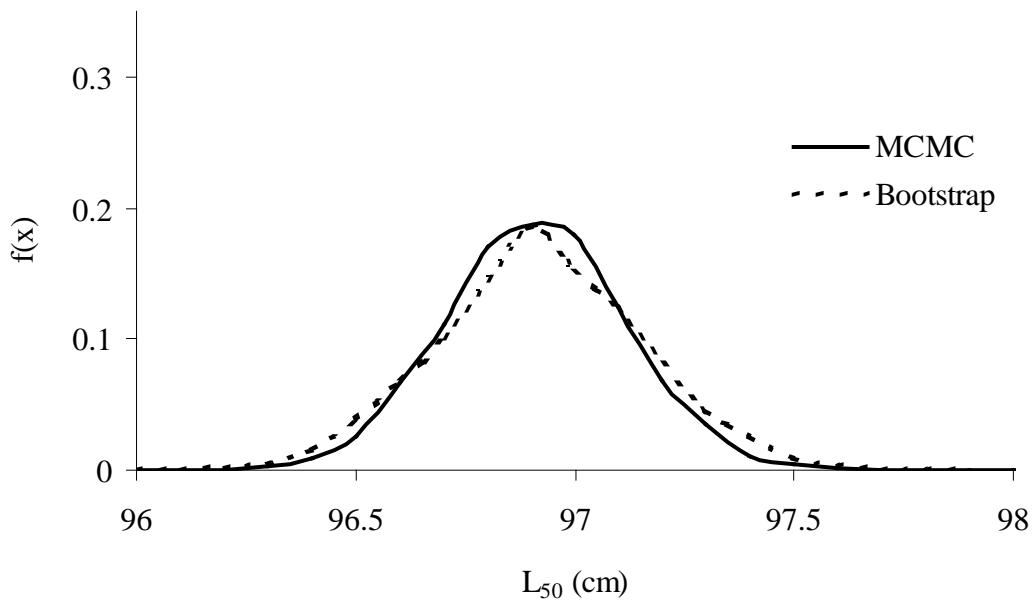


**Figure 19:** **Estimated Bayesian posterior distribution for female L$_{50}$ (solid line). The L$_{50}$ bootstrap distribution is provided for comparison (dashed line).**

## 6.4　Discussion

Both the bootstrap and the MCMC methods of deriving $L_{50}$ confidence intervals produced similar results; confidence bounds being relatively narrow around the $L_{50}$ male and female estimated values.

The $L_{50}$ estimates differ slightly from those published by Poortenaar et al. (2001) (males 83 cm compared with 81 cm; females 97 cm compared with 94 cm). Poortenaar also binned the fish into 5 cm intervals however they did not specify the value used to represent the length interval (lower; mid; upper), although we suspect they assigned the interval the lower bound value in their analyses. This study has used middle values for each bin as we believe this to be more appropriate.

The Poortenaar data set is made up of east and west coast North Island kingfish of which the analysis makes no distinction. The results therefore may be biased (direction unknown) if growth and maturity rates differ significantly between the two areas.

# 7    CONCLUSIONS

A monthly progression of modal lengths was observed in juvenile kingfish sampled at the Poor Knights Islands FADs. Otolith derived age estimates suggest that the length samples comprised a single cohort of 1+ age fish. The results indicate that it is feasible to track a single age cohort of young kingfish in the wild at least over their assumed second year of life. The data indicated that young kingfish grow quickly during summer with the possibility that growth slows during colder months. Otolith material collected from these fish may be useful in determining the status of the first otolith band in further investigations.

A thin section otolith preparation technique was found to be useful for estimating kingfish ages. Annuli were clearly discernable through a stereomicroscope on resin-embedded and sectioned kingfish sagittal otoliths. For otoliths with good readability score, exact between-reader agreement was 76% and within-one-zone agreement was 94% after adjustment was made for reader difference in first ring interpretation. The mean c.v. for between-reader ageing was 4.6%, which is good relative to other studies. The status of the first zone is yet to be proven, and the method used in this study to prepare and read kingfish otoliths has not been validated.

The length and age composition of the Whakatane Charter Boat (WCB) kingfish catch was broad. The age range of the females was 4 to 22 years. The age range of the males was 4 to 23 years.  The length range for both sexes was 55 to 147 cm. It was assumed that the WCB data was likely to be representative of the eastern Bay of Plenty mature kingfish population. The age structure indicated that kingfish were not fully recruited to the recreational charter boat fishery until age seven. A catch curve analysis produced total mortality estimates of 0.29; this in conjunction with the observed maximum age, suggest that a plausible range for natural mortality is 0.20 to 0.25.

There was some evidence in the raw WCB age data that female kingfish grow to a larger average length than males, however a Kimura likelihood ratio test did not support different growth curves for male and female kingfish. It is possible that future analyses my find a difference particularly if data from older large fish is available. Fitting a von Bertalanffy growth model to the sex-combined WCB data produced $K$ and $L_{inf}$ estimates of 0.096 and 140 cm respectively.

The von Bertalanffy growth curve derived for recreational tag increment data collected up to 2004 was not statistically dissimilar to the WCB age data curve; $K$ and $L_{inf}$ estimates of 0.13 and 142 cm respectively.

A reanalysis of Poortenar et al. (2001) length-at-maturity data using bootstrap and Bayesian methods produced relatively narrow confidence bonds around male and female $L_{50}$ (length at 50% maturity) estimates. The revised male $L_{50}$ estimate is slightly larger than the published Poortenar et al. (2001) value (82.89 cm compared with 81.15 cm). The revised female $L_{50}$ estimate is also larger (96.86 cm compared with 94.36 cm). We suspect that the differences between the two analyses were largely due to adopting the middle values of each 5 cm length bin in the current analysis rather than the lower interval value likely to have been used by Poortenar et al. (2001).

# 8    ACKNOWLEDGMENTS

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# 10 APPENDICES

**Appendix 1:      Comparing Length Frequency distributions by bootstrapping the Kolmogorov-Smirnov d-statistic.**

Descriptions of the Kolmogorov-Smirnov test for comparing two frequency distributions can be found in most good statistical texts, e.g., Sokal & Rohlf (2001). The KS test statistic is derived by expressing the two frequency distributions as cumulative curves with values from 0 to 1. The maximum proportional difference between the two curves is the KS d-statistic. The d-statistic random variable is described by the KS probability density function and this function underlies the classical KS parametric test. This test is typically overly sensitive to very large sample sizes typical of fisheries data and hence the test is prone to Type I error (falsely rejecting the null hypothesis). To overcome this problem a bootstrap procedure was used to derive expected distributions of the d-statistic against which the observed d-statistic could be compared. Two length frequency distributions were sampled with replacement from a combined distribution and a d-statistic computed. The bootstrap process was repeated 10 000 times to generate an expected distribution for the d-statistic. The original d-statistic was then compared to generated distribution. The proportion of bootstrap d-statistic values less than the observed value was considered to represent the rejection probability of the null hypothesis (Type I rejection probability). The test is by nature only one-tailed in the sense that very small d-statistic values, although unlikely, represent almost perfect correspondence between the two compared distributions. We should therefore be interested only in the rejection tail corresponding to large d-statistic values (i.e., the right hand tail).

**Appendix 2:** **Length frequencies of juvenile kingfish caught at the Poor Knights FADs and Tutakaka coast between 19/02/02 and 25/06/02.**

|  | Frequency | | | |
|---|---|---|---|---|
| Length (cm) | Week 1 FAD | Week 9 FAD | Week 16 Ngunguru Horahora | Week 20 Ngunguru |
| 20 | 0 | 0 | 0 | 0 |
| 21 | 0 | 0 | 0 | 0 |
| 22 | 0 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 0 |
| 24 | 1 | 0 | 0 | 0 |
| 25 | 0 | 0 | 0 | 0 |
| 26 | 4 | 0 | 0 | 0 |
| 27 | 1 | 0 | 0 | 0 |
| 28 | 11 | 0 | 0 | 0 |
| 29 | 8 | 0 | 0 | 0 |
| 30 | 4 | 0 | 0 | 0 |
| 31 | 3 | 2 | 0 | 0 |
| 32 | 2 | 2 | 0 | 0 |
| 33 | 0 | 5 | 0 | 0 |
| 34 | 0 | 11 | 1 | 0 |
| 35 | 0 | 7 | 0 | 0 |
| 36 | 0 | 2 | 0 | 2 |
| 37 | 0 | 1 | 2 | 5 |
| 38 | 0 | 1 | 4 | 5 |
| 39 | 0 | 0 | 3 | 8 |
| 40 | 0 | 0 | 0 | 3 |
| 41 | 0 | 0 | 0 | 5 |
| 42 | 0 | 0 | 0 | 2 |
| 43 | 0 | 0 | 0 | 0 |
| 44 | 0 | 0 | 0 | 0 |
| 45 | 0 | 0 | 0 | 1 |
| Mean | 28.59 | 34 | 37.7 | 39.13 |
| Total | 34 | 31 | 10 | 31 |

| length | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | | | | | | | | | | | | | | | | | | | | 0 |
| 51 | | | | | | | | | | | | | | | | | | | | 0 |
| 52 | | | | | | | | | | | | | | | | | | | | 0 |
| 53 | | | | | | | | | | | | | | | | | | | | 0 |
| 54 | | | | | | | | | | | | | | | | | | | | 0 |
| 55 | | | | | | | | | | | | | | | | | | | | 0 |
| 56 | | | | | | | | | | | | | | | | | | | | 0 |
| 57 | | | | | | | | | | | | | | | | | | | | 0 |
| 58 | | | | | | | | | | | | | | | | | | | | 0 |
| 59 | | | | | | | | | | | | | | | | | | | | 0 |
| 60 | | | | | | | | | | | | | | | | | | | | 0 |
| 61 | | | | | | | | | | | | | | | | | | | | 0 |
| 62 | | | | | | | | | | | | | | | | | | | | 0 |
| 63 | | | | | | | | | | | | | | | | | | | | 0 |
| 64 | | 1 | | | | | | | | | | | | | | | | | | 1 |
| 65 | | | | | | | | | | | | | | | | | | | | 0 |
| 66 | | | | | | | | | | | | | | | | | | | | 0 |
| 67 | | | | | | | | | | | | | | | | | | | | 0 |
| 68 | 1 | | | | | | | | | | | | | | | | | | | 1 |
| 69 | 1 | 1 | | | | | | | | | | | | | | | | | | 2 |
| 70 | | | | | | | | | | | | | | | | | | | | 0 |
| 71 | | | 1 | | | | | | | | | | | | | | | | | 1 |
| 72 | | | 1 | | | | | | | | | | | | | | | | | 1 |
| 73 | | | | | | | | | | | | | | | | | | | | 0 |
| 74 | | | 1 | | | | | | | | | | | | | | | | | 1 |
| 75 | 1 | | 1 | | | | | | | | | | | | | | | | | 2 |
| 76 | | | | 1 | | | | | | | | | | | | | | | | 1 |
| 77 | | | | | | | | | | | | | | | | | | | | 0 |
| 78 | | | | | | | | | | | | | | | | | | | | 0 |
| 79 | | | | 1 | | | | | | | | | | | | | | | | 1 |
| 80 | | | | 2 | | | | | | | | | | | | | | | | 2 |
| 81 | | | | 1 | 1 | | | | | | | | | | | | | | | 2 |
| 82 | | | | 3 | | | | | | | | | | | | | | | | 3 |
| 83 | | | | | | | | | | | | | | | | | | | | 0 |
| 84 | | | | | | | | | | | | | | | | | | | | 0 |
| 85 | | | | 1 | | | | | | | | | | | | | | | | 1 |
| 86 | | | | 2 | 1 | | | | | | | | | | | | | | | 3 |
| 87 | | | | | | | | | | | | | | | | | | | | 0 |
| 88 | | | | | 2 | | | | | | | | | | | | | | | 2 |
| 89 | | | | | 2 | | | | | | | | | | | | | | | 2 |
| 90 | | | 1 | 1 | 2 | | | | | | | | | | | | | | | 4 |
| 91 | | | | | | 1 | | | | | | | | | | | | | | 1 |
| 92 | | 1 | | | | 1 | | | 1 | | | | | | | | | | | 3 |
| 93 | | | | 3 | | | | 1 | | | | | | | | | | | | 4 |
| 94 | | | | | 1 | 1 | | 1 | | | | | | | | | | | | 3 |
| 95 | | | | | | | 1 | | | | | | | | | | | | | 1 |
| 96 | | 1 | | | 1 | | | | | | | | | | | | | | | 2 |
| 97 | | | | | | 1 | | | | | | | | | | | | | | 1 |
| 98 | | | | | 1 | 1 | 1 | | | | | | | | | | | | | 3 |
| 99 | | | | | | 1 | 1 | 1 | | | | | | | | | | | | 3 |
| 100 | | | | | | 1 | 2 | | | | 1 | | | | | | | | | 4 |
| 101 | | | | | | | 1 | 3 | | | | | | | | | | | | 4 |
| 102 | | | | | | 2 | 2 | 2 | 1 | | | | | | | | | | | 7 |
| 103 | | | | | | 1 | 1 | 1 | | | | | | | | | | | | 3 |
| 104 | | | | | | | 1 | | | | | | | | | | | | | 1 |
| 105 | | | | | 1 | | 1 | | 1 | | | | | | | | | | | 3 |
| 106 | | | | | | 1 | 1 | | 2 | | | | | | | | | | | 4 |
| 107 | | | | | | | | 1 | 3 | 1 | | 1 | | | | | | | | 6 |
| 108 | | | | | | | | 1 | 1 | | | | | | | | | | | 2 |
| 109 | | | | | | 1 | | 2 | 2 | | | | | | | | | | | 5 |
| 110 | | | | | | | | | | | | | | | | | | | | 0 |
| 111 | | | | | 1 | | | | 2 | | | | | | | | | | | 3 |
| 112 | | | | | | | 1 | | 1 | 1 | | | | | | | | | | 3 |
| 113 | | | | | | | | | 1 | | | | | | | | | | | 1 |
| 114 | | | | | | | | | | | | | | | | | | | | 0 |
| 115 | | | | | | | | | | | | | | | | | | | | 0 |
| 116 | | | | | | | | | | 1 | | | | | | | | | | 1 |
| 117 | | | | | | | | | | 2 | | | 1 | | | | | | | 3 |
| 118 | | | | | | | | | | | | | | | | | | | | 0 |
| 119 | | | | | | | | | | | | 1 | | | | | | | | 1 |
| 120 | | | | | | | | | | | | | | | | | | | | 0 |
| 121 | | | | | | | | | | 1 | | | | 1 | | 1 | | | | 3 |
| 122 | | | | | | | | | | | | | | | | | | | | 0 |
| 123 | | | | | | | | | | | | | | | | | | | 1 | 1 |
| 124 | | | | | | | | | | | | | | | | | | | | 0 |
| 125 | | | | | | | | | | | | | | | | | | | | 0 |
| 126 | | | | | | | | | | | | 1 | | | | | | | | 1 |
| 127 | | | | | | | | | | | | | | | 1 | | | | | 1 |
| 128 | | | | | | | | | | | | | | | | | | | | 0 |
| 129 | | | | | | | | | | | | 1 | | | | | | | | 1 |
| 130 | | | | | | | | | | | | | | | | | | | | 0 |
| 131 | | | | | | | | | | | | | | | | | | | | 0 |
| 132 | | | | | | | | | | | | | | | | | | | | 0 |
| 133 | | | | | | | | | | | | | | | | | | | | 0 |
| 134 | | | | | | | | | | | | | | | | | | | | 0 |
| 135 | | | | | | | | | | | | | | | | | | | | 0 |
| 136 | | | | | | | | | | | | | | 1 | 1 | | | | | 2 |
| 137 | | | | | | | | | | | | | | | | | | | | 0 |
| 138 | | | | | | | | | | | | | | | | | | | | 0 |
| 139 | | | | | | | | | | | | | | | | | | | | 0 |
| 140 | | | | | | | | | | | | | | | | | | | | 0 |
| **Total** | 3 | 4 | 5 | 15 | 13 | 12 | 13 | 13 | 15 | 6 | 1 | 4 | 1 | 2 | 2 | 1 | | | 1 | 111 |

| length | age 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | Tot |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 60 | | | | | | | | | | | | | | | | | | | | | |
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| 63 | | | | | | | | | | | | | | | | | | | | | |
| 64 | | | | | | | | | | | | | | | | | | | | | |
| 65 | 1 | | | | | | | | | | | | | | | | | | | | |
| 66 | | | | | | | | | | | | | | | | | | | | | |
| 67 | | | 1 | | | | | | | | | | | | | | | | | | |
| 68 | | | | | | | | | | | | | | | | | | | | | |
| 69 | 1 | | | | | | | | | | | | | | | | | | | | |
| 70 | 1 | | | 1 | | | | | | | | | | | | | | | | | |
| 71 | | | 1 | | | | | | | | | | | | | | | | | | |
| 72 | | 1 | | | | | | | | | | | | | | | | | | | |
| 73 | | | | 1 | | | | | | | | | | | | | | | | | |
| 74 | | | | 1 | | | | | | | | | | | | | | | | | |
| 75 | | 1 | | 1 | | | | | | | | | | | | | | | | | |
| 76 | | | | 1 | | | | | | | | | | | | | | | | | |
| 77 | | | | | | | | | | | | | | | | | | | | | |
| 78 | | | | 1 | | | | | | | | | | | | | | | | | |
| 79 | | | 1 | | | | | | | | | | | | | | | | | | |
| 80 | | | | 1 | | | | | | | | | | | | | | | | | |
| 81 | | | | | | | | | | | | | | | | | | | | | |
| 82 | | | | | | | 1 | | | | | | | | | | | | | | |
| 83 | | | | | | | 1 | | | | | | | | | | | | | | |
| 84 | | | | | | | | | | | | | | | | | | | | | |
| 85 | | | 1 | | | | 1 | | | | | | | | | | | | | | |
| 86 | | | | | | | | | | | | | | | | | | | | | |
| 87 | | | | | | | | | | | | | | | | | | | | | |
| 88 | | | | | 1 | | | | | | | | | | | | | | | | |
| 89 | | | | 1 | | | | | | | | | | | | | | | | | |
| 90 | | | | 1 | 1 | 1 | | | | 1 | | | | | | | | | | | |
| 91 | | | | | 1 | 1 | | | | | | | | | | | | | | | |
| 92 | | | | | 1 | 1 | | | | | | | | | | | | | | | |
| 93 | | | 1 | | | | 1 | | | | | | | | | | | | | | |
| 94 | | | | | 2 | | 2 | | | | | | | | | | | | | | |
| 95 | | | | | | | | | | | | | | | | | | | | | |
| 96 | | | | | | | | | | | | | | | | | | | | | |
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| 98 | | | | | | 1 | | | 1 | | | | | | | | | | | | |
| 99 | | | | | 1 | | 1 | | | | | | | | | | | | | | |
| 100 | | | | | | 1 | 1 | 1 | | | | | | | | | | | | | |
| 101 | | | | | | | 2 | | | | | | | | | | | | | | |
| 102 | | | | | | 2 | | 1 | | | | 1 | | | | | | | | | |
| 103 | | | | | | | 2 | | | | | | | | | | | | | | |
| 104 | | | | | | | | | | | | | | | | | | | | | |
| 105 | | | | | | | | | | | | | | | | | | | | | |
| 106 | | | | | | | | | 1 | 1 | | | | | | 1 | | | | | |
| 107 | | | | | | | | | | | | | | | | | | | | | |
| 108 | | | | | | | | 1 | | | | | | | | | | | | | |
| 109 | | | | | | | 1 | | 1 | | | 1 | | | | | | | | | |
| 110 | | | | | | | 1 | 1 | 2 | | | | | | | | | | | | |
| 111 | | | | | | | | | | 1 | | | | | | | | | | | |
| 112 | | | | | | | 1 | | 1 | | 1 | | | | | | | | | | |
| 113 | | | | | | | | | | | | | | | | | | | | | |
| 114 | | | | | | | | | 1 | | | | | | | | | | | | |
| 115 | | | | | | | | | | | | | | | | | | | | | |
| 116 | | | | | | | | | | | | 1 | | | | | | | | | |
| 117 | | | | | | | | | | | | | | | | | | | | | |
| 118 | | | | | | | | | | | 1 | | | | 1 | | | | | | |
| 119 | | | | | | | | | | 1 | | | | | | | | | | | |
| 120 | | | | | | | | | | | | | | | | | | | | | |
| 121 | | | | | | | | | | 1 | | | | | | | | | | | |
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| 123 | | | | | | | | | | | | | | | | 1 | | | 1 | | |
| 124 | | | | | | | | | | | | | | | | | | | | | |
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| 137 | | | | | | | | | | | | | | | | | | | | | |
| 138 | | | | | | | | | | | | | | | | | | | | | |
| 139 | | | | | | | | | | | | | | | | | | | | | |
| 140 | | | | | | | | | | | | | | | | | | | | | |
| **Total** | 3 | 3 | 8 | 5 | 7 | 9 | 13 | 4 | 8 | 5 | 3 | 2 | | | 1 | 2 | 1 | | 1 | 1 | |

**Appendix 5:** **Estimates of mean length and weight at age as derived from the von Bertalanffy growth fit to the total projected age sample. 95% confidence intervals are based on Bayesian posteriors. (length weight parameters a = 0.03651 b = 2.762 from Walsh et al. 2003 both sexes combined).**

| | Length (cm) | | | Weight (kg) | | |
|---|---|---|---|---|---|---|
| Age | $\overline{x}$ | Lower 95 | Upper 95 | $\overline{x}$ | Lower 95 | Upper 95 |
| 1 | 28.42 | 27.68 | 29.21 | 0.38 | 0.35 | 0.41 |
| 2 | 38.73 | 38.01 | 39.42 | 0.89 | 0.84 | 0.93 |
| 3 | 48.10 | 47.21 | 48.99 | 1.62 | 1.54 | 1.70 |
| 4 | 56.60 | 55.64 | 57.59 | 2.53 | 2.42 | 2.66 |
| 5 | 64.32 | 63.36 | 65.28 | 3.61 | 3.46 | 3.76 |
| 6 | 71.33 | 70.39 | 72.26 | 4.80 | 4.63 | 4.97 |
| 7 | 77.70 | 76.84 | 78.48 | 6.08 | 5.89 | 6.25 |
| 8 | 83.48 | 82.78 | 84.20 | 7.41 | 7.24 | 7.59 |
| 9 | 88.73 | 88.13 | 89.29 | 8.77 | 8.61 | 8.92 |
| 10 | 93.50 | 92.96 | 93.98 | 10.14 | 9.97 | 10.28 |
| 11 | 97.83 | 97.23 | 98.40 | 11.49 | 11.29 | 11.67 |
| 12 | 101.77 | 100.95 | 102.55 | 12.81 | 12.52 | 13.08 |
| 13 | 105.34 | 104.30 | 106.42 | 14.09 | 13.71 | 14.49 |
| 14 | 108.59 | 107.21 | 110.02 | 15.32 | 14.79 | 15.88 |
| 15 | 111.53 | 109.82 | 113.37 | 16.50 | 15.80 | 17.26 |
| 16 | 114.21 | 112.15 | 116.41 | 17.61 | 16.75 | 18.56 |
| 17 | 116.64 | 114.25 | 119.19 | 18.67 | 17.63 | 19.82 |
| 18 | 118.85 | 116.13 | 121.75 | 19.66 | 18.44 | 21.01 |
| 19 | 120.86 | 117.78 | 124.10 | 20.60 | 19.17 | 22.15 |
| 20 | 122.68 | 119.27 | 126.26 | 21.47 | 19.85 | 23.23 |
| 21 | 124.34 | 120.63 | 128.24 | 22.28 | 20.48 | 24.25 |
| 22 | 125.84 | 121.86 | 130.06 | 23.03 | 21.07 | 25.22 |
| 23 | 127.21 | 122.96 | 131.73 | 23.73 | 21.60 | 26.12 |
| 24 | 128.45 | 123.95 | 133.27 | 24.38 | 22.08 | 26.97 |

**Appendix 6:**     **Staging classification adopted to determine maturity status of male and female kingfish.**

While most kingfish gonads are easy to stage macroscopically, they can be ambiguous when they lie between spent and regressed ovarian stages (a) or spent and spermatogenic testis stages (b). This is the difference between mature and immature.
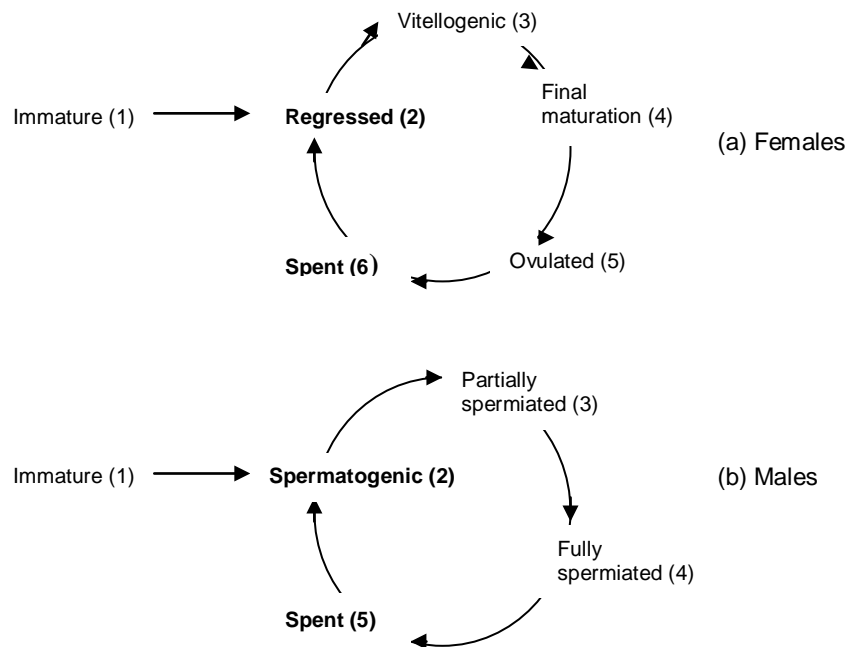


**Cycle of reproductive development in (a) female and (b) male kingfish.  Bold text bounds the gonad stages that are difficult to differentiate macroscopically.**