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Contents

Introduction

The genus *Arripis* Jenyns contains four species endemic to temperate Australian and New Zealand waters (Paulin 1993). The tommy rough, *A. georgianus* (Valienciennes), and the western Australian salmon, *A. truttaceus* (Cuvier), are endemic to Australian waters. The northern kahawai, *A. xylabion* Paulin, is found around northern New Zealand, Lord Howe Island, Norfolk Island, and the Kermadec Islands. The New Zealand kahawai or eastern Australian salmon, *A. trutta* (Bloch & Schneider), is found off southeastern Australia, Tasmania, and throughout New Zealand waters.

In New Zealand, kahawai are an important commercial, recreational, and traditional species (Annala & Sullivan 1996). Maori have long regarded kahawai as an important and valued food source, and among recreational fishers it is a highly desirable sportsfish, particularly on light tackle. Diary surveys between 1991 and 1994 in the Ministry of Fisheries South, Central, and North regions estimated the annual recreational catch to be about 1.5 million kahawai, or about 1800 t (Annala & Sullivan 1996). Commercially, most kahawai are caught by purseseine. The purseseine fishery had a catch limit set initially at 5356 t for the 1990–91 fishing year which was reduced in stages to 3551 t for the 1995–96 fishing year. Kahawai are also caught (often as bycatch) by set net, ring net, beach seine, trawling, and bottom longlining.

Historically, kahawai have been aged from scales and otoliths. Early Australian work (Fairbridge 1951, Malcolm 1959, 1960, 1966, Nicholls 1973) relied solely on scales. Maximum ages derived from these studies were 7 years for *Arripis trutta* and 9 years for *A. truttaceus* (Eggleston 1975).

Eggleston collected both scales and otoliths from *A. trutta* to determine the suitability of each for ageing. Scales were found to be unsuitable in fish over 5 years of age or 40 cm (FL), as "no period of annulus formation could be distinguished although subjective recording of the state of the scale edge indicated a cycle of growth and resorption" (Eggleston 1975). Otoliths proved more suitable and readings were taken from broken and burnt, or whole baked, otoliths. Later counts were restricted to whole baked otoliths. Otolith readings have shown that in New Zealand waters kahawai can live to at least 26 years (Eggleston 1977, 1978).

Wood *et al.* (1990) sampled kahawai from waters around New Zealand to provide age and length frequency information. Kahawai were aged from whole baked otoliths and broken, polished, and burned preparations. Age-length relationships were similar to those reported by Eggleston (1975).

The purpose of the present study was to develop and validate a standardised ageing methodology for kahawai by counting successive opaque and translucent (hyaline) growth zones in otoliths. Results from three preparation techniques were compared. Thin otolith sections were used for age validation by tetracycline injection. Length frequency data was used as an alternative method of validation by following year classes over a time series.

Methods

Otolith collection

Otoliths (sagittae) of kahawai were obtained from returned tagged fish, trawl surveys, catch samples, beach and purse seining, and recreational samples (Appendix 1). Much of the initial validation and otolith reading used otoliths from tagged and recaptured kahawai.

A kahawai tagging programme in 1991 aimed to validate age and growth through oxytetracycline (OTC) injection, and to "learn more about their [kahawai] distribution and behaviour" (Griggs 1995). Kahawai were caught by purseseine from FV *Waihola* in Tasman Bay and FVs *San Columbia, San Tortugas,* and *Western Ranger* in the Bay of Plenty. Each fish was measured (FL to the nearest whole centimetre below actual length), tagged, and given a 50 $mg.kg^{-1}$ intramuscular injection of OTC (Roscocycline-5) before release.

The OTC dosage rate was determined from earlier experiments with tank held kahawai (P. Taylor, NIWA, pers. comm.). A range of OTC doses were tested (0, 25, 50, 75, and 100 $mg.kg^{-1}$). At 25 $mg.kg^{-1}$ the OTC fluorescence in the otoliths was pale and indistinct, at 50 $mg.kg^{-1}$ it was clear and distinctive and there were no mortalities. At higher doses (75 and 100 $mg.kg^{-1}$) mortality levels were unacceptably high. However, tagging studies with snapper, *Pagrus auratus* (Francis *et al.* 1992), and flounder, *Rhombosolea leporina* and *R. retiaria* (Stevens 1993) have used a dose of 100 $mg.kg^{-1}$ successfully.

In all, 9606 kahawai were tagged: 4984 in Tasman Bay in March and 4622 in the Bay of Plenty in June. To November 1997, 1490 fish and/or tags (15.5% of fish released) had been returned (Griggs *et al.* in press).

Otolith preparation

Three methods were used to prepare kahawai otoliths for reading: thin sectioning; breaking, grinding, and baking; and breaking, grinding, and burning. All otoliths were broken or sectioned transversely through the nucleus. Ageing from whole baked otoliths (Eggleston 1975) was not attempted because of the poor correlation between ages from this region (the dorsal ridge in thin sections) and transverse sections, and the need for a consistent reading axis.

Thin sections

Kahawai otoliths, like those of most other teleosts, comprise a "series of lobes radiating from the nucleus" (Francis *et al.* 1992), reflecting the underlying epitaxial nature of otolith growth. The optimal sectioning plane was taken to be a dorsoventral axis through or close to the nucleus and the straightest, most uniform ventral lobe. The emphasis was placed on the ventral lobe as it is the most consistent readable axis. Most of the initial increment work was on thin sections.

Thin sections were prepared as follows. Each otolith was marked distally (sulcus side down) across the intended sectioning plane with a fine pen, then aligned in a disposable specimen mould with up to three other otoliths (depending on size). Each mould was filled with slow curing epoxy resin (Araldite K142) and heated to 50 °C for 24 h. Once hardened, a thin transverse section was cut out of each resin block with a Struers Accutom-2 low speed saw. One side of the section was then ground and polished and slide mounted (polished surface down) in quick setting epoxy resin (5-minute Araldite). After at least 1 h, each specimen was ground on a Struers Planopol-2 orbital grinder with a series of progressively finer carborundum papers (400, 1200, and 4000 grit) to a thickness of 250 to 350 μm (when increment clarity and resolution were optimal). A suspension of 1.0 μm alumina powder (Linde A) was used for the final polish. Thin sections were read with transmitted light under a binocular or a compound microscope. Polarised light filters were often used on lower magnifications to help enhance zone clarity.

To provide comparisons with other preparation techniques, several otoliths were prepared by the more conventional techniques of baking or burning, as follows.

Breaking, grinding, and baking

Each otolith was marked transversely across the nucleus with a fine pen, scored with a scalpel, and broken along the line. The preferred portion was ground and polished with a series of coarse and fine carborundums through to the nucleus. Each otolith was then baked in an oven (275 °C for 3 min) until amber coloured. When cool, the otoliths were mounted in plasticine on a strip of cardboard for reading. The polished otolith surface was covered lightly with immersion or paraffin oil and read with reflected lighting under a binocular microscope.

Breaking, grinding, and burning

Each otolith was marked, split, and polished across the nucleus. An alcohol flame was used to burn each otolith until opaque and translucent zones were visible. The prepared surface was lightly covered with immersion oil and examined under a binocular microscope with reflected light (McKenzie *et al.* 1992). This technique was relatively slow, and it required the otoliths to be mounted in plasticine or a similar mounting medium before reading.

Otolith reading protocol

A schematic diagram of a thin otolith section (Figure 1) gives the terminology and reading axes discussed in the text.

A series of opaque (dark) and translucent (clear) growth zones was visible in the thin otolith sections. These zones were dark (opaque) and light brown (translucent) respectively in baked and burnt preparations. The darker opaque zones were initially assumed to represent periods of dense, slower otolith growth, and the lighter translucent zones periods of relatively fast growth. For ageing purposes, opaque zones were counted in the regions either side of the sulcus where growth zones were clearest (Figure 1). In thin otolith sections, zonation patterns were clearest in the ventral side of the sulcus, and in broken and baked or burned preparations they were clearest in the dorsal side. Where possible, counts were obtained from both sides. If there was a discrepancy between counts, they were rechecked and the higher count used. Easily read zones were followed along the proximal face to help to ensure that increments were not omitted or misinterpreted. If an unrealistic gap was present between successive increments, and it seemed reasonable that an increment was not visible, then another year was added to the count.

The dorsal ridge and the relative size of the otolith were useful if a rough age estimate was needed for a difficult preparation (i.e., is the otolith about 5 or 10 years old?). In otoliths of older fish (over 10 years old) the outer increments are close together and at times difficult to interpret. Often there were crests or ridges along the proximal edge of otolith sections composed of 'extra' increments (as highlighted by broken arrows in Figure 1). Oxytetracycline validation work (*see* below) has shown that these zones are annual increments formed during periods of uneven otolith growth. If there was a crest or ridge along the proximal edge, all increments within it were counted. Otolith growth does not cease alongside these crests, but slows down to the point where it is not easily visible (Figure 2). In older fish it was often difficult to determine if an opaque zone was present on the edge of an otolith section. If the marginal increment (the outer most zone) was translucent and appeared wide enough to have an opaque margin, it was counted as an extra year.

Between-technique comparisons

Thin otolith sections versus baked otoliths

Baked preparations and thin sections from 200 day old, and 1, 2, and 3 year old kahawai were compared. One otolith from each fish was broken, ground, and baked, and the other was thin sectioned to allow direct comparisons between different preparations.

Baked versus burnt otoliths

To compare the appearance of broken and baked with broken and burnt preparations, 10 otoliths were randomly selected. Each was cut transversely through the nucleus with a diamond blade on a Struers Accutom-2 low speed saw. Both halves of each otolith were ground and polished on a Struers Planopol-2 orbital grinding wheel with fine and coarse carborundums (400 and 1200 grit). One half was baked for 6 min at 280 °C, and the other half was gently burnt over an alcohol flame. Both halves were then mounted in plasticine, the prepared surfaces coated with oil, and the counts compared. The otoliths were heated only moderately, and were a similar colour to the baked otoliths.

Age validation

Age validation was attempted by OTC injection, marginal increment analysis, and progression of juvenile length-frequency modes. Additional age and length-frequency information from the Hauraki Gulf was used for length modes in young kahawai.

Oxytetracycline (OTC) injection

All kahawai tagged in the 1991 tagging study were injected with OTC before release. A subsample of otoliths from tagged kahawai recaptures was aged and validated following the procedure described by Francis *et al.* (1992).

Each otolith was thin sectioned and photographed in transmitted light through a Wild photomacroscope. Photographs were assigned a sequential validation number and overlaid with a transparency sheet. Each otolith was aged by counting opaque zones on the thin-section photographs and marking these opaque zones on the transparency. The photographs were re-examined, this time knowing the date the fish was tagged (June 1991 in Bay of Plenty or March 1991 in Golden Bay) and the date of recapture. Based on this knowledge, the position of the OTC check was predicted and marked on the transparency. Each thin section was then examined under transmitted and ultraviolet light to clarify the actual position of the OTC check. Results were graded according to the following scale:

0	OTC check not visible
1	OTC check predicted in the correct zone and position
2	OTC check predicted in the correct zone but wrong position
3	OTC check predicted in the wrong zone and position

Marginal increment analysis

Validation by marginal increment and marginal state analysis was attempted for 150 thin otolith sections from recaptured tagged kahawai. In both techniques, thin otolith sections were evaluated and graded according to the completeness of their outermost (marginal) increment. Each otolith was graded according to both scales. Marginal state analysis is a simple system based on two grades, either the marginal increment was opaque (1) or translucent (2). Marginal increment analysis is more complicated and based on a six - point scale.

1	opaque zone just starting (barely visible)
2	opaque zone one-half complete
3	opaque zone complete
4	translucent zone just starting (barely visible)
5	translucent zone one-half complete
6	translucent zone complete

Progression of juvenile length frequencies

Unpublished length frequency data were available from monthly beach seine catches of juvenile kahawai in Wellington Harbour from May 1973 to September 1976. Data from January 1974 to December 1975 are comprehensive and suitable for determining growth rates and validating the first year's growth of juvenile kahawai.

Hauraki Gulf age-length data

Length frequency data for small kahawai were available from Hauraki Gulf trawl surveys over a 3 year period. Each trawl survey was conducted at about the same time of the year (late October to mid November), and the data show clear length modes which may represent year classes.

Between-reader and within-reader comparisons

To assess the level of within-reader variability, 328 otoliths were read twice by the author 4 years apart. Ninety-nine baked otolith preparations were re-read from the sample reported by Eggleston (1975) (between-reader variation) to help to assess the parameters calculated in that study.

Calculation of productivity parameters

Von Bertalanffy growth curves were fitted to the age-length data using a non-linear least squares fitting procedure in S. Separate equations were derived for each sex and area as appropriate.

Results

Otolith interpretation

The following interpretations relate to opaque zones, which appear dark when viewed as thin sections under transmitted light and an opaque white in reflected light. In baked preparations the dark zones correspond to opaque growth zones.

The nuclear region is thought to represent the first "winter" of the fish as a planktonic juvenile (kahawai recruit inshore at about 35–50 mm FL). The size of this initial zone varies greatly, possibly because of variable recruitment. (This region is easily distinguished from the 1 year zone by its small size and more symmetrical shape (Figure 3a.))

Beyond the nuclear region and before the first major opaque zone (the 1 year zone) there is a straw brown region (as viewed under transmitted light) which ends in an abrupt check (the "transition zone"). This region is usually easily distinguished from the 1 year zone. It is a noticeably darker hue than adjacent translucent regions and the outer check is thinner (and lighter) than adjacent opaque zones. This transition zone is visible in most thin sections but difficult to distinguish in baked preparations. The reason for this broad transitional zone is unknown.

The first broad opaque zone is usually the 1 year zone representing the second "winter" growth period (Figure 3b). This zone is distinct in thin sections but not always obvious in baked otoliths. The 1 year zone can be verified by following the first broad opaque zone dorsally and ventrally. Four main points distinguish the 1 year zone.

1. It is generally the first broad opaque zone beyond the nucleus.
2. It is the broadest of the opaque zones.
3. Dorsally it flattens and meets, or nearly meets, the edge.
4. Ventrally the 1 year opaque zone tapers to a blunt point.

With these criteria the 1 year zone may be distinguished even if it is not visible in the sulcal region. In late recruits or poor quality sections the 1 year zone may be closer to the nucleus and difficult to interpret. If the zone is tapered ventrally and slightly flattened dorsally (even if it is not close to the dorsal margin), it is likely to be the 1 year zone.

From a transverse section, the 1 year zone can be easily distinguished based on otolith shape at age 1. It is useful, however, to have a basic understanding of otolith growth as viewed in the transverse plane.

The otoliths of fish up to 6 months old (Figure 3a) are largely bilaterally symmetrical. In some specimens the ventral axis is slightly longer and more pointed than the dorsal axis. After the first year of growth the otolith (Figure 3b) becomes more asymmetrical with a longer ventral axis. Dorsally the otolith is usually slightly flattened; ventrally it is elongate and tapered. This is reflected by the shape of the first opaque band in older fish. During the second year of growth (Figure 3c) the dorsal edge becomes flatter and more pointed proximally, ventrally growth slows down considerably. Growth becomes largely confined to the proximal face with increasing age. Figure 3d shows the otolith of a 2+ year old fish. The opaque zone of the second winter is complete but the third opaque zone is yet to form. From the opaque increment spacing this otolith is from a 3 year old fish. A clear transition zone is visible in this illustration and in the one below it (Figure 3e). From the third year onwards (Figure 3e), the otolith becomes increasingly asymmetrical and growth is largely confined to the proximal face. This is thought to reflect the physical constraints of otic capsule size.

The proximal face of the dorsal edge angles outwards and becomes more attenuated with each year's growth. A rough age estimate can be obtained from counts along this dorsal ridge. Ventrally, growth is minimal and the increments are close together. Proximally, the otolith grows in a more uniform manner. A proportionality is maintained between increments even in the otoliths of very old fish. The most uniform and consistent regions of the otolith are immediately either side of the sulcus. In terms of increment clarity and readability the primary axis for thin sections is the area immediately ventral to the sulcus.

Between-technique comparisons

Thin otolith sections versus baked otoliths

For this comparison all otoliths were aged according to the otolith reading protocol (*see* above), and the ages were identical for each otolith examined. The following trends were derived from 33 pairs of otoliths.

The nuclear region is a pale opaque brown in baked preparations and a dark brown in thin sections. The pale opaque area in baked preparations often extends beyond the area of the nuclear region in thin sections, some times as far as the transition zone. The transition zone is difficult to distinguish in baked preparations. It is slightly darker than subsequent translucent regions, but the difference is minor. Reading errors are unlikely given the difficulty in finding this zone in baked preparations. The thin dark brown zones in the sulcal reading axes of baked preparations correspond to the opaque ("winter") zones of thin sections, although the translucent (hyaline or "summer") zones are broader and a more medium brown in baked preparations. This added width appears to correspond to the early transitional area of the opaque zone in thin sections. In this region there is a gradual change in texture and colour between late translucent and early opaque zones. In baked preparations this area is a medium rather than darker brown. The position of the first broad opaque zone or "1 year zone" is more difficult to determine in baked preparations than in thin sections, although if the first year is verified by following the zone dorsally and ventrally interpretation errors should be minimal.

This comparison indicates that counts from thin sections are comparable with counts from either baked or burnt preparations if the readers are experienced and only dark zones are counted. The most likely source of error between preparations derives from different interpretations of the first true annulus, which can be avoided by careful examination.

Baked versus burnt otoliths

Based on the 10 otoliths examined there was no detectable difference between the techniques. All otoliths were aged according to the otolith reading protocol, and the ages were identical for each otolith examined. This is not surprising as both rely on heating the otolith, one with a naked flame and the other by baking it. The results of this test suggested that the ages obtained by readers from Nelson and Wellington (who bake the otoliths) are comparable with those by readers in Auckland (who burn the otoliths), assuming that both groups used a similar reading protocol.

Age validation

OTC marks

Most (84.2%) thin otolith sections from tag returns showed a clearly visible OTC check when viewed under UV light (Table 1). The check usually occurred in the mid opaque zone in Bay of Plenty fish (tagged in June) and in the early (or occasionally mid) opaque zone in Tasman Bay fish (tagged in March).

In some preparations, the following made age validation difficult.

1. Although the OTC check was clearly defined in most preparations, it was not always visible in the regions either side of the sulcus. The relative position of the OTC check was then inferred by following increments along the proximal face to the reading axis.

2. Often the position of the OTC check appeared to vary along the proximal edge (from opaque through to translucent). For consistency and readability the ventral side of the sulcus is the most reliable area for OTC validation. Dorsally the OTC check often appeared to be out of alignment with the predicted position.

3. In most thin sections, otolith growth at liberty (and somatic growth) was significantly slower than pre-tagging growth, making validation difficult. This needed to be taken into account when reading otoliths. The opaque zones were sometimes very close together, often appearing to merge.

4. Otolith growth is not always uniform along the proximal face. As with many teleost species, deposition rates of new otolith material vary considerably between otoliths, particularly in older fish. Some otoliths showed relatively uniform growth increments along the reading surface: others had extremely restricted growth in some areas.

The position of the OTC check was predicted in the correct zone in 119 (86%) of the 139 thin otolith sections that were suitable for tetracycline validation (*see* Table 1). Ninety-four of these were predicted in the correct position in the correct zone. Only 20 sections were predicted in the wrong zone. The main sources of error were due to poor quality specimen preparation, very slow and uneven deposition of otolith material (while at liberty), and reader error. From the high correlation between the predicted and actual positions of the OTC check (86%), it is concluded that the opaque growth zones of kahawai otoliths are formed annually.

Marginal increment analysis

Initially, a sample of 150 thin sections was examined to test the feasibility of marginal increment and marginal state analysis as alternative means of "annual" increment validation. Unfortunately, this was difficult because of the effects of tagging on otolith growth. Opaque zone increment widths and clarity varied considerably between and within otoliths, and it was difficult to maintain a consistent reading axis throughout the sample. Of the 150 sections examined, only 41 were suitable for marginal increment analysis (Table 2). This sample exhibited no correlation between seasonality and the formation of opaque ("winter") growth zones. Given the successful validation of these increments through OTC injection of tagged fish, the failure of the marginal increment analysis is almost certainly due to interpretational problems with the otolith preparations.

Progression of juvenile length frequencies

Length frequency histograms of juvenile kahawai sampled by beach seine in Wellington Harbour from 1974 to 1975 (Figure 4) show a clear monthly progression of juvenile length modes, indicating seasonal changes in growth rates. Some kahawai recruit to estuarine and shallow coastal waters at 35–50 mm FL in March of each year. By May they are 40–60 mm FL and about 100 days old (Table 3). The range of ages suggests a protracted spawning period from early January to late February/early March, with a peak in early February. Based on this information, 1 February is taken to be the hypothetical "birthday". Growth is rapid, particularly during summer and early autumn (December to March), and by March the following year the 1+ fish are 80–130 mm FL.

An interesting size class appeared in March 1974 (Figure 4). These fish ranged from 80 to 136 mm FL, considerably larger than those sampled in previous months. The sample appears to have two distinct peaks, probably because of the small sample size (n = 26). This is likely to represent a wide range of growth rates from slightly different hatch dates, indicating a protracted spawning period.

Hauraki Gulf age-length data

Length frequency histograms of kahawai from Hauraki Gulf trawl surveys over a 3 year period (1992–94) show clear modal peaks at similar positions (Figure 5b–d), i.e., at 17–25, 25–33, and 33–41 cm FL. From age-length data from fish collected in the Hauraki Gulf at the same time of the year (Figure 5a) these modes represent 1+, 2+, and 3+ year old fish. The data probably represent the progression of three year classes over a 3 year period.

Within-reader and between-reader comparisons

Of the 328 otoliths that were read twice by the same reader (DWS) 74.1% of readings were identical, 24.4% were within 1 year, and the remaining 1.5% were within 3 years of the first reading (Table 4). There was a problem with ageing 4 and 5 year old fish in the first reading (February 1993). Thin otolith sections from 19 5-year-old and 10 6-year-old fish were underaged by 1 year. This was due primarily to problems interpreting the first year which have since been resolved, and to a lesser extent poor specimen preparation.

Of the 99 otoliths that were re-read, 28.3% of readings were identical, 41.4% were within 1 year, and the remaining 30.3% were within 5 years of Eggleston's (1975) readings (Table 5). There is poor correlation between the two readers, but in general the author's (DWS) readings are higher. This discrepancy may reflect differences in specimen preparation, and in interpreting the position of the first year. In general, Eggleston's otolith preparations were too light (not baked for long enough or at too low a temperature) and the reading surface was irregular and difficult to interpret. When the otoliths were originally baked they were simply broken in half and read. Before they were read a second time the reading surface of each otolith was ground flat and aligned with the nucleus, thereby clarifying the opaque growth zones.

Growth parameters

The estimation of growth parameters is described in Appendix 2. Von Bertalanffy growth parameters are provided for age-length data from the Bay of Plenty (Figure 6), the west coast South Island (Figure 7) and the east coast South Island (Figure 8). The fits obtained suggest that the simple Von Bertalanffy equation is inadequate to describe kahawai growth.

Discussion

Otolith interpretation

Eggleston (1975) and Wood *et al.* (1990 used the same preparation and ageing techniques and the age-length relationships were similar (Wood *et al.* 1990). Unfortunately, the present study has shown that readings taken from whole baked otoliths, particularly from older fish, are unreliable. The region used by Eggleston (immediately dorsal of the nucleus on the distal surface) corresponds to the dorsal ridge of transverse sections, which is useful only for rough age estimates. In young fish (under 7 years) there is often excellent agreement between sulcal counts and those obtained along the dorsal ridge. In older fish the outer increments are often very close together, punctuated by sub-annual checks (which are not visible in the sulcal reading axes) and difficult to interpret. In general, growth is less consistent in this region than it is alongside the sulcus. Ageing errors are likely, particularly in older fish, and the use of whole otoliths for ageing kahawai is not recommended.

Kahawai otoliths are best read as transverse sections (either broken and baked or burnt, or thin sections) in the regions either side of the sulcus (*see* Figure 1). Some increments, particularly the finer outer increments of older fish, are visible only in one or two regions. It is therefore important that a count is taken from each side of the sulcus where possible and that easily read zones are followed along the proximal face to ensure increments are not omitted or misinterpreted, particularly in the otoliths of older fish. It is also important to be able to recognise the transition zone when working with thin sections, as failure to do so may result in over-ageing the specimen by 1 year. In baked and burnt preparations this zone is difficult to distinguish from the surrounding translucent material and reading errors are unlikely.

Because kahawai otoliths are small (a 20 year old kahawai has an otolith that is less than 1.8 mm thick through the sulcus), it was often difficult in older fish (over 5 years) to determine whether or not the marginal increment (the outermost zone) had an opaque edge. This was further compounded by some otolith sections, particularly baked or burnt preparations, having an otolith margin that looked opaque in some areas and translucent (hyaline) in others. Consequently, if the marginal increment was translucent and appeared wide enough to have an opaque margin, it was counted as an extra year. In young fish (less than 5 years) the marginal state was clearer and problems were less likely.

Otolith preparation techniques

Comparisons between the different preparation techniques in this study suggest that counts from all three techniques may be interpreted in a similar way. Baked and burnt preparations are a more cost-effective method of ageing kahawai than thin otolith sections, both in terms of labour and materials. However, the contrast between increments was inferior to that obtained by using thin sections, although accurate counts could still be obtained for most preparations. The thin dark brown zones in baked and burnt preparations correspond to the dark opaque zones of thin sections, although the translucent (hyaline or "summer") zones of baked preparations are broader than in thin sections. This is thought to be due to the early transitional area of the opaque zone baking a medium rather than darker brown. In baked and burnt preparations it was important that the ground surface passed through or close to the nucleus. If the surface lay significantly outside the nuclear region, increment interpretation was often difficult and reading errors could occur.

More recently otoliths from a number of commercial species (southern blue whiting, hoki, hake, silver warehou, bluenose) have been marked, baked, and embedded in ordered rows in epoxy resin (Araldite K142) blocks. Each resin block is cut along each row providing transverse sections of up to 90 otoliths. This technique (which has not been used on kahawai) offers several advantages over plasticine mounting. The mounting medium is more permanent, limiting damage to otoliths, and the otoliths are easier to read as the focal length is similar and the sections are aligned close together. It is recommended that future kahawai otoliths are either thin sectioned or baked and embedded in epoxy resin blocks.

Age validation

Age validation of kahawai was achieved by OTC injection of tagged fish and progression of juvenile length frequencies. Thin otolith sections from 165 tagged kahawai recaptures were suitable for OTC validation of annual increments. OTC checks were clearly visible in most (84.2%) of these thin otolith sections. The correlation between the predicted and the actual positions of the OTC checks in thin otolith sections was extremely high (86%), and it is concluded that the opaque growth zones of kahawai are formed annually. However, based on these thin otolith sections, kahawai otoliths do not always grow uniformly in the same axis. Growth may be extremely restricted in some areas, and care needs to be taken to avoid ageing errors, particularly in older kahawai.

Length frequency histograms of juvenile kahawai collected in Wellington Harbour from 1974 to 1975 showed a clear monthly progression of juvenile length modes. Juvenile kahawai appear to recruit into Wellington Harbour in March when they are 35–50 mm FL. Growth is rapid and by March the following year they are 80–130 mm FL and over 1 year old (1+), clearly validating the first year of growth in Wellington Harbour. Length frequency histograms of small kahawai collected from Hauraki Gulf trawl surveys from 1992 to 1994 show three clear length modes, which, based on otoliths collected in the Hauraki Gulf during the same time of the year, represent 1+, 2+, and 3+ year old fish. These length modes seem discrete, but there may be some, probably minor, overlap, particularly in the 3+ and 4+ year classes. The length modes are of similar size ranges over the 3 years, and although there is insufficient evidence to validate these year classes, the data seem to represent the progression of three distinct year classes over a 3 year period. Based on these length frequency progressions, variable nuclear widths, variable "daily" growth increment counts, and anecdotal information it appears that kahawai have an extended spawning period.

Unfortunately, age validation by marginal increment analysis was unsuccessful because of the effects of tagging on otolith growth causing interpretational problems with the thin otolith sections. Any further attempt at marginal increment and marginal state analysis should be with baked otolith preparations from young kahawai (with their correspondingly wider marginal otolith increments) from standard catch samples, rather than tagged fish. It is clear that using otoliths from tagged returns is not ideal for this type of analysis. Also, the extra information presented in thin otolith sections may confuse, rather than aid, the reader in marginal increment analysis.

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Table 1: **Correlation between the actual position of the OTC check and that predicted by DWS (n = 165). Area: 9, Bay of Plenty; 38, Tasman Bay. Grading scale: 0, OTC not visible; 1, OTC check predicted in the correct zone and position; 2, OTC check predicted in the correct zone but wrong position; 3, OTC check predicted in the wrong zone and position**

Area	n	Days at liberty		Grading scale				No. (%) in
		Min.	Max.	0	1	2	3	correct zone
Short term recaptures								
9	68	285	383	10	35 (60.3%)	12 (20.7%)	11 (19.0%)	47 (81%)
38	41	301	478	10	18 (58.1%)	7 (22.6%)	6 (19.3%)	25 (80.7%)
Total	109	285	478	20	53	19	17	72 (80.9%)
Longer term recaptures								
9	46	626	830	3	34 (79.1%)	6 (13.9%)	3 (7.0%)	40 (93%)
38	10	614	905	3	7 (100%)	-	-	7 (100%)
Total	56	614	905	6	41	6	3	50 (94%)

Table 2: **Marginal state and marginal increment analysis for 41 thin sectioned otoliths. Marginal state analysis: 1, opaque marginal increment; 2, translucent marginal increment. Marginal increment analysis: 1, opaque zone just starting (barely visible); 2, opaque zone approximately one half complete; 3, opaque zone complete; 4, translucent zone just starting (barely visible); 5, translucent zone about one half complete; 6, translucent zone complete**

	Summer		Autumn			Winter	
Scale	Jan	Feb	Mar	Apr	May	Jun	Jul
Marginal state analysis							
1	1	1		5		11	2
2	2		2	3		11	3
Total	3	1	2	8		22	5
Marginal increment analysis							
1	1	1				11	2
2				3			
3				2			
4	2		1			3	1
5			1	1		5	
6				2		3	2
Total	3	1	2	8		22	5

Table 3: **"Daily" growth increment counts for juvenile kahawai sampled in Wellington harbour on 12 May 1976 (n = 90). (Archival data collected by D. Eggleston)**

	n	Range	Mean	s.d.
Fork length (cm)	90	40 – 58	47.8	6.09
"Daily" growth increment count	90	78 – 123	101.2	12.43
Back-calculated birthday	-	11 Jan to 22 Feb	2 Feb	-

Table 4: Within-reader comparisons of 328 thin otolith sections. Age, age at first reading (Feb 1993); Diff, the extent to which the second reading (Feb 1996) differed from the first; Sim 1, the percentage of otolith readings that were the same for both readings; Sim 2, the percentage of second readings that were within one year of the first reading

Diff	Age													Total
	3	4	5	6	7	8	9	10	11–12	13–14	15–16	17–19	20+	
3				1							1			2
2				1							1			2
1		19	10	7	4	4	3	2		3	1	2		55
0	0	91	53	53	18	9	3	0	5	7	2	2	0	243
-1			5	5	5	1	1	1	2		3	2		25
-2							1							1
-3														
Total	0	110	68	67	27	14	8	3	7	10	8	6	0	328
Sim 1	0	82.7	77.9	79.1	66.7	64.3	37.5	0	71.4	70	25	33.3	0	74.1
Sim 2	0	100	100	97	100	100	87.5	100	100	100	75	100	0	98.5

Table 5: Between-reader comparisons of 99 baked, broken, and ground otoliths. Age, age as read by DWS; Diff, extent to which the second reader (D. Eggleston) differed from the first reader (DWS); Sim 1, the percentage of otolith readings that were the same for both readers; Sim 2, the percentage of otolith readings by the second reader that were within 1 year of the first reading

Diff	Age													Total
	3	4	5	6	7	8	9	10	11–12	13–14	15–16	17–19	20+	
5											1			1
4						1			1					2
3									2	3	2			7
2					1	2	1		5	2	1		1	13
1	1	2		1	1		1	2	6	7	4	2		27
0	4		1		2	1	1		7	5	3	2	2	28
-1						2	1			7	2	2		14
-2										1		1		2
-3											1	1		2
-4												1	1	2
-5												1		1
Total	5	2	1	1	4	6	4	2	21	25	14	10	4	99
Sim 1	80	0	100	0	50	16.7	25	0	33.3	20	21.4	20	50	28.3
Sim 2	100	100	100	100	75	50	75	100	61.9	76	64.3	60	50	69.7

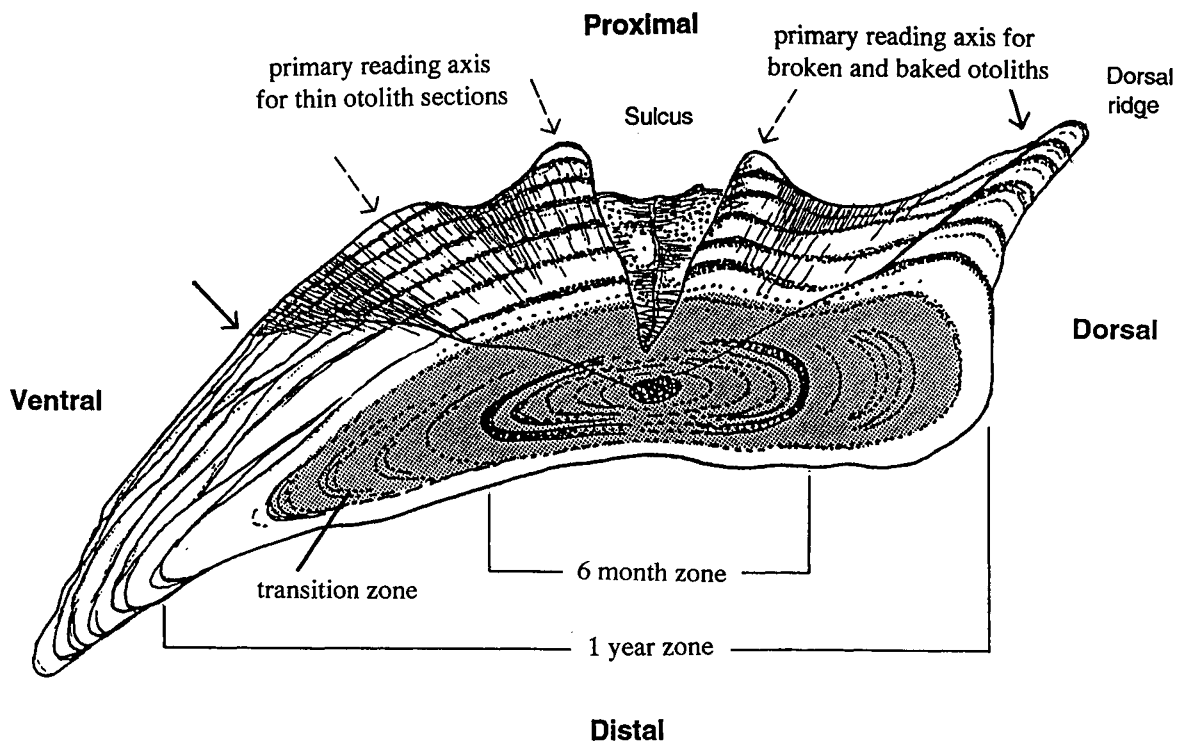

Figure 1: **Schematic diagram of a thin section of a kahawai otolith showing terminology and reading axes mentioned in the text.**

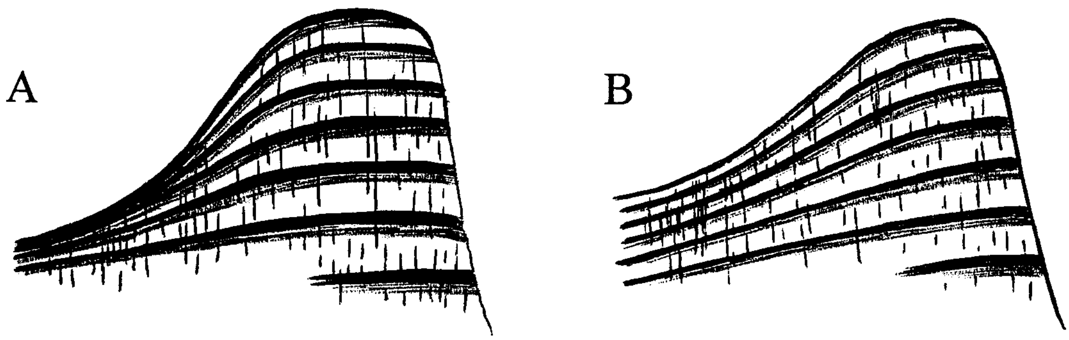

Figure 2: **Variation in increment growth in the dorsal ridge of a kahawai thin otolith section.**
A: uneven deposition of otolith material
B: more 'typical' growth in the dorsal ridge

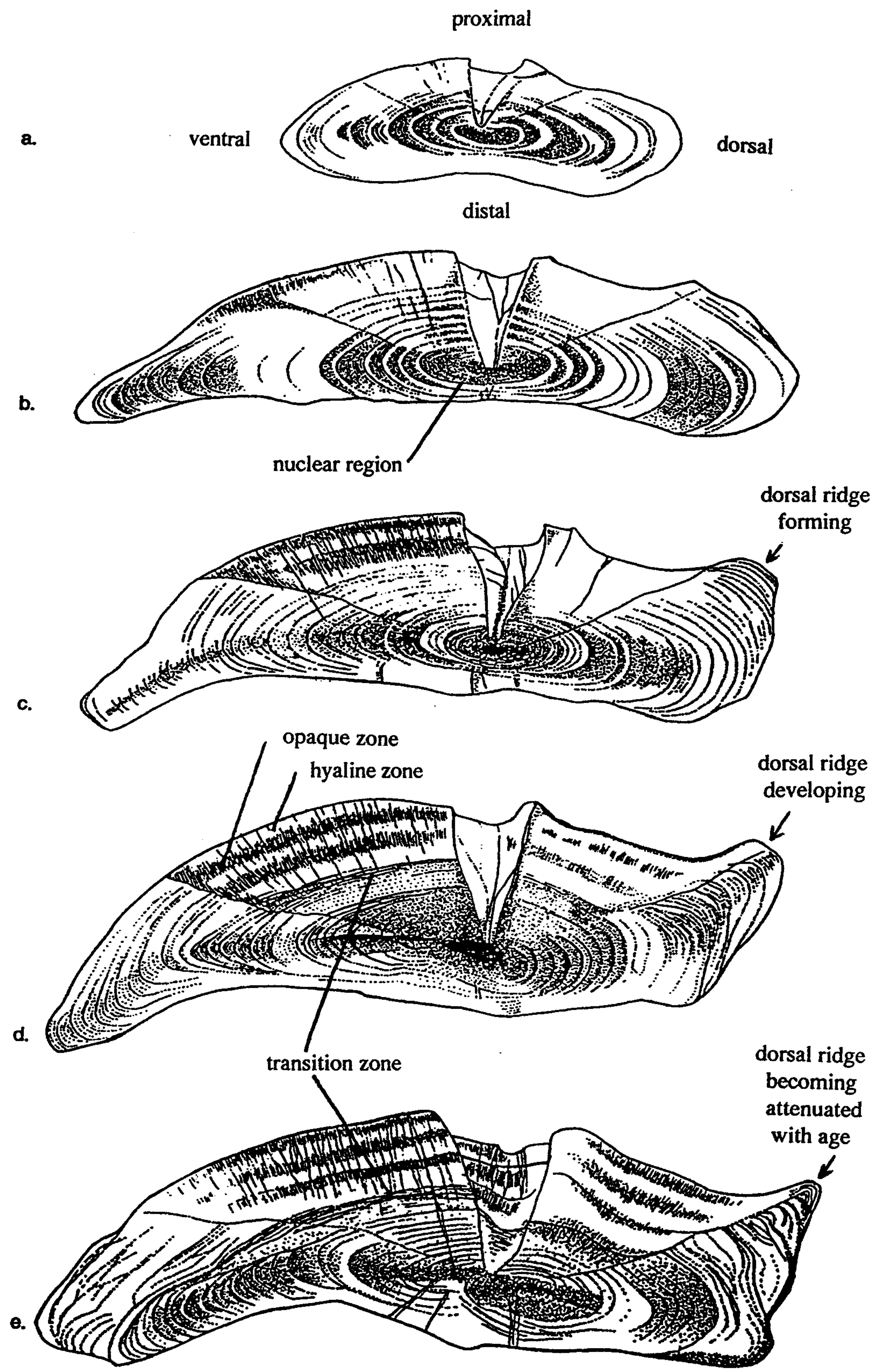

Figure 3: **Drawings of thin transverse sections of kahawai otoliths.**
3a: thin otolith section of a 5–6 month old kahawai
3b: thin otolith section of a 1 year old kahawai
3c: thin otolith section of a 2 year old kahawai
3d: thin otolith section of a 2+ year old kahawai with a complete hyaline edge
3e: thin otolith section of a 3 year old kahawai

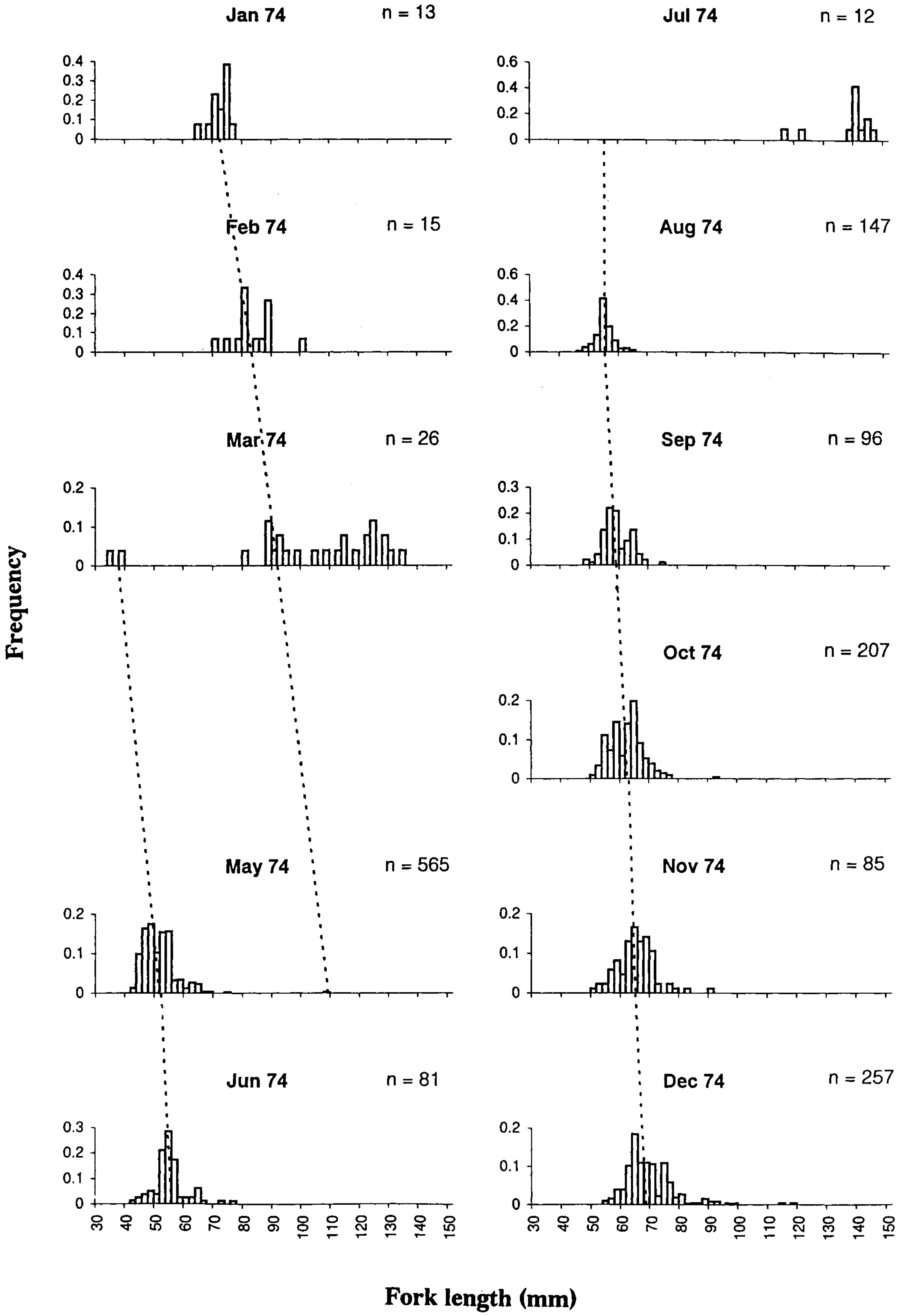

Figure 4: Length-frequency histograms of juvenile kahawai caught by beachseine in Wellington Harbour from January 1974 to December 1975 (Archival data collected by D. Eggleston).

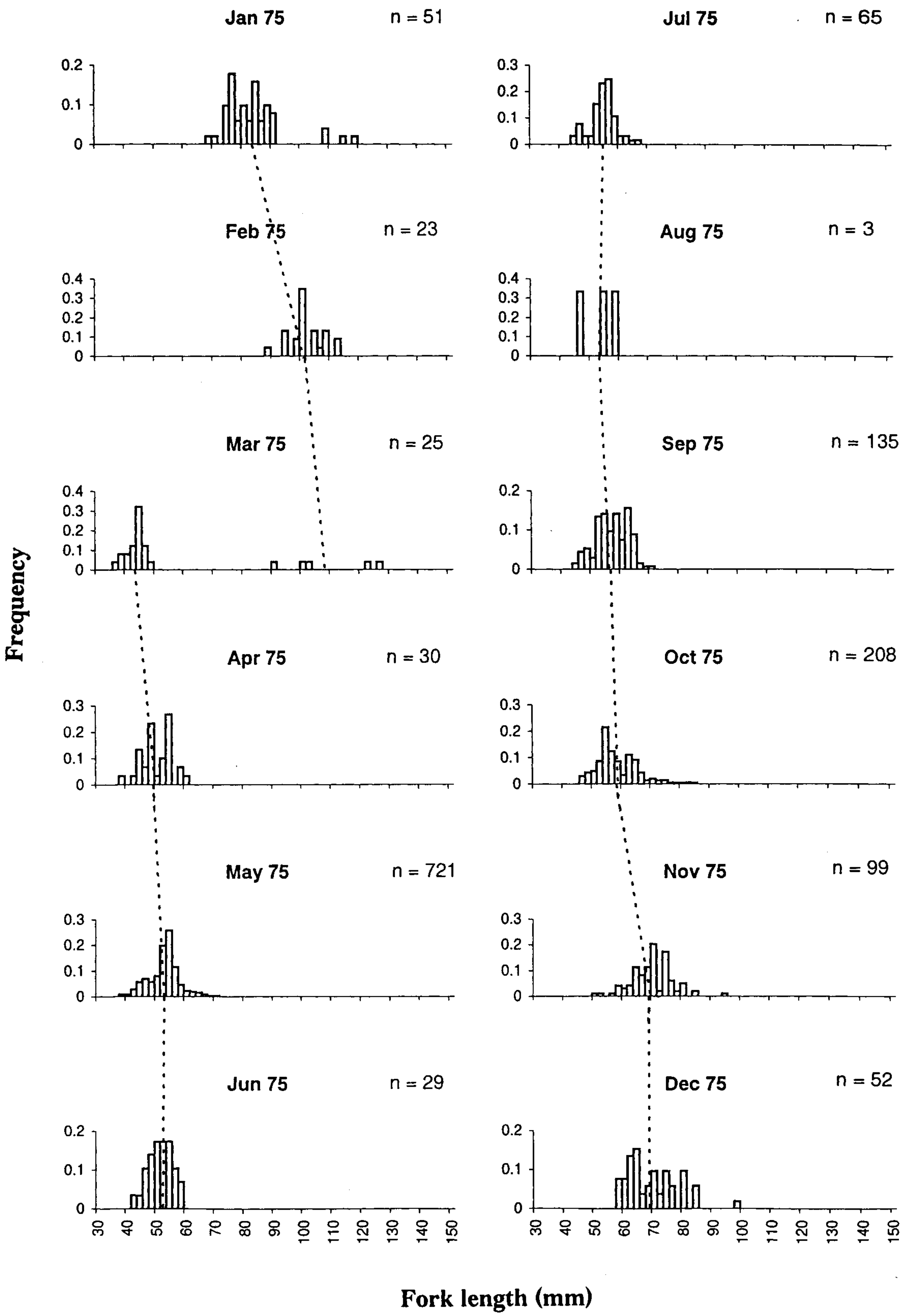

Figure 4: Length-frequency histograms of juvenile kahawai (cont.).

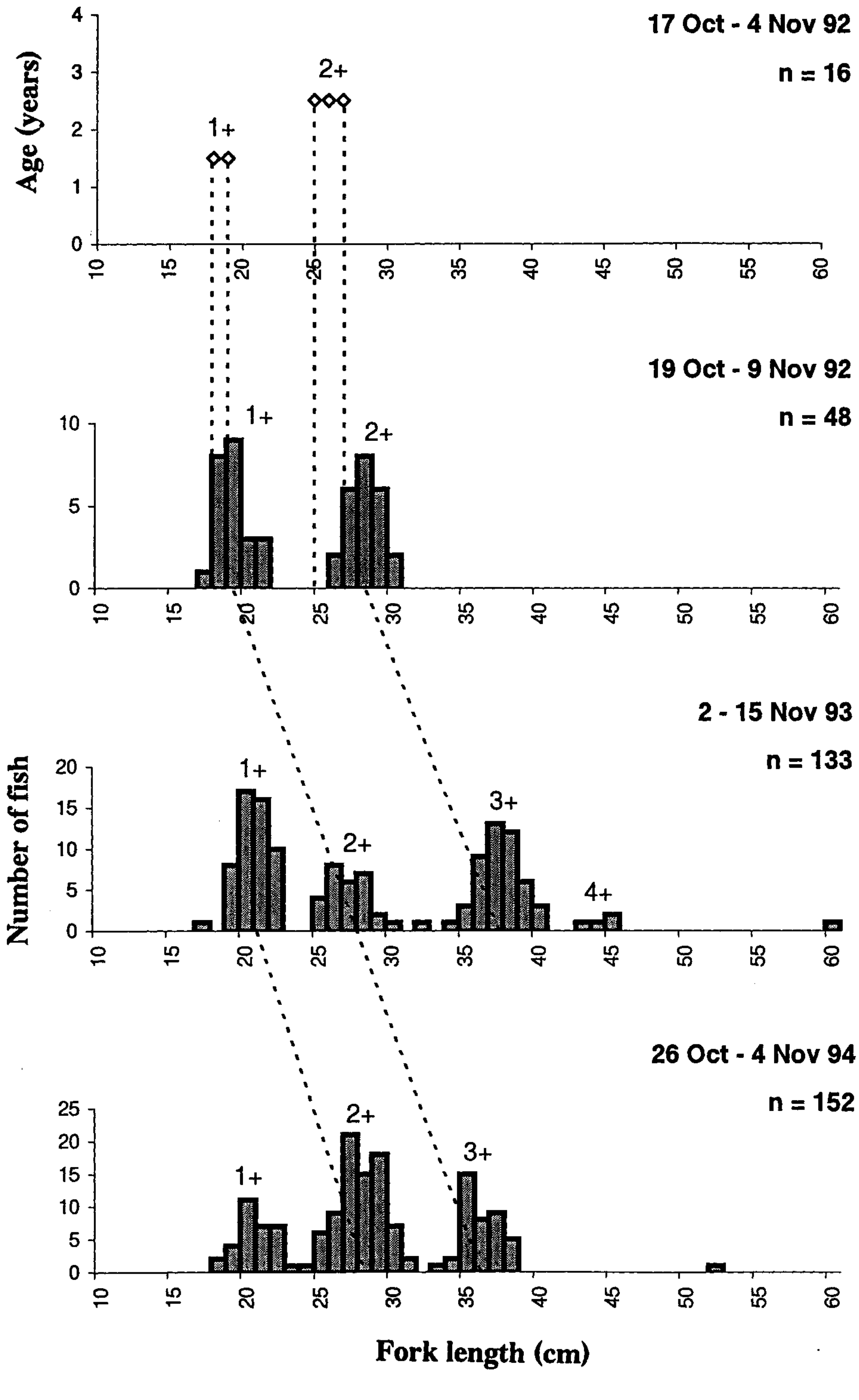

Figure 5: Age-length relationships and length-frequency histograms of Hauraki Gulf kahawai.
5a: Age-length relationships of 16 small kahawai
5b: Kahawai caught on the KAH9212 trawl survey
5c: Kahawai caught on the KAH9311 trawl survey
5d: Kahawai caught on the KAH9411 trawl survey

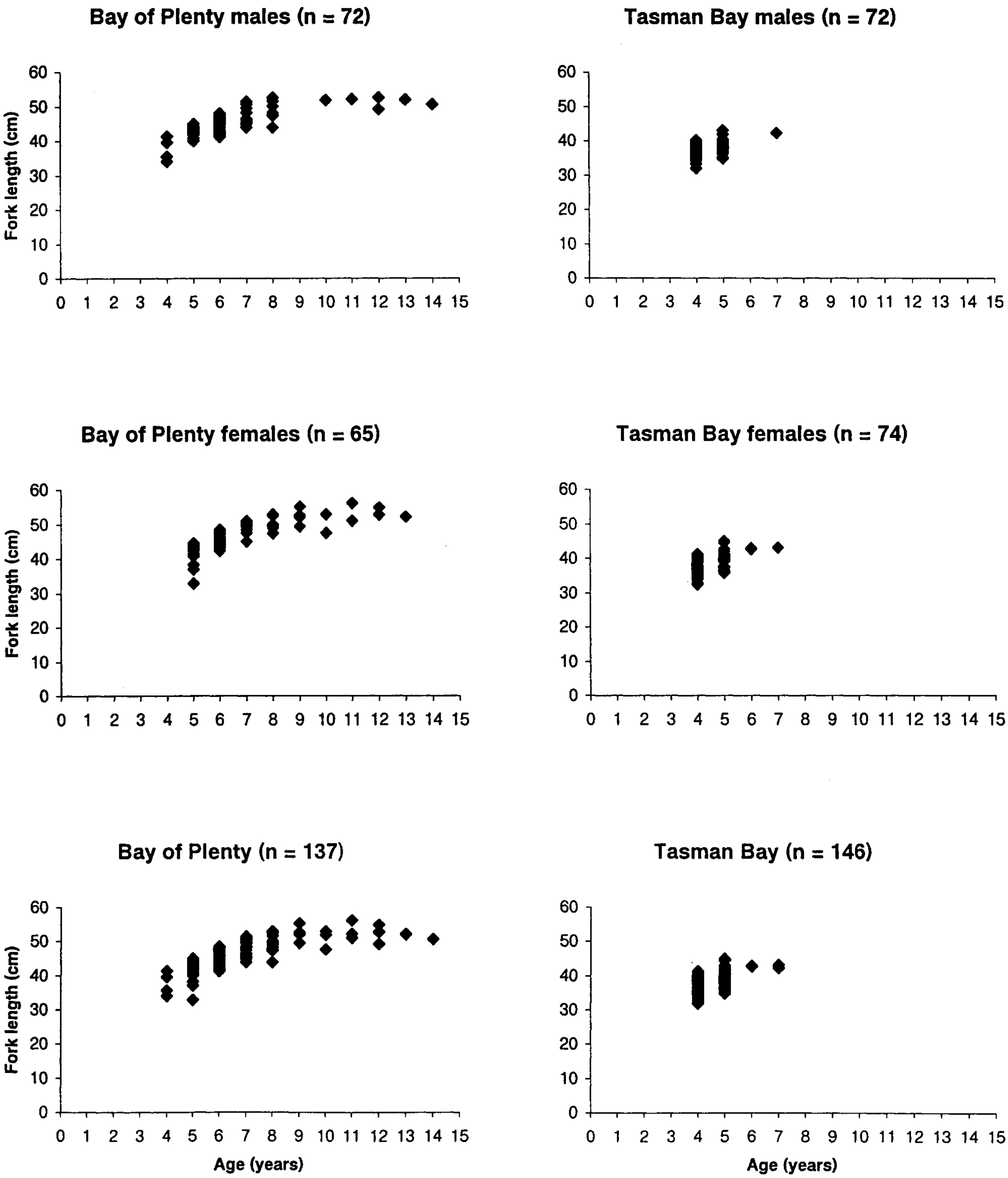

Figure 6: Age-length data by area and sex from OTC validated tagged kahawai recaptures.

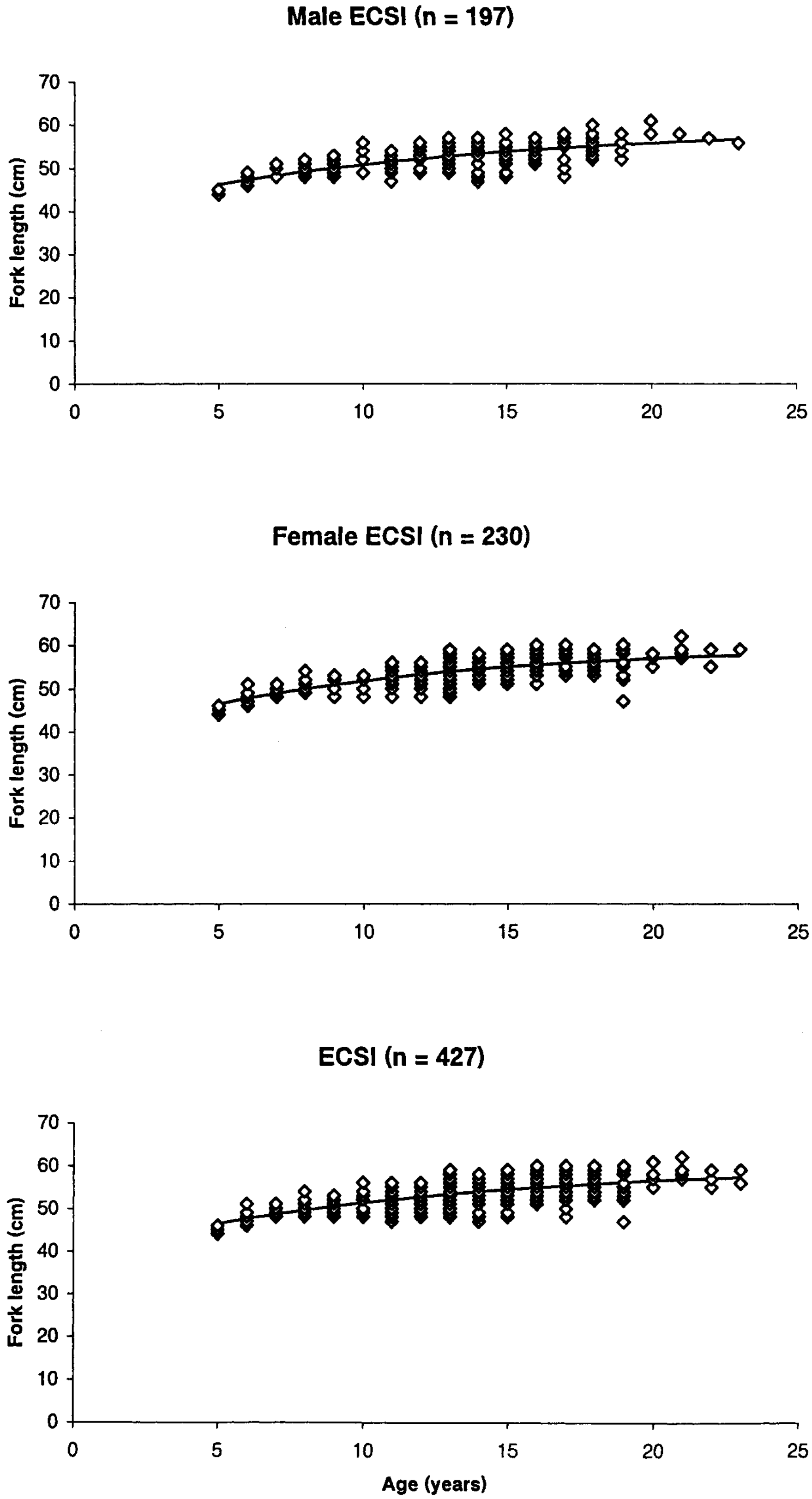

Figure 7: Age-length data and von Bertalanffy growth curves for kahawai sampled from the east coast of the South Island.

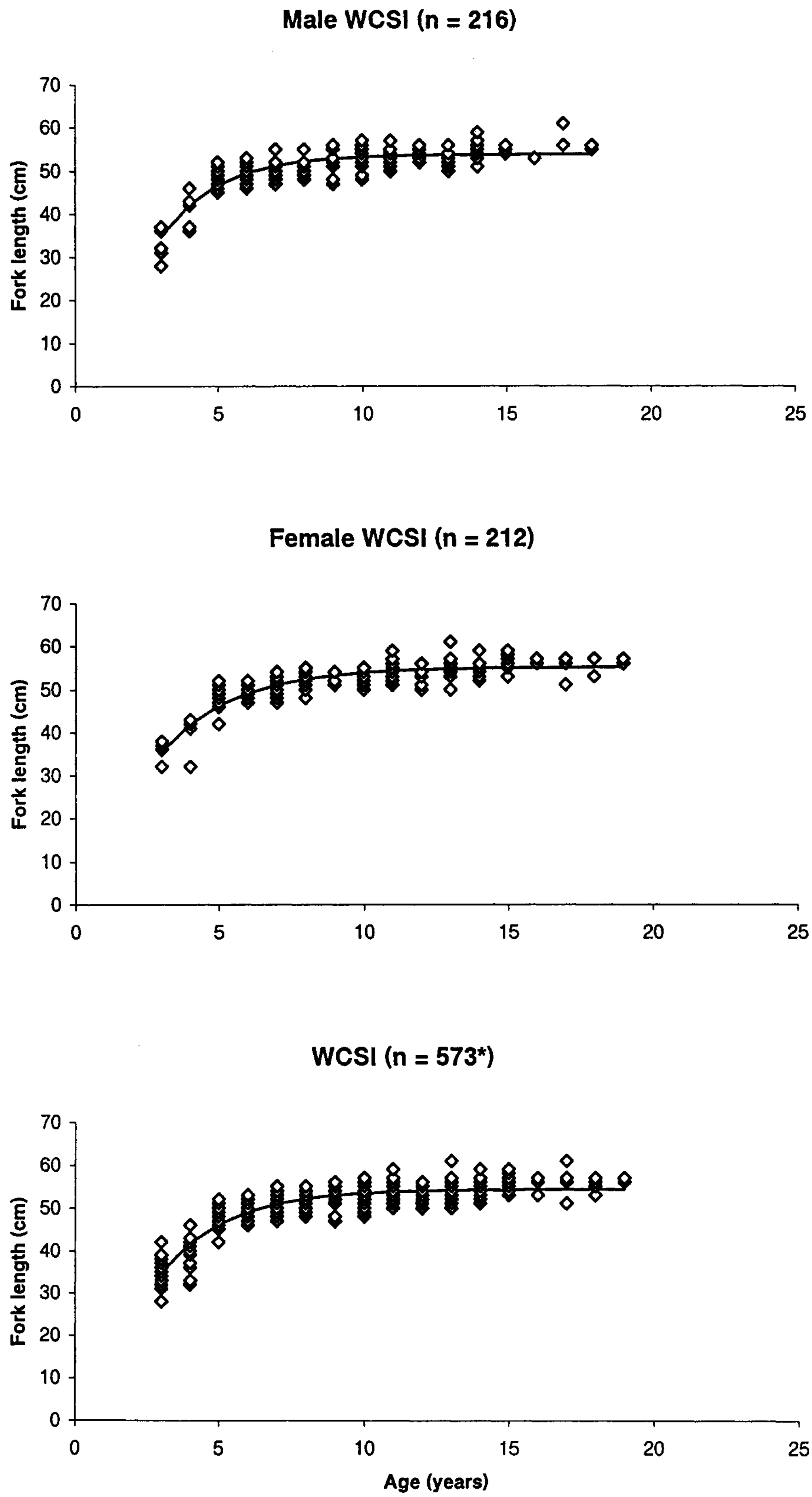

Figure 8: Age-length data and von Bertalanffy growth curves for kahawai sampled from the west coast of the South Island. (*includes 145 kahawai from Golden Bay).

Appendix 1: Details of otolith samples examined in this report

KV (kahawai validation) series

(the primary ageing series, mainly recaptures from the tagging programme)

KV no.	n	Source
1 – 359	359	early recaptures (refer Table 1)
360 – 379	20	KAH 9211 - Hauraki Gulf (a sample of large fish)
380 – 461	82	longer term recaptures (refer Table 1)
Total	461	

JKV (juvenile kahawai validation) series

(otoliths from a selection of young kahawai used for evaluating the first 3 years of growth)

JKV no.	n	Date	Source
1 – 4	4	Jun 75	Days Bay, Wellington Harbour
5 – 6	2	Aug 75	Wellington Harbour
7 – 10	4	Jun 75	Days Bay, Wellington Harbour
11 – 15	5	Oct 82	Wellington south bays
16 – 21	6	Oct 82	Island Bay, Wellington
22	1	Mar 76	Petone foreshore, Wellington Harbour
23 – 25	3	Jan 76	Days Bay, Wellington Harbour
26 – 28	3	Nov 74	Wellington Harbour
29	1	Mar 76	Wellington Harbour
30	1	Nov 74	Wellington Harbour
31 – 32	2	Mar 76	Wellington Harbour
33	1	Oct 74	Wellington Harbour
34 – 37	4	Oct 74	Hauraki Gulf
38	1	Oct 74	Kaipara Harbour
39 – 52	14	Oct 74	Hauraki Gulf
53 – 55	3	Jan 76	Days Bay, Wellington Harbour
56 – 71	16	Nov 74	Evans Bay, Wellington Harbour
72 – 83	12	Dec 92	Days Bay, Wellington Harbour
Total	83		

DRUM (Kim Drummond) series

(a series of WCSI and ECSI baked otolith preparations)

Area	n	Date	Source
East coast, South Island	427	Oct 92 – Jan 93	shed samples from purse seine catches
West coast, South Island	445	Dec 92	shed samples from purse seine catches

EGG (Dave Eggleston) series

(130 originally examined, but only 99 suitable for between-reader comparisons)

Origin	Voyage code	n	Date	Area
RV *James Cook*	JCO 7208	5	May 72	Castlepoint / Kaikoura
	JCO 7209	1	Jul 72	Castlepoint / Kaikoura
	JCO 7210	1	Jul – Aug 72	West coast North Island
	JCO 7318	4	Nov 73	North North Island
	JCO 7403	3	Feb 74	North Cape to Mercury Isl
	JCO 7406	2	Apr 74	Bay of Plenty, fin. in Tauranga
	JCO 7407	2	Apr – May 74	North Cape to Mercury Isl
	JCO 7410	4	Jul 74	North Cape to Mercury Isl
	JCO 7411	36	Aug 74	Tasman Bay, South Taranaki
	JCO 7508	6	May 75	Tasman Bay
	JCO 7511	13	Jul 75	Tasman Bay / WCSI
RV *W.J. Scott*	WJS 7307	3	-	-
	WJS 7318	1	-	-
FV *Paramount*	-	1	Nov 74	purseseined, Bay of Plenty
Origin unknown	-	15	Oct – Nov 75	incl. market sampled fish
Recreational	-	1	Mar 75	Albert Rock, Doubtless Bay
samples	-	1	Mar 75	Waiheke Passage
Total		99		

Appendix 2: Growth parameters

by Elizabeth Bradford

Unresolved problems have arisen while fitting the von Bertalanffy growth equation to the kahawai age length data. One explanation of the results is that the growth parameters are age dependent. The results of fitting the age length data described in this report are given below.

The growth parameters have been estimated using the von Bertalanffy equation

$$L = L_{\infty} (1 - \exp(- k (A - t_0)))$$

where L is the length, A the age, and L_{∞}, k, and t_0 are the von Bertalanffy parameters.

The three parameters were estimated non-linearly, though some of the parameters are linear.

The first fits of the von Bertalanffy equation to data used age length data from the Bay of Plenty age validation study. These fits were looked at in more detail than subsequent ones. The growth parameters (with asymptotic 95% confidence intervals for the estimates) are given in Appendix Table 1 for females, males, and all fish. These kahawai were all caught roughly a year after the tagging. The sample sizes are small, and the data do not cover all age classes. The fits are poor. Although there are apparent differences in the growth parameters for males and females, the values obtained are the same within the confidence limits. There are no 4 year old females in the sample, and the length distribution of the 5 year old females is skewed towards the smaller sizes. Removing the smallest female from the sample made no substantive difference to the results. The stress of tagging may have changed the growth rates of some of the fish, particularly the smaller or weaker fish and good estimates of growth parameters may not be likely from tagged fish.

Some 1 – 4 year old fish from another sample were included with the Bay of Plenty tagged fish, but residual plots showed the two sets of data had incompatible growth rates and these results are not shown.

Technically, the parameter determinations were bad in another sense. "Profile" plots which should be linear in the vicinity of the estimated parameters from the non-linear fit were noticeably curved (Venables & Ripley 1994). This is a sign of misfitting, perhaps of bad parameterisation in the growth equation.

No attempt was made to fit growth curves to kahawai recovered from the Tasman Bay tagging as most of those fish belonged to two age classes so there were not enough data to fit a three parameter curve.

Two data sets collected by Kim Drummond (*see* tables 6, 8, and 9 in Drummond 1995) from the west coast of the South Island and the east coast of the South Island have been re-aged. Growth parameters are given in Appendix table 1. The east coast South Island sample contained several large (over 60 cm FL) and old (over 20 years) kahawai, and the youngest kahawai in the sample were aged 5 years. There is little length change with age shown in this sample (Figure 8) which is reflected in the low values of k and t_0.

Appendix Table 1: Von Bertalanffy parameters (with 95% confidence intervals) for kahawai from the age validation tagging study in the Bay of Plenty, the west coast South Island, and the east coast South Island

Data	n	L_∞	k	t_0
Bay of Plenty age validation data				
Female	65	54 (51–56)	0.44 (0.24–0.64)	1.7 (0.5–2.9)
Male	72	53 (50–56)	0.31 (0.16–0.46)	0.0 (-1.0–1.0)
All	137	54 (52–56)	0.32 (0.22–0.42)	0.4 (-0.8–1.6)
West coast South Island				
Female	286	55.1 (54.5–55.7)	0.39 (0.35–0.43)	0.4 (0.2–0.7)
Male	289	54.0 (53.4–54.6)	0.47 (0.42–0.52)	0.8 (0.6–1.0)
All	765	54.6 (54.2–55.0)	0.43 (0.40–0.46)	0.6 (0.4–0.8)
East coast South Island				
Female	286	59.7 (56.3–63.1)	0.10 (0.05–0.15)	-10 (-16–-4)
Male	198	59.9 (53.9–65.9)	0.08 (0.02–0.14)	-13 (-23–-3)
All	429	60.3 (56.7–63.9)	0.09 (0.05–0.13)	-12 (-18–-6)