Estimates of age, growth, and mortality parameters of sea perch (*Helicolenus percoides*) off the east coast of the South Island, New Zealand

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Estimates of age, growth, and mortality parameters of sea perch (*Helicolenus percoides*) off the east coast of the South Island, New Zealand.

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This report addresses the overall objective of Project SPE2000/01, “To determine the age, growth and natural mortality of sea perch (*Helicolenus percoides*).”

From 30 fish, otoliths, scales, fin spines, and vertebral hard parts were examined to determine a suitable ageing procedure, and different otolith preparations were cross-checked. All showed growth marks (zones, annuli), with poor to average agreement between them. Otolith thin sections proved to be the most suitable (though still difficult). The growth marks in other structures generally supported the interpretation of otolith growth zones to a count of about 10, and may be useful in future studies of fish in this lower age range. Two readers agreed on most features, and established an ageing protocol for thin sections.

Otolith thin sections showed a central dense region, surrounded by a dark zone only slightly differentiated from it; the latter was assumed to represent the first growth zone, based on its relative position, and tentative counts of daily increments. This and subsequent growth zones (dark in transmitted light) comprised numerous fine bands. The nature of the latter is unknown, they hinder recognition of assumed annual growth zones because their within-zone spacing is similar to between-zone spacing, and they prevent a clear definition of marginal
increment characteristics beyond about age 5. Oxytetracycline marking of two large fish held in captivity for one year suggested that a single dark growth zone formed during winter, commencing May or June.

Most of the main sample of 430 otoliths was collected during east coast South Island (ECSI) trawl surveys. To obtain a better coverage of large (over 35 cm) fish, 24 fish were added from Chatham Rise trawl surveys.

Reader 1 read the main sample twice, Reader 2 once. There was moderate within- and between-reader agreement, differences occurred mainly at higher counts where narrow dark zones/lines could either be grouped or counted separately. The best estimate of age was considered to be the mean of the ages estimated by both readers in their first reading.

Growth is relatively slow throughout life. After about age 5, males grow relatively faster than females. Von Bertalanffy growth parameters were calculated for ECSI males and females.

The ECSI growth curves were compared with estimated modal length progression for two Chatham Rise cohorts measured in an 8-year time series of trawl surveys. There was moderate agreement, but the ECSI growth curves rise more sharply, indicating faster growth and/or some ageing errors. Juvenile modal lengths from another region (northeast North Island) agree moderately well with the calculated curve.

Size at maturity was determined from 757 fish sexed and staged on survey kah0014 (December 2000-January 2001). Most mature males were resting; macroscopic distinction from immature fish was difficult, but maturity was estimated to occur between 19 cm and 25 cm. Most females had maturing to fully ripe gonads, many with eyed larvae; maturity was more easily estimated to occur between 15 cm and 20 cm. The difference in reproductive status between the sexes reflects viviparity; males ripen first, fertilise the females, and there may be a delay before the female gonads begin enlarging as the oocytes develop into eyed larvae. Age at maturity was determined by comparing these fish sizes with the Von Bertalanffy growth curve; it was estimated as 5–7 years for males, 5 years for females.

From the maximum observed ages for ECSI and Chatham Rise fish of 32 and 43 years, the respective natural mortalities ($M$) are estimated to be 0.13 and 0.10. The latter, from fish collected in 1976 before intensive trawling began, is likely to be more reliable. If longevity is 50 years, $M$ would decline to 0.08.

8. Objectives

There were two specific objectives:

1. To determine the age and growth of sea perch.

2. To estimate natural mortality rate ($M$) of sea perch.
9. Introduction

9.1 General

Sea perch have always been a small bycatch in the line fishery for groper and ling in central and southern New Zealand, with small quantities landed for sale. They are moderately common on the outer shelf and upper slope around the South Island, particularly off the east coast, and as trawl fisheries extended into deeper water in this region more sea perch were caught and landed. In the early 1980s total New Zealand reported landings were 300-500 t, and this increased steadily to reach 2000 t by 2000 (Paul 1998). The quantity caught and discarded prior to and during this time is unknown. On average, 85% of total reported landings have come from QMAs 3 (east coast South Island (ECSI)) and 4 (Chatham Rise). Most (59%) have come from QMA 3, particularly the east coast shelf between Cape Campbell and Otago Peninsula. Most of the Chatham Rise landings (26% of the total) have come from around Mernoo Bank and along the northern edge of the Rise. Targeting for sea perch in some parts of QMA 3 began in the 1990s, accounting for 10-30% of this QMA’s landings.

A competitive quota of 1000 t in QMA 3 imposed in 1991 has been approached but not reached. Sea perch were introduced into the Quota Management System (QMS) in October 1998. The Total Allowable Commercial Catches (TACCs) in October 1999 were 638 t in QMA 3 and 316 t in QMA 4 (Annala et al. 2001). From fishing year 1997-98 onwards (i.e., since their introduction) both TACCs have been exceeded. In May 2001 there was an industry-sponsored proposal (SEFMC 2001) to increase the SPE 3 TACC to 1200 t under the Adaptive Management Programme (AMP), to be monitored by CPUE indices in the target commercial trawl fishery in QMA 3 and in the western component of the annual Tangaroa Chatham Rise trawl surveys (Annala et al. 2001). This remains under consideration.

All TACCs were based only on regional (Fishstock) catch or landing levels in the mid 1990s. There is little biological information on stock size(s), and on productivity (growth rate, longevity, fecundity) relevant to stock assessment. There is some information on stock sizes through the 1990s (Annala et al. 2001). Biomass indices of sea perch from trawl surveys of the east coast South Island have been variable, and determined with only moderate precision (CVs around 30%). Winter ECSI surveys from 1991 to 1996 gave values between 1700 t and 3300 t, with no trend. Summer surveys from 1996-97 to 2000-01 gave values which trended down from 4000 t to 1800 t, but these values are not considered reliable. Chatham Rise (summer) surveys from 1991-92 to 2001 have also been variable but with lower CVs (9-15%); most surveys gave values around 3000 t to 1998, with a subsequent rise to 6300 t in 2001. Biomass indices have also been developed from a standardised CPUE analysis of the SPE 3 target trawl fishery; they show little trend over time but have high variability (SEFMC 2001, Annala et al. 2001).

The present study develops an ageing procedure, and presents first estimates of growth rate, maximum age, age at maturity, and rate of natural mortality ($M$), in order to better understand this species.
9.2 Background biological information

Identity
The New Zealand sea perch, *Helicolenus percoides*, is at present considered to be a single species, but some uncertainty over the number of populations or stocks and their likely differences in biology remains. Paulin (1989) described the reddish, larger-eyed ‘form’ of sea perch as *H. barathri*. These two species were listed with depth ranges which overlapped considerably, but *H. barathri* was considered to be the ‘deeper-water’ species. Subsequent genetic and morphological (eye-diameter) evidence has been unable to show that there is more than one species in New Zealand waters (Smith 1998). Fish from shallow and deep water do look different, mainly because of their colour pattern, but might simply represent the two ends of a depth cline (NIWA, unpublished observations). There have been anecdotal reports of “very small but mature” sea perch in some localities, which could potentially be a closely similar (and perhaps uncommon) dwarf species, but it has not been possible to obtain any further information on this point.

A study using the same genetic marker has revealed two species in Australia (Paxton and Colgan 1993), which in many recent publications (e.g. Stewart 1993, Park 1994, Andrew et al. 1997) continue to be listed as *H. percoides* and *H. barathri*, although with reservations. It is not known how closely the Australian and New Zealand species of *Helicolenus* are related. It is highly desirable to have some understanding of the identity of a species and its relationships; the differentiation of the “sea perches” *Helicolenus* (and the related rockfish genus *Sebastes*) into species, subspecies, and populations (e.g., Barsukov 1979, McGlade et al. 1983, Kotlyar 1988, Johansen et al. 1993, Palladino & Mecozzi, 1997), causes fisheries assessment difficulties in many parts of the world.

Size and abundance
In south-eastern Australia, research trawl surveys over major fishing grounds in 1976 and 1996 showed that both the abundance and mean size of ocean perch (nominally *Helicolenus percoides*) had declined significantly over this 20 year period (Andrew et al. 1997). There has been no comparable study over a similar time scale in New Zealand, but trawl survey data from the 1990s show no change (but for one inconclusive case with a possible decline in abundance). These trawl survey data will become increasingly valuable as their time series extend.

Reproduction
Information on reproduction is relevant to ageing studies because it helps establish a birthday, and may help explain seasonal growth activity. It is useful to know of any unusual features, such as viviparity, that may influence growth patterns.

Many species in the family Scorpaenidae are viviparous (Krefft 1961, Boehlert & Yamada 1991), typically releasing fertilised eggs or developing larvae in a gelatinous and buoyant “egg mass”.

Thomson (in Thomson & Anderton 1921) recorded the viviparity of *H. percoides*. Graham (1939, 1956) observed an aquarium-held *H. percoides* extrude a jelly-like mass which floated to the surface and dissolved to release some 90 000 small larvae; he suggested an extended spawning season, based on the presence of eggs and all larval stages in single ovaries, and the capture of some mature females in most months. Eggs and/or larvae were described and illustrated by these authors.
Studies on reproduction in Australian Helicolenus are briefly described by Lyle & Ford (1993) and Park (1994). Mating was inferred to occur in winter, with presence of fertilised ova peaking in spring. Differences in timing and other features of the reproductive cycle were noted between shallow and deep water fish.

9.3 Previous work on age and growth

Early ageing studies on Helicolenus (mainly H. dactylopterus) were based on reading growth zones from the lateral surface of whole otoliths; more recent studies (including one on Australian H. percoides) were based on otolith thin sections from the larger fish in the samples, and higher maximum ages were obtained (Table 1).

<table>
<thead>
<tr>
<th>Species</th>
<th>Method</th>
<th>Maximum age</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>H. dactylopterus</td>
<td>?</td>
<td>9</td>
<td>Peirano &amp; Tunesi 1986¹</td>
</tr>
<tr>
<td>H. dactylopterus</td>
<td>Whole</td>
<td>16</td>
<td>Isidro 1987</td>
</tr>
<tr>
<td>H. dactylopterus</td>
<td>?Whole</td>
<td>9</td>
<td>Ragonese 1989</td>
</tr>
<tr>
<td>H. dactylopterus</td>
<td>?</td>
<td>7</td>
<td>D’Onghia et al. 1992¹</td>
</tr>
<tr>
<td>H. dactylopterus</td>
<td>Whole</td>
<td>10</td>
<td>Ragonese &amp; Reale 1995</td>
</tr>
<tr>
<td>H. dactylopterus</td>
<td>Whole</td>
<td>14</td>
<td>Esteves et al. 1997</td>
</tr>
<tr>
<td>H. dactylopterus</td>
<td>Thin section</td>
<td>30</td>
<td>White et al. 1998</td>
</tr>
<tr>
<td>H. dactylopterus</td>
<td>Thin section</td>
<td>43</td>
<td>Kelly et al. 1999</td>
</tr>
<tr>
<td>H. dactylopterus</td>
<td>Thin section</td>
<td>43</td>
<td>Allain &amp; Lorance 2000</td>
</tr>
<tr>
<td>H. dactylopterus</td>
<td>Whole</td>
<td>30</td>
<td>Massuti et al. 2000</td>
</tr>
<tr>
<td>H. percoides</td>
<td>Thin section</td>
<td>42</td>
<td>Withell &amp; Wankowski 1988</td>
</tr>
</tbody>
</table>

Notes:

There are no published studies of the age and growth of New Zealand sea perch. Paul (1998) reported on about 600 otolith age-readings from west coast South Island made earlier by Fisheries Research Division (MAF) staff and held in NIWA archives, and on his re-reading of a subsample of 15 of these that yielded somewhat different results. The initial readings (undefined “ages”) were based on whole otoliths immersed in oil and viewed with reflected light, they ranged from 2 to 17, with 4–10 being most common counts. A subsample (22 otoliths) had also been read using the break and burn technique, giving similar (± 1) counts to those from entire otoliths, with only one cross-section age being significantly higher (11 cf. 7).

Re-interpretation of these otoliths by Paul (1998) gave counts that averaged double the original counts, and were up to three times higher. This difference resulted from interpreting most narrow dark zones as annual growth zones, and not a sequence of split zones. Although they were closely-spaced as well as narrow, they were judged as sufficiently regular and complete around much of the otolith to be considered the main annual growth zones. The maximum count was 39.

These higher counts, although unvalidated, formed a realistic growth curve, compared with linear growth implied by the original readings. They also agreed with the age readings from Australian Helicolenus percoides by Withell and Wankowski (1988), which were generally less than 20 years, but included counts up to 42. Von Bertalanffy growth parameters suggested that growth of the two sexes was very similar.
Some of the studies on the age and growth of other species of *Helicolenus*, mainly subspecies of *H. dactylopterus* in the North Atlantic and Mediterranean (see Table 1), appear to have been quick and superficial, based on whole-otolith readings, now considered unreliable for older fish. Maximum ages were at first in the range 9–16 years, but subsequently extended to 30 (Massutí et al. 2000). Several of these studies acknowledged that the whole otolith method appeared unsatisfactory. Esteves et al. (1997), giving a maximum age of 14, observed that the "annual growth increments [for females] were nearly constant over time" (which suggests that they were under-estimating ages), and commented on the difficulty of interpreting "false rings, checks, splits, etc.". White et al. (1998) used thin sections to age 1100 fish from a population of *H. dactylopterus* off the south-eastern United States; their maximum age was 30 years, but their length-at-age data were unusual and could not be fitted to the von Bertalanffy growth equation, or any other growth function. Kelly et al. (1999) aged over 500 fish from the Rockall Trough west of Ireland to obtain a maximum age of 43, though most fish were less than 14 years. Their careful study of thin otolith sections gave a distinctly different (slower) growth rate than that described by other authors for the Mediterranean and Azores, even at young ages. This may have resulted from their use of thin sections cf. whole otoliths, but they did observe that whole otoliths were readable, although with difficulty, up to about 12 years. The difference may also have reflected a regional difference in growth rate, their sample coming from cooler (more northern, and deeper) waters.

The maximum ages for *H. dactylopterus* of 30 (White et al. 2000, Massutí et al. 2000) and 43 (Kelly et al. 1999) are comparable with the 42 years obtained for Australian *H. percoides* (Withell & Wankowski 1988).

Validation of the annual nature of the growth features counted in studies on *Helicolenus* otoliths has been described as difficult. However, several authors reported rings or zones to be annual, based on observed (sometimes quantified) seasonal changes in the otolith's margin. Kelly et al. (1999) were not able to validate their ages, but assumed annual ring formation based on earlier studies. Another validation procedure is to follow the progress of a strong yearclass through a time series of length-frequencies and/or otolith collections. This opportunity arose with the appearance of a single very strong (1990) yearclass of *H. dactylopterus* in the North Sea (Heessen et al. 1996); its early growth has been followed, but the opportunity to directly validate older otoliths (recommended by Heessen (1994), Heessen et al. 1996, and Kelly et al. 1999)) does not yet appear to have been taken up.

In summary, ageing studies on *Helicolenus* have shown: growth zones are difficult to interpret; whole otoliths are probably not appropriate for ageing older fish (though may be useful where most fish are less than 10–15 years, as is possible in some heavily exploited stocks); thin sections of otoliths give plausible results; growth rates of different stocks of the same species may vary; age-at-length data may not always fit standard growth functions; and modal size progression of dominant yearclasses may be a useful indicator of growth.

10. Methods

10.1 Size frequencies and progression of length frequency modes

Unscaled length-frequency data collected during Ministry of Fisheries trawl surveys were examined for the presence of juvenile modal structure that could be used to estimate growth rate. The survey series examined were Stewart–Snares Shelf, east coast South Island (ECSI),
Chatham Rise, northeast coast North Island, east coast North Island, and west coast North Island. Fish were measured as total length, to the cm. below. Only one data set exhibited clear and consistent length modes progressing from juveniles through to adults: the *Tangaroa* Chatham Rise survey series carried out annually in December-January between 1992–93 and 2000–01. Attempts to fit Von Bertalanffy growth curves to this data set using the MULTIFAN model (Fournier et al. 1990) were unsuccessful, apparently because of the presence of numerous overlapping, slow growing, age classes. Instead, we estimated by eye the modal lengths of two cohorts (presumed to be age classes) that progressed through the length-frequency distributions. Northeast coast North Island data sets taken by *Ikatere* and *Kaharoa* contained smaller (less than 15 cm) length modes, and because these were collected intermittently over many years they were grouped by season to show a progression through what was assumed to be the first two years of life.

In this report, trawl surveys by different vessels are designated as follows: *Ikatere* (ika), *Kaharoa* (kah), *Tangaroa* (tan). Of the four subsequent numbers, the first two refer to the year, the second two to the cruise number.

10.2 Fish sampling for age and growth

For the initial investigation of growth increments visible in different hard parts (otoliths, spines, etc.), fish were obtained from two regions: (1) shallow water (less than 50 m) on the Wellington coastline (handline, n = 7), and (2) deep water (600 m) of the South Island west coast (from one station in research trawl survey tan0007, n = 23).

The three pairs of otoliths (sagittae, asteriscii, lapilli) were dissected from each fish, cleaned in water and stored dry. Fin spines, vertebrae, scales, opercula and branchiostegal rays were cleaned in household bleach until adherent membranes were dissolved, then rinsed in water and left to air dry for one week.

For the main sample, 430 otoliths were taken from collections made during two trawl surveys off the east coast of the South Island (kah9618, December-January 1996–97; kah0014, December-January 2000–01), supplemented with some from larger fish from the Chatham Rise (jco7615, September 1976). They covered the available size range, with larger numbers selected from larger fish in order to cover higher ages as fully as possible. All otoliths had been stored dry.

Otoliths

The most complete sagittal otolith of each pair from the initial sample (n = 30) was photographed whole immersed in high refraction oil. A selection of these were examined by scanning electron microscopy under a Philips 505 SEM LaB6 at 2 to 5 kV, after acid etching (HCl 0.1M, 10 to 30 s). One sagitta of the pair was baked at 280 °C for about 6 minutes, embedded in an epoxy resin block, cut dorso-ventrally through the nucleus, and the sectioned surface (cross-section) polished smooth. The other sagitta and an asteriscus were thin-sectioned using a method similar to that described for spines (below). (The sagittae were viewed under polarised light in order to locate and mark the dorsal-ventral sectioning line directly through the nucleus.) The very small asteriscii were embedded and sectioned individually under a microscope. Sections were mounted on slides using a thermoplastic resin method (Kristensen 1980, Dawe & Natsukari 1991). Final otolith sections were ground and polished to a thickness of 0.3–0.4 mm, when a pattern of growth zones became clearly visible.
Section surfaces were coated with high refraction immersion oil and read under a compound microscope with transmitted light at 40x, 60x, or 80x magnification. Each section was scored subjectively for readability on a five-point scale: 1, excellent; 2, good; 3, acceptable (some zones not clear, or some uncertainty in distinguishing 'true' zones from sub-zones or checks); 4, poor (many zones not clearly defined and alternative counts possible); 5, virtually unreadable, but an approximate count could be made by extrapolating from some visible zones in different parts of the otolith section.

Otolith margins were examined to determine whether they could be categorised as light/dark or opaque/translucent, and whether the width of the marginal increment could be quantified.

Otoliths from two fish which had been injected with oxytetracycline (OTC) were contributed to this study from a separate investigation of reef fish biology in Otago/Southland. These fish were held in an outdoor pond at the Portobello Marine Laboratory for one year (8 May 2000 to 11 May 2001), supplied with natural seawater (Glen Carbines, NIWA, and Weimin Jiang, pers. comm.). Thin sections were prepared as described above, and photographed at high magnification under both transmitted and UV light. Interpretation of the number of zones outside the OTC mark was done without knowledge of the date of injection or time in captivity before sacrifice.

Otolith sections from three small (15-16 cm) fish were ground and polished thinner than those in the trial and main samples, until a sequence of very fine lines, assumed to be daily growth increments, became visible. These were photographed at a magnification of c. 300x, and the increments counted from the photographs at a further magnification of 10x.

Scales
A selection of cleaned scales from each fish were mounted between two microscope slides. Because they had no readable annuli when examined under transmitted light, they were viewed and photographed with polarised light in a manner similar as that ascribed to Farran (1924) by Savvatimsky (1971), and the annuli counted.

Fin spines and other structures
Spines (the largest spine from the dorsal and anal fins) were embedded in an epoxy resin block and sectioned with a twin-blade sectioning saw to give thin wafers of approximately 0.5 mm thickness. Sections from both the mid and upper positions of the various spines were taken to see if there were any differences in readability and number of growth zones between locations. After polishing, the sections were embedded on a slide and further ground and polished using a graduated series of silicon carbide papers until zones became visible under stereomicroscopic examination.

Opercula and vertebrae were examined whole with reflected and/or transmitted light under a stereomicroscope.

10.3 Age reading

For the initial investigation of the growth increments on different hard parts, colour photo micrographs were taken using a Nikon Microphot FX-A or Leica Mz12 stereomicroscope. These were interpreted for each structure (scales, otoliths, spines, etc.) from all 30 fish, before the photographs of different structures from each fish were compared.
For the main sample of otoliths, thin sections were read directly at 40x or 60x magnification under a compound microscope, with 80x magnification sometimes used when the outermost growth zones were closely spaced. They were read in random order of fish size, and without knowledge of fish length, sex, or otolith weight, although some inference on size and/or age could be drawn from the size and shape of the otolith section. Readings were made independently. Reader 1 made two readings, 3 weeks apart, Reader 2 made one reading. After initial analysis of results, two subsets of otolith sections were read again by both readers, independently, and then jointly to arrive at an agreed age.

Terminology
The narrow growth marks on scales are termed **annuli** in this account. On otoliths, fin spines, and other hard parts, they are termed **zones**. Within each otolith growth zone there are usually a series of finer **bands**. Most counts were made of otolith growth zones. Because of possible confusion over the terms opaque, translucent, and hyaline, we use the purely descriptive terms 'dark' and 'light', and define in the relevant sections below the lighting conditions under which each count was made.

However, in the main study of the growth zones seen in otolith thin sections, these were counted with transmitted light, and the counts were of dark zones. These were assumed (in most cases) to represent a slow-growth (probably winter+spawning) period. We make no assumptions on the structure of the zones we counted, given the present uncertainty in the literature on otoliths as to whether they result from changes in relative proportions of protein and calcium, from differences in crystalline structure, or both.

10.4 Ageing variability and growth rate estimation

To determine the level of within-reader variability, each otolith was read twice by one reader (Reader 1), 3 weeks apart. Each otolith was also read once by a second reader (Reader 2) to determine the level of between-reader variation. Ageing bias was assessed using age-bias plots as recommended by Campana et al. (1995).

Otolith zone counts were converted to ages by adding the fraction of the year elapsed between 1 January (the hypothetical birthday) and the date of collection. ECSI otoliths were collected in December-January, so the youngest fish in the sample were near their first birthday. Zone counts for ECSI were therefore increased by one. Chatham Rise otoliths were collected in mid-late September, and their zone counts were increased by 0.72.

Growth curves were fitted to ECSI length-at-age data using the Von Bertalanffy growth model:

\[ L_t = L_\infty \left(1 - e^{-K(t-t_0)}\right) \]

where \( L_t \) is the expected length at age \( t \) years, \( L_\infty \) is the asymptotic maximum length, \( K \) is the Von Bertalanffy growth constant, and \( t_0 \) is the theoretical age at zero length. Growth curves were fitted separately to males and females. Sixteen small unsexed fish from ECSI were included in both the male and female data sets.

Growth curves fitted separately to the ECSI age data for Reader 1 and Reader 2 differed most for females over the age range 10–20. To identify the source of the difference, and determine whether it was consistent over time, we randomly selected 20 otoliths from female sea perch between 27 and 35 cm long for further examination. Both readers independently counted each
otolith again (Reader 1, reading 3 and Reader 2, reading 2), without reference to their earlier
counts. They then discussed their readings, and re-counted the otoliths jointly to produce a
final, agreed age for each fish.

Twenty-four large Chatham Rise sea perch were also aged by both readers; all were females.
Growth curves were fitted to the combined ECSI and Chatham Rise female data to determine
what effect the inclusion of large, presumably old, fish would have on the ECSI growth curve.
Both readers again counted a subset of 11 fish aged 35 or greater by Reader 1 in the second
reading, and then discussed their results to produce an agreed age, as described in the previous
paragraph.

10.5 Maturity

To determine size and age at maturity, on cruise kah0014 the stage of gonad development was
recorded for 757 fish (357 males, 400 females). Because sea perch are viviparous, a modified
staging scale was used (Table 2).

Table 2: Gonad maturity scale used for sea perch.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Immature</td>
<td>Threadlike</td>
<td>Thin, oval, transparent</td>
</tr>
<tr>
<td>2 Resting</td>
<td>Slightly enlarged</td>
<td>Granular, small oocytes</td>
</tr>
<tr>
<td>3 Maturing</td>
<td>Hard edge, milt expressible with slight pressure</td>
<td>Eggs yolky (yellow/orange)</td>
</tr>
<tr>
<td>4 Ripe/Gravid</td>
<td>Milt flows freely from cut gonad</td>
<td>Eggs with dark eye-spots</td>
</tr>
<tr>
<td>5 Spent</td>
<td>Blotchy, bloody, hard</td>
<td>Bloody, flabby</td>
</tr>
</tbody>
</table>

10.6 Natural mortality

Estimates of the natural mortality coefficient, $M$, were obtained using Hoenig’s (1983)
regression equation describing the relationship between mortality rate and life span:

$$\log_e M = 1.46 - 1.01\log_e(t_{\text{max}})$$

where $t_{\text{max}}$ is the maximum age reached by the species.

11. Results

11.1 Size frequencies

General
The size distribution of sea perch taken during trawl surveys around the South Island show
some regional differences (Figure 1). This may partly be due to differences in the depth range
sampled during different survey series, and to differences in codend mesh, but it is difficult to
adjust for these. It also appears likely that some of the apparent regional size differences are
real. The top two graphs (west coast) are of fish taken by vessels with different trawl gear and
codend mesh, and fishing different depth ranges (Kaharoa 20–400 m, Tangaroa 500+ m). The size distribution is similar, with the Tangaroa sample differing mainly in having more
large (larger than 30 cm) fish, possibly because of the difference in depth range. The next two
graphs (east coast) are of fish taken by the same vessel (Kaharoa) but at different seasons and with different mesh. The size distribution is generally similar, apart from more small (10–20 cm) fish taken in the smaller mesh of the summer series.

Most west coast fish were smaller than 25 cm, with a mode at 17–18 cm. The sea perch taken in east coast South Island trawl surveys were larger, with the main mode at 25 cm. Fish taken in Chatham Rise trawl surveys were larger again, with a mode at 25–30 cm, and relatively more fish in the size range 30–45 cm. Fish from the Stewart-Snares shelf had a different size distribution, with fewer small fish and the main mode at about 35 cm.

Sea perch can only be sexed reliably above about 15 cm. The sex ratio from the east coast South Island was about unity, while in other regions there were slightly more males.

In all South Island regions, there were relatively few fish smaller than 15 cm, and little evidence of any age group modes. In the east coast South Island samples, there were fish at 10–17 cm, but only a slight mode at 13–15 cm in summer. This may partly be a consequence of mesh escapement by the smallest fish, but size modes of other fish species between 10 cm and 20 cm are caught in these surveys (NIWA, unpublished data). Juveniles may be concentrated over rough seafloor not sampled by trawl surveys.

The east coast South Island winter and summer sea perch size distributions are shown by individual survey in Figures 2 and 3. Fish from the winter (May-June) trawl surveys are mostly larger than 15 cm, and have very slight modes between 20 cm and 26–27 cm. Fish from the summer (December-January) surveys also have possible modes in this size range, but in both series they are too poorly defined to be identified as age group progression. The summer samples (Figure 3) also show a small size mode of fish at 12–16 cm, present each year from 1996 to 2000, and smaller fish at around 10 cm comprising a possible mode in the two years (1998–99 and 1999–2000). If the latter are 0+ fish at the end of their first year’s growth, the first two years growth would be to c.10 cm, and c.14 cm.

These east coast South Island size distributions are shown by 50 m depth zones in Figure 4, data from all surveys combined. In the two shallowest zones the size distribution is similar, the greater size range in the 51–100 m zone probably resulting from the larger sample size. The modal size is 22–24 cm. In the next two zones the size range is similar, but the modal size increases to 24–27 cm in 101–150 m, and to 26–30 cm in 151–200 m. Sample sizes are smaller in the deeper zones, but there is no evidence for a continuing increase in size. Small fish (11–16 cm) occur in all depth zones out to 400 m.

Northeast North Island juveniles
Sea perch samples taken during trawl surveys around the North Island contain a much higher proportion of small fish (Figure 5). This partly results from smaller codend mesh sizes (12 mm, 20 mm, 40 mm) being used. The most comprehensive sampling has occurred off northeastern New Zealand, where there are sufficient data to provide a summary (all years) by season. In summer there is a strong mode at 10–11 cm, which progresses through to 12–15 cm in spring. A small mode at 5–6 cm in summer becomes 6–7 cm in autumn and winter, and 8–10 cm in spring. If the two summer modes at 5–6 cm and 10–11 cm are age groups, and spawning occurs in spring-summer, the first two year’s growth would be to these sizes. This is slower than that for the South Island, but neither data set is very convincing, and the spawning period in each region is not well known. It is also possible that the smallest (i.e., first) mode is missing in the South Island samples.
Northeast North Island trawl surveys cover the depth range 50–600 m. There is an apparent increase in mean size beyond 400 m, but the sample sizes are too small, and taken with too many different mesh sizes, for meaningful comparisons.

East coast North Island trawl surveys (summer) have a mode at 17–19 cm, and west coast North Island surveys (spring) have a mode at 12–15 cm (Figure 5); these are comparable with the northeast North Island modes, but do not provide any further information on the youngest juveniles.

**Progression of length frequency modes, Chatham Rise**

Length-frequency histograms from the Chatham Rise trawl surveys showed an apparent progression of two cohorts of fish that first recruited in 1992–93 (tan9212) and 1996–97 (tan9701) respectively (Figure 6). The first cohort grew from about 14.5 cm to 28.5 cm in seven years, and the second cohort grew from about 13.5 cm to 19.5 cm in three years (Figures 6 and 7). Both cohorts therefore grew at about 2 cm per year.

11.2 Otoliths

Otoliths became relatively longer, with a distinct rostrum, and also ‘thicker’, with increasing size, but at all sizes were quite variable in shape and in the degree of marginal smoothness. Because of the small number (30) of fish in the trial sample, the otoliths from shallow and deep water fish could only be subjectively compared. No gross differences could be seen in size and shape. No differences could be seen in the growth zone structure of the baked cross-section surfaces, and thin sections, of the two subsamples.

**Whole otoliths**

The concave (lateral) surface of whole sagittal otoliths viewed under transmitted (white or polarised) light, or reflected light, was, in general, difficult to interpret (Figure 8). Otoliths from large fish were thick and dense; the inner zones were not clear, and it was suspected that the narrow outer zones extended ‘around the edge’ and out of sight. Counts of growth zones were lower than from baked cross-sections of the same otolith or from thin sections from the other otolith of the pair. The central region of the otolith, assumed to represent the first growing season, was particularly dense, as were one or two zones outside this. It may be feasible to use whole otoliths to age young (perhaps 1 to 5 year old) fish, but this could not be investigated during this study; the main sample included ages from 0+, but the size frequency distributions of sea perch taken in South Island trawl surveys lacked clear modes needed to confirm the ages of juvenile fish.

Counts were made of the dark zones in transmitted light, with the central dark region counted as zone 1.

**Electron microscopy of otolith surface**

SEM images of the lateral (concave or outer) surface topography of sagittal otoliths revealed countable ridges or corrugations in some fish, more clearly defined towards the margin (Figure 9). Etching these corrugations did not greatly improve their resolution. Only Reader 2 felt confident in counting these features. Future study of their spacing, with direct comparison of the zones seen in the same whole otolith under optimum lighting conditions, might prove useful in clarifying the pattern of growth zones of young (less than 5 year old) fish. Large otoliths have the problem of older (later) growth zones being present only on the medial
(convex or inner) surface, and not visible on the lateral surface. These corrugations are apparent on thin sections, and do generally correspond to what have been interpreted as the early growth zones, but are less clearly correlated with them towards the section tips (otolith edges). SEM images may be useful in clarifying early growth patterns, but this technique is too costly to use for routine ageing.

**Baked cross-sections**

Under reflected light, sagittal otolith cross-sections showed an alternating series of light (bright, or whitish) and dark (amber/brown) zones (Figure 10). The central light region (corresponding to the dense region in whole otoliths) was typically large; it may represent the first growing season, but it is usually interrupted by one or more dark ‘lines’ which range from what are probably minor growth checks to what could be true growth zones. The next two light zones are relatively large (i.e., the first three light zones are broad, interrupted by narrow dark zones), and then the light and dark zones both become progressively narrower towards the edge of the section. On the axis towards the otolith’s dorsal tip, the light zones remain relatively wider than the dark; elsewhere they are sometimes about equal, but they often become quite variable in relative width, with the dark zones relatively wider. On some otolith sections the distinction between light and dark zones remains clear, but on many it becomes very uncertain and the zones merge (in colour) towards the edge of the otolith.

**Thin sections**

With transmitted light, thin sections of sagittal otoliths showed an alternating series of light (translucent, or whitish) and dark (amber/brown) zones (Figure 11). The central region (corresponding to the dense region in whole otoliths, and the light region in baked cross-sections) was very dark. In thicker (0.4 mm) sections it was uniformly dark. In thinner (< 0.2 mm) sections most of the central region is lighter in appearance, with a darker margin reasonably similar to the dark zones in the outer part of the otolith (Figure 12,A). The first obviously lighter zone outside the centre was variable in most otoliths, and usually poorly defined. In most otoliths it was widest and lightest on the long axis extending towards the dorsal tip; it was reasonably wide on the ventral axis, but often subdivided by narrow dark lines, interpreted as checks. Outside this was the first typical (dark) growth zone.

The first 3–5 pairs of light and dark zones (each pair assumed to represent a year’s growth) were usually larger than successive pairs of zones. In some otoliths the zones diminished rapidly in size and spacing beyond these first 3–5, and in others there was only a gradual decrease. This variation also occurred within a single otolith; in some regions the zones decreased abruptly, while in others the same zones (which could often be followed around each half of the section, though not across the sulcal region) diminished regularly in size and spacing.

A separate issue was encountered when interpreting sections of different thickness. In very thin (< 0.2 mm) sections the narrow dark zones appear broader, and are seen to comprise a series of fine bands (Figure 12,B-D). The light zones appear very much narrower.

### 11.3 Scales

Scales were of the typical ctenoid shape (Figure 13,A). Growth marks were visible with transmitted light, but varied greatly in clarity and spacing; some were almost certainly annual rings (annuli), others minor checks, but many were intermediate in appearance and difficult to
interpret. With transmitted polarised light the growth marks were clearer, more uniform in appearance, and were usually more uniform in spacing. However, counts of these scale markings (annuli plus what may have been checks) using polarised light had a low between-reader agreement. Scales are rejected in most modern ageing studies because of "subjectivity" or "replacement" problems, and because it is known that annulus formation ceases in the older individuals of slow-growing species when somatic growth slows or stops.

11.4 Fin spines and other structures

Many of the spines were difficult to interpret, as they had hollow and vacuolated interiors. It was not clear whether all zones remained present, or the innermost (early) growth zones were missing. The innermost visible zones were sometimes paired and hard to interpret, but later zones were very clear (Figure 13,B-E). However, repeated readings by each reader gave different counts, the agreement between readers was often not close, and zone counts from the larger (older) fish were generally less than the zone counts from otoliths. Zone counts from sections across the mid-point of the dorsal and anal spines were judged to be clearest (Figure 13,B,C). There was moderate agreement with otolith thin section counts to about 10 or 15, but less agreement with higher counts. Given the difficulties of interpreting otoliths from young (0+ to 3+) fish, further investigation of fin spines may be useful in clarifying early growth and identifying juvenile age groups.

Rings were visible on pectoral and pelvic fin spine sections, branchiostegal ray sections, and opercular bones (Figure 13,D-G). They were sometimes clear, but difficult to interpret.

Ridges were visible on the concave surface of the vertebral centra, but were difficult to interpret (Figure 13,H,I). There was uncertainty as to the position of the first ridge, and it was unclear whether some subsequent ridges should be counted individually or grouped. One third of the vertebrae were judged unreadable.

11.5 Comparison of counts from different hard parts

Growth zone or annulus counts from different hard parts are listed in Table 3. The counts were made from photographs, augmented by re-examination under the microscope in a few difficult cases. They were made independently by the two readers, and each hard part was read independently. This work was not undertaken to choose the most suitable hard part for ageing, as the only samples available in existing collections were otoliths. Its main purpose was to investigate the relative clarity of baked cross-sections and thin-section preparations from otoliths – the two options for the main sample. It was anticipated, however, that by examining different otolith preparations, and other hard parts likely to show growth marks, a clearer understanding of growth mark characteristics would be obtained.

To facilitate this account of different counts, it is necessary to choose one series as a standard. Otolith thin section counts were considered to be the most appropriate, as it was possible to obtain clearer and higher-magnification photographs of these preparations. This did not presuppose that thin sections would be the final choice. There was moderate agreement between the counts from thin sections and baked cross-sections by both readers. There was also a consensus that all counts were difficult, and in the larger otoliths, in particular, there could be two interpretations of growth zones, leading to either high or low counts that were
difficult to choose between. Reader 1 recorded one value for each count, even when there was considerable uncertainty. Reader 2 recorded the uncertainty as either a range of counts, or as a pair of alternate counts (Table 3). The following account covers the differences in counts between readers, and the differences between hard parts.

For otolith thin sections, there was moderate agreement between readers when the higher of Reader 2’s paired counts were used. Counts by Reader 1 up to 10 were often higher than those of Reader 2 for the same otolith; after discussion, it was found that Reader 1 counted the outer edge of the dark central region as zone 1 because of its relative spacing out from the centre of the otolith, while Reader 2 omitted this feature because it was not a ‘typical’ zone. Beyond 10, readings were either similar or the counts by Reader 2 were higher.

For otolith baked cross-sections, the counts by both readers were usually similar, but with Reader 1’s counts being one higher from counting the central region as zone 1. Conversely, for some of the larger fish, Reader 2’s readings were higher.

In a comparison between otolith thin sections and baked cross-sections, Reader 1 achieved reasonable agreement but had slightly higher counts from thin sections. Reader 2 had good agreement at low (less than 11) counts, but above this had higher counts from baked cross-sections.

For whole otoliths, there was good agreement between readers in counts from small otoliths (3–5 zones), but poor agreement from larger otoliths. There was generally poor agreement between whole otoliths and otolith thin sections, particularly at higher counts. Reader 1 had poor agreement above a count of 6, while Reader 2 had poor agreement above 10. The highest counts from whole otoliths were 16 and 18, compared to 25–28 from thin sections. This almost certainly results from the later growth zones not reaching the concave lateral surface on which the whole otolith counts are made; the structure of otoliths seen in thin section shows that only zones 1–10 consistently reach the lateral surface, with later zones either becoming very crowded and irregular at the outer edge, or failing to curve around the edge to appear on that surface at all.

The lateral surface ridges visible in SEM images were recognised by Reader 1 but their counts were considered too subjective and were not recorded. Reader 2 achieved good agreement of ridge counts with thin section counts up to 11, but beyond that the ridge counts were much lower. These ridges can be seen in thin section, and correspond well with growth zones. The poor agreement in counts when the thin sections show more than about 10 growth zones is a consequence of the later zones appearing only irregularly on the otolith’s lateral surface.

Dorsal spine sections had very clear zones, although some subjectivity was required to count the innermost and outermost zones; the former had splits and were disrupted by a vacuolated core, the latter were very narrow. There was some agreement in between-reader counts, but Reader 2 counted about 15% more zones than Reader 1. There was poor agreement between spine zone counts and otolith thin section zone counts, the discrepancy increasing in larger fish.

Anal spine sections gave results similar to those for dorsal spines. Zones were clear, but the innermost and outermost difficult to interpret. Between-reader agreement was poor. Reader 1 obtained poor agreement with otolith thin section counts beyond 5, and Reader 2 poor agreement beyond 10.
Table 3: Comparison of readings from different structures (otoliths, spines, scales, vertebrae), and different otolith preparations, by Reader 1 and Reader 2.

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Notes:
- WCSI = west coast South I., 600 m; C St = Wellington coastline, 10–50 m.
- Entries in sequence, Reader 1: Reader 2.
- n, not read, interpretation considered too subjective.
- x, preparation considered unreadable.
- , sample not prepared.
- 8-9, reading uncertain, but 'about 8 or 9'.
- 11/26, reading uncertain, depending on whether zones are split or grouped could be either 11 or 26.
Pectoral and pelvic spine sections, and sections from branchiostegals, also gave similar results: clear zones, poor between-reader agreement, and poor agreement with otolith thin section counts. Reader 2 counted more zones than Reader 1, and so had a closer relationship between spine zones and otolith thin section zone counts to about age 10.

The operculum had a series of growth lines, some of which were very distinct. However, the anterior (early) ones merged into a vacuolated area of bone and their position was unclear. Counts by Reader 1 had no relationship with otolith thin section counts, while counts by Reader 2 had a very general relationship up to 15 followed by no relationship in larger fish. The between-reader relationship was linear, but Reader 2 counted from 1 to 6 zones higher.

Scales photographed with polarised light showed numerous relatively clear annuli, but they were interpreted differently by Readers 1 and 2. There was no between-reader agreement, and no relationship between scale counts and otolith thin section counts.

Vertebral growth zones were difficult to interpret, and many samples were unreadable. Reader 1 obtained only a poor agreement with otolith thin section counts, but Reader 2 obtained a good agreement (±1) up to 10. There was some between-reader agreement, but the maximum count was 11, compared with 29 from thin sections.

11.6 Otolith marginal increments

It was difficult to assess the marginal state of most otoliths. In the youngest (0+ to 3+) fish it was difficult to even locate and count the dark growth zones. In older fish, growth zones were too closely spaced, in two different ways. In the thicker (0.4 mm) sections the edge effect (light refraction) made characterising the edge as light (broad zone) or dark (narrow zone) very subjective. In the thinner (≤ 0.2 mm) sections the edge effect was less pronounced, but the dark zones were broadened into a series of fine bands, with only slightly wider spacing between the sets of bands in successive dark zones. In these otoliths it was difficult to assess whether a light margin was a light zone, or a light band within a dark zone. It was also apparent, in the clearest sections, that the marginal state was different in different parts of the otolith. A dark zone was often present around the dorsal tip edge (presumably formed first on this longer axis), but absent elsewhere. Conversely, one or more dark zones may be present on the edge adjacent to the sulcus but absent elsewhere, possibly as an artefact of section preparation. This would not be a problem if the marginal state could be recorded at a standard otolith location, but this could not be done in the present study. No part of the otolith was sufficiently clear in a large enough proportion of the sample.

Most of the otoliths examined from the main sample, taken in summer (Dec-Jan), had a broad light marginal zone along the proximal edge. They sometimes had a dark zone a short distance in from the edge at the dorsal tip, and some otoliths may have had a narrow dark zone along some of the proximal edge. We interpret this dark zone as the preceding ‘winter’ zone (see following Section on OTC-marked otoliths), with summer growth just commencing beyond it. Our counts did not include this zone (except, probably, inadvertently in the most difficult sections where it was only possible to obtain a zone count along the axis towards the dorsal tip). This count was adjusted in the calculation of growth rate by adding 1 to obtain ‘age’, or more strictly ‘dark zone count’.
The fish in the initial trial sample which were caught in winter (June-August) from deep water off the west coast of the South Island also had a light margin (where this could be determined). This was interpreted as being the previous summer’s growth zone, with the slow-growth (winter) dark zone not yet visible.

11.7 OTC-marked otoliths

The two fish injected with oxytetracycline and held for a year yielded otoliths with clear, easily-read thin sections. Their estimated ages at sacrifice were 19 and 21 years, based on counts of dark growth zones in transmitted light. The OTC marks were visible around the proximal edge of the section, and from enlarged photographs (Figure 14) were determined to lie just inside (i.e., prior to the formation of) the outermost dark zone. Beyond the latter, a light zone estimated to be of normal width extended to the otolith’s edge. Because of light refraction at the edge, it could not be determined whether another dark zone was beginning to form. However, in the twelve months between injection and sacrifice, each fish had formed one dark and one light zone, strongly suggesting that the zone pair represented one year’s growth. The position of the narrow dark zone, just beyond the OTC mark (early May), suggested that it had formed during the slow growth winter period. It may additionally represent the spawning season, although this is believed to be an extended period, perhaps from late winter through summer, and is different for each sex (see Section 11.11).

11.8 Daily growth increments

The very fine lines seen in thinly ground and polished otolith sections, and assumed to be daily growth increments, proved difficult to count along the entire dorsal axis of the otolith. They diminished in width from the otolith’s core to the edge, but within a particular area were sufficiently uniform to allow an extrapolation of counts across short distances (5–15 increments) where they were obscure. However, there were some irregularities, particularly from midway along the axis to the edge, where the increments became very closely spaced and uncountable, and/or there was an apparent check within the sequence of lines. If these features represent very slow growth and/or growth cessation, the counts must be regarded as an underestimate of the number of increments.

The three fish in this sample were initially aged as two year olds, from the larger pattern of light and dark growth zone counts. Figure 12, A shows the clearest of these, with the position of the two slow-growth (winter?) zones marked by arrows. In very thin sections, the dark centre of the otolith has a slightly separated outer edge, and this was assumed to be zone 1. The next dark zone, read as 2, is broad and apparently split. Counts of fine increments were made from the otolith’s centre to the inner and outer edge of zone 1, to the inner and outer edge of zone 2, and to the otolith margin (total count). In Table 4 the counts to each zone are given as ranges, using the inner and outer edges of each zone to give minimum and maximum counts to and between them.
Table 4: Counts of fine lines, assumed to be daily growth increments, on very thin sections of otoliths from three sea perch considered to be two years old.

<table>
<thead>
<tr>
<th>Fish</th>
<th>Otolith centre to zone 1</th>
<th>Zone 1 to zone 2</th>
<th>Total count</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 cm M</td>
<td>140–160</td>
<td>170–210</td>
<td>510</td>
</tr>
<tr>
<td>15 cm F</td>
<td>130–170</td>
<td>190–210</td>
<td>590</td>
</tr>
<tr>
<td>16 cm F1</td>
<td>220–240</td>
<td>260–300</td>
<td>730</td>
</tr>
</tbody>
</table>

Notes:
1. Zones are dark zones, assumed to form in winter, and may incorporate the spawning period.
2. Minimum count is inner edge of zone 1 to inner edge of zone 2, maximum count is outer edge of zone 1 to outer edge of zone 2. Zone 2 was not well defined.
3. Increment counts are rounded to the nearest 10, considered to be the level of count precision.
4. This was the most difficult otolith to interpret, both when defining the annual growth zones and in counting the fine lines. Re-examination following the count of fine growth increments suggest that it may have been three years old, not two, with a small first growth zone and poorly defined and separated second and third zones.

The two 15 cm fish give counts to the inner and outer edge of zone 1 (selected subjectively prior to the counts, see Figure 12,A) of 130–140 and 160–170. If the fine lines are daily increments, this suggests a first-season growth period of 4–5 months. The spawning season of sea perch is poorly known, but data from cruise kah0014 show females to be maturing or ripe in December–January, with a few spent fish (see Section 11.11). For present purposes January 1 is designated the birthdate. The position of an injected OTC mark indicated that the dark zone (at least of older fish) started forming some time after early May (see Section 11.7). These three pieces of information (birthdate, count of fine lines, and time of dark zone formation) have different uncertainties, but do support the assumption that the outer edge of the dark central region of the otolith represents the first winter growth zone.

The counts between equivalent zones 1 and 2 should represent one full year’s growth, and should approximate 365 if they are formed daily. The counts from all three fish fall short of this, being a maximum (outer edge of dark zone 1 to outer edge of dark zone 2, i.e. one light plus one dark zone) of 210 to 300 (Table 4). However, this is not surprising, given the observed checks in the sequence of lines, and the general finding that daily increment sequences beyond age 1 in temperate species are incomplete (Campana & Neilson 1985). Similarly, the total counts (otolith centre to edge) for two fish fall short of the 730 increments that would be expected for two year old fish (birthdate of 1 January, captured December-January). The total count of 730 for the third, 16 cm, fish is considered anomalous; the section was difficult to interpret, and it is possible that the fish may have been three years old.

11.9 Comparison of otolith zone counts between readers

Issues of readability

In comparison with many other fish species, otolith sections were subjectively judged difficult to read. In thick sections the dark growth zones were relatively narrow and had the typical appearance of slow-growth zones. In very thin sections the dark zones were broad and subdivided into narrow bands, and some subjectivity was involved when interpreting the outermost zones. It was often difficult to decide whether these relatively narrow dark 'lines' were individual growth zones and counted, or sets of bands to be aggregated into zones.

The 5-point scale of readability (1, excellent to 5, virtually unreadable) proved difficult to follow, and Readers 1 and 2 often differed in their scoring of individual sections. Very few (about 5) sections gave clear and consistent zone counts along all axes and could be scored
as 1. It was also difficult to separate sections in category 4 (poor) from those in category 5 (virtually unreadable). No sections were rejected as unreadable. Even on very poor otolith sections a zone count could be made along one axis, or readings combined from partial counts along two or more axes. About five readings were placed in category 5 by both readers. After the three readings were completed, the 5-point scale was considered to be too detailed and the readability scores were condensed into three: 1, excellent to good (combining 1 and 2 on the original scale); 2, average (3 on the original scale); and 3, poor (combining 4 and 5 on the original scale). The distribution of readability scores by each reader are summarised in Table 5.

Table 5: Distribution of readability scores for sea perch otolith sections, by Readers 1 and 2; the values are percentages of the total (n = 430) sample or sexed sample (n = 414). The readability scores are 1 = good, 2 = average, 3 = poor.

<table>
<thead>
<tr>
<th>Readability scores</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reader 1 (reading 1)</td>
<td>Total</td>
<td>18</td>
<td>45</td>
</tr>
<tr>
<td>Reader 1 (reading 2)</td>
<td>Total</td>
<td>13</td>
<td>53</td>
</tr>
<tr>
<td>Reader 2</td>
<td>Total</td>
<td>10</td>
<td>66</td>
</tr>
<tr>
<td>Reader 1 (reading 1)</td>
<td>Male</td>
<td>22</td>
<td>50</td>
</tr>
<tr>
<td>Female</td>
<td>13</td>
<td>39</td>
<td>47</td>
</tr>
<tr>
<td>Reader 1 (reading 2)</td>
<td>Male</td>
<td>13</td>
<td>57</td>
</tr>
<tr>
<td>Female</td>
<td>13</td>
<td>49</td>
<td>39</td>
</tr>
<tr>
<td>Reader 2</td>
<td>Male</td>
<td>14</td>
<td>71</td>
</tr>
<tr>
<td>Female</td>
<td>5</td>
<td>61</td>
<td>34</td>
</tr>
</tbody>
</table>

Of the total sample (n = 430), half to two-thirds were considered about average in readability (though in relation to other species they were considered difficult). A quarter to more than one-third were assessed as poor. Only 10–18% were assessed as good to excellent.

Of the sexed sample, relatively more otolith sections from male fish were scored as good or average in readability, and relatively more from female fish were scored as poor. The reason for this difference is unknown. If the growth zones are influenced by the spawning cycle, the greater investment by females in gonad development (particularly in a viviparous species) might result in a clearer distinction between periods of fast and slow growth. On the other hand, the viviparity of sea perch, and the possibility that they are batch spawners, could result in a prolonged period of slow but intermittent growth, particularly in females, and complex and less distinct differences between the otolith’s fast and slow growth zones. The relatively greater clarity of otoliths was noted in ling, hoki, hake, etc. by Horn (1993, and pers. comm.), but otherwise not seem to be commented on.

Interpretation of growth zones
In the trial reading of potential age structures and preparations, Reader 1 tended to make slightly higher counts than Reader 2 from thin sections, mainly at the more difficult lower ages (Table 3). Counts from the baked cross-sections were generally more similar, apart from some outliers at counts above 10, which were attributed to uncertainty over whether to count some narrow dark zones singly or to aggregate them. Apart from this uncertainty, and the difficulty in recognising growth zones in general, the readers believed they were counting essentially the same features visible in otolith thin sections. However, after the main samples had been read and the within-reader and between-reader differences quantified (see following Section), some otolith sections were re-examined jointly to determine whether there were any
obvious reasons for the discrepancies (see Section 10.3). It was then apparent that Reader 1 usually counted the outer edge of the dark central region as zone 1, while Reader 2 usually counted the dark zone immediately outside this as zone 1. Reader 1 also counted relatively more of the outer zones singly instead of aggregating them, although this was not consistent.

**Within- and between-reader comparisons**

Of the 430 otoliths that were read twice by Reader 1, 32.6% of readings were identical, 68.4% were within 1 zone, and 84.7% were within 2 zones of each other (Figure 15,A). The largest differences in zone counts occurred among the older fish, with a maximum difference of 24 zones. The first and second readings often differed significantly, with the second reading producing higher counts than the first reading (Figure 15,B).

In a comparison of the first counts of Readers 1 and 2, 27.7% of readings were identical, 67.9% were within 1 zone, and 83.3% were within 2 zones of each other (Figure 16,A). The largest difference was 13 zones. Readers 1 and 2 did not differ significantly from each other up to about 20 zones (Figure 16,B). However, Reader 1 consistently produced higher counts than Reader 2, with the discrepancy increasing in older fish, suggesting that there was a real, but small, bias.

Removal from the dataset of otoliths that were judged difficult to count (readability scores 4 and 5 in the original scale) produced only minor changes to the patterns shown in Figures 15 and 16.

**11.10 Growth curves**

Length at age data for the three readings of all 430 otoliths are presented in Figure 17. Males tended to be slightly longer at a given age than females. In the two readings by Reader 1, there was an indication that Chatham Rise females were longer at a given age than ECSI females, though there was little overlap of the two datasets. The ages assigned to the Chatham Rise females in the three readings differed substantially, with the highest ages coming from the second reading of Reader 1.

For ECSI males and ECSI females, growth curves fitted separately to each of the three otolith readings were similar (Figure 18). When ECSI and Chatham Rise females were combined, the growth curve for reading 2 of Reader 1 extended further to the right than the other curves because of the greater ages assigned to Chatham Rise fish. In all growth curve comparisons, the length at age increased in the order Reader 1 reading 2, Reader 1 reading 1, and Reader 2 reading 1. This ranking is consistent with the pattern of ageing biases shown in Figures 15 and 16. However, differences among the growth curves for the three readings were small. For example, the variation in predicted female length at 10 years was 2.3 cm (ranging from 27.9 cm for Reader 1, reading 2 to 30.2 cm for Reader 2, reading 1).

For the subsample of 20 ECSI otoliths that were re-read by both readers, Reader 1 counted 1.2 more zones on average than Reader 2 (Table 6). When the two readers discussed their interpretations of the otoliths, and recounted them jointly, they agreed on ages that were (on average) intermediate between their most recent counts (Table 6). Furthermore, Reader 1’s third reading produced results that were more similar to those in his first reading than his second reading.
A similar pattern was apparent for the subsample of 11 Chatham Rise otoliths that were re-read by both readers, except that the difference between readers was 2.8 zones on average, and the agreed ages were closer to Reader 1’s third reading than Reader 2’s second reading (Table 7).

The high zone counts produced by the second reading of Reader 1 were inconsistent with all other counts. We believe that the best estimate of age for ECSI sea perch is the mean of the ages estimated by both readers in their first reading. For the estimation of longevity, we used the same mean ages for ECSI sea perch, and the agreed ages for the Chatham Rise sample (Table 7).

Final growth curves are not presented for the combined Chatham Rise and ECSI female data, as there appeared to be differences in length at age, and it is unknown whether the fish from east and west coasts of the South Island are part of the same stock.

The final growth curves for male and female ECSI sea perch are shown in Figure 19, and growth parameters are in Table 8. Male and female growth curves diverged at about 5–8 years, with males growing faster and larger than females. The oldest male was 32.0 years, and the oldest female was 26.5 years, but samples sizes of old fish were inadequate for determining whether males grow older than females.

<table>
<thead>
<tr>
<th>Sex</th>
<th>Sample size</th>
<th>$L_m \pm SE$ (cm)</th>
<th>$K \pm SE$ (years$^{-1}$)</th>
<th>$t_0 \pm SE$ (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>222</td>
<td>42.45 ± 0.85</td>
<td>0.120 ± 0.008</td>
<td>-0.74 ± 0.22</td>
</tr>
<tr>
<td>Female</td>
<td>200</td>
<td>38.33 ± 0.75</td>
<td>0.139 ± 0.009</td>
<td>-0.65 ± 0.21</td>
</tr>
</tbody>
</table>
The oldest (agreed age) Chatham Rise sea perch was 43 years. All Chatham Rise fish selected for this study were females; however, large and presumably old males do occur there, so this does not mean that females are older than males on the Chatham Rise.

The final ECSI growth curves are compared with the estimated modal lengths for two Chatham Rise length cohorts in Figure 7. The growth curves were positioned in relation to the length modes by assuming that the fish comprising cohort 1 in 1992–93 were three years old. The ECSI growth curves rise more steeply than the Chatham Rise length modes, indicating faster growth and/or ageing errors.

11.11 Relationship between otolith weight and age

Otolith weight and mean age data were strongly correlated, and there were no apparent differences between males and females (Figure 20).

11.12 Size and age at maturity

Length and age at maturity could not be determined directly from the aged sample, or clearly determined from the larger (n = 757) sample of sea perch examined for stage of gonad development during kah0014.

Most (98%) of the mature males were stage 2 (resting), the remaining 2% being stage 3 (maturing). Most of the mature females were ripe (55%) or maturing (38%), with 1% spent. This difference between sexes results from the mode of reproduction, which involves internal fertilisation and ovarian gestation. White et al. (1998) described a delay of 1–3 months between insemination and fertilisation in *Helicolenus dactylopterus* off the southeast United States, which when added to the time taken for the fertilised ova to develop in the ovary results in an autumn (September-November) spawning peak for males and a winter to early spring (December-April) spawning peak for females. They cite a similar pattern for this species in the northeastern Atlantic (Isidro 1987, in Esteves et al. 1997); males spawn in September, females in January-April. Allain (2001) found spawning to occur in this region from March to June, but notes earlier statements which imply considerable geographic variation in timing between the Mediterranean and Britain. It appears likely that the east coast South Island sample of *H. percoides* taken in December-January comprised males which were recovering from a peak of spawning activity some time (months?) earlier, and fertilised females which were approaching spawning. However, the spawning cycle of this species in New Zealand waters cannot yet be defined.

The distinction in macroscopic appearance between immature and resting testes was small and subjective, and this may have contributed to the considerable overlap in size between fish sizes in these categories. Males were immature up to 35 cm, but the relatively few fish recorded in this category above 25 cm may have been mature but resting. The smallest mature (and resting) male was 14 cm, but this stage was more generally recognisable in fish 19 cm and above. The data are not sufficiently reliable to provide a length at 50% maturity, but it appears that maturity occurs between 19 cm and 25 cm. This approximates ages 5 to 7 on the Von Bertalanffy growth curve in Figure 19.
The distinction between immature and mature ovaries was more straightforward. Omitting a few outlier values, the largest immature female was 22 cm. The smallest mature females were 14 cm (ripe), 16 cm (resting), and 17 cm (maturing), but the clearest division between immature and mature fish was at 19-20 cm. This approximates age 5 on the Von Bertalanffy growth curve in Figure 19.

11.13 Natural mortality

Using the maximum observed ages for ECSI and Chatham Rise sea perch of 32 and 43 years respectively, the natural mortality rates for the two regions are estimated to be 0.13 and 0.10. The ECSI has been trawled intensively for decades, and fishing mortality of sea perch may have been substantial (mainly as discarded bycatch until recently), so true longevity is probably greater than we observed. The longevity observed for the Chatham Rise sample collected in 1976 before intensive trawling of the Chatham Rise began is likely more reliable. A natural mortality rate of 0.10 is therefore most plausible. If longevity is as great as 50 years, \( M \) would decline to 0.08.

12. Discussion

12.1 Age determination from different hard parts

The preliminary examination of growth marks (zones and annuli) on different otolith preparations, and other hard parts was not comprehensive enough to clearly define the optimal structure, and optimal preparation, for age determination. However, some generations are possible. Otolith thin sections were subjectively considered to be the most appropriate preparation for the main ageing study, the first on this species in New Zealand. They were not the simplest preparation (whole otoliths, baked cross-sectioned otoliths, and scales could be examined more quickly), and their growth marks were not as clear as those on other hard parts (especially spine sections). The readings from thin sections, and from baked cross-sections, were comparable. The latter could be prepared more quickly, but thin sections were able to be viewed under much higher magnification, and under a greater variety of — and more easily standardised — lighting conditions.

Whole otoliths showed growth zones, and there was reasonable agreement with thin section counts up to about zone 5 (Reader 2) or to about zone 10 (Reader 1). Discrepancies between whole otoliths and thin sections from larger (= older) fish almost certainly result from the later growth zones not extending around the otolith edge to appear on the lateral surface (where the counts on whole otolith counts are made). This deficiency was usually recognised in the earliest ageing studies on the related species *Helicolenus dactylopterus* which used whole otoliths; more recent studies have used thin sections, and obtained higher maximum ages. SEM images of the otolith’s lateral surface show ridges which are almost certainly growth structures. Thin sections also show these ridges, and they are associated with the growth zones counted in sections, but the link between zone and ridge becomes tenuous near the edge of the otolith. Because the later zones (after about 10) only narrowly or irregularly intersect the lateral surface, SEM images have the same limitation as standard views of whole otoliths in transmitted or reflected light.
Thin sections from fin spines showed clear growth zones, but the inner vacuolated section was difficult to interpret, and the outermost zones (after about 10) became irregular and narrowly spaced. It seems highly probable that fin spines in a species which reaches an age of 40+ and grows slowly in its later years, as the present study suggests, are unable to show a full complement of zones. However, dorsal and anal spine thin sections are easy to collect and prepare, and further study of their characteristics may well prove them to be useful in identifying and following year classes within the age range of 3–10 years (which would cover most fish in the commercial catch).

Thin sections from the smaller fin spines (pectoral, pelvic) showed even fewer zones and were not considered useful. Branchiostegal rays also gave low zone counts, possibly because the vacuolated centre obscured early zones. Opercular bones sometimes yielded counts in moderate agreement with otolith thin section counts, but more generally they were difficult to interpret.

Sea perch scales are small, with poorly-defined annuli in transmitted light; these were judged unsuitable for ageing work, as it was immediately obvious that the counts of the clearest annuli were much lower than otolith zone counts. Numerous 'rings' became visible in polarised light; these gave counts that were higher than otolith counts less than 15, and lower when the otolith counts were above 15. These counts are also considered unreliable. A similar misleading pattern of scale markings (in polarised light) was recorded from a deepwater macrourid by Bergstad (1990, 1995); otoliths are now considered more appropriate for that species. Although polarised light, sometimes in association with chemical impregnation of scales, has been attempted for several fish species which are difficult to age by more conventional methods, the results are uncertain and not generally accepted as validated ages (Wilson 1982, Bergstad 1990). However, there may be some value in further investigation of sea perch scales using transmitted light, in conjunction with fin spine sections, to clarify the early growth of this species, in particular the position of the first growth check, which is unclear in otolith preparations.

Vertebral centra did show zones, which presumably represented growth checks, but the high number of unreadable preparations, combined with difficulty in reading the others, and the poor relationship with otolith zone counts, rule them out as useful structures for age determination.

12.2 Otolith readability

Both readers found all otolith preparations from this species difficult to interpret, and gave low readability scores to a high proportion of the main sample. Within- and between-reader agreement was only moderate, particularly at higher counts of growth zones. The differences between readers and readings did not have a large effect on the growth rates, maximum age, and mortality rates that were subsequently calculated, but it must be kept in mind that these are based on unvalidated ages, and on growth zone readings – particularly above 15 – that were not very certain.
12.3 Comparison with previous studies

The results of some earlier ageing work on New Zealand sea perch summarised by Paul (1998) can now be updated. Almost 600 otoliths from west coast South Island were aged in 1976, read whole when immersed in oil (NIWA, unpublished data). Their mean lengths at 'age' formed a linear relationship from 2 to 13, rather than a typical growth curve, and the maximum 'age' was only 17. Nevertheless, these mean values fall reasonably close (± 1 year) to the growth curve derived in the present study between ages 2 and 12. Otoliths from the 15 largest (greater than 40 cm) fish in this sample were re-read in 1997 as thin sections. These gave ages of 18 to 39; the values fall above the present mean growth curve (i.e., the fish are larger at equivalent ages), but they cannot be directly compared because they were selected by fish size.

The results obtained by Withell & Wankowski (1988) from ocean perch, Helicolenus percoides, off southeastern Australia can also be compared. (The species is nominally the same, but the specific or sub-specific relationships of shallow and deepwater forms of Helicolenus off both Australia and New Zealand have yet to be determined (P.J. Smith, NIWA, pers. comm.)) A mean growth curve plotted through the values in Table 8 of Withell & Wankowski (1988) lies very close to the calculated growth curves in this study (Figure 19). It differs from (lags behind) the New Zealand male and female curves by about one year between ages 2 and 10, but then lies between these two curves to age 30+. The greatest Australian age was "about 42", comparable with 43 from a Chatham Rise fish; Park (1994) subsequently suggested a maximum age for Australian fish of 47 years.

The related bluemouth or blackbelly rockfish Helicolenus dactylopterus of the Atlantic Ocean has a similar pattern of growth zones in otolith thin sections (see White et al. 1998, Figure 2; Kelly et al. 1999, Figures 3 and 4). Some studies on ageing which were based on whole otoliths gave maximum ages between 14 and 30 (see Table 1). Studies which used otolith thin sections gave maximum ages from 30 to 43. The latter are considered more reliable (Kelly et al. 1999) because of the thickness and opacity of large otoliths, but it is also possible that the studies which reported lower maximum ages were based on well-fished populations. The growth curves for this species given by Kelly et al. (1999) and Massutí et al. (2000) are similar in shape to that for H. percoides in this study, increasing only slowly to an asymptote, but show a much slower growth rate. The latter results from the smaller size of fish in the H. dactylopterus samples studied, with relatively few above 30 cm; the maximum reported size of H. dactylopterus at 45 cm, however, is not much smaller than that for H. percoides at 53 cm (NIWA, unpublished data).

In the present study males were found to grow faster than females. This is comparable to the studies on H. dactylopterus reported by White et al. (1998), Kelly et al. (1999), and Massutí et al. (2000). The difference between sexes was attributed by Massutí et al. (2000) to the high energetic requirements of viviparous reproduction. Conversely, the study by Withell & Wankowski (1988) on Australian H. percoides showed that females grew relatively faster; the difference was very small but significant, although it appears to be influenced by a small number of fish at the upper end of the age range.
12.4 Maturity

The recorded gonad development stages, with males resting while females are maturing or ripe, are in agreement with published studies on *Helicolenus dactylopterus* (and some *Sebastes* species) that show the seasonal maturity cycle of males and females to be out of phase. In *H. dactylopterus* the males mature first, there is insemination, a period of one to three months while sperm are retained by the females before fertilisation, then development of the fertilised eggs in the ovary to the eyed-ova stage. The latter appears to be reached four to five months after the males were at peak maturity.

In Australian *H. percoides* mating is reported to occur from June to August, with a peak of vitellogenesis (egg formation) occurring in “spring”, from studies reported on briefly by Park (1994). The reproductive cycle of the “inshore form” is reported to be 1–2 months earlier than that for the “offshore form”; the taxonomic status of these forms is still uncertain.

The reproductive cycle is not known in New Zealand *H. percoides*; the few observations are based only on females. Graham (1956) suggests that spawning might occur in all months except July and August, but this appears to be an extension, derived from a few records of mature females (Graham 1939), to the observation by Thomson & Anderton (1921) that “the females of this species are ripe from September to December.” It is possible that there is an extended spawning season, but from the evidence to hand it can only be stated that females off the east coast South Island are mature to ripe in December and January.

The age at maturity, estimated at 5–7 years, is considerably younger than reported for *H. dactylopterus* off the Carolinas (10–15 years, White et al. 1998), and in the northeast Atlantic (13–16 years, Kelly et al. 1999). Allain (2001) reports female maturity at 7 years in the latter region, based on one possibly anomalous fish, and predicts an age of maturity of 3–4 years based on a Von Bertalanffy growth curve, but recognises considerable uncertainty in age determination. Length and age at maturity were not reported for Australian *H. percoides* by Withell & Wankowski (1988), but the suggestion by Lyle & Ford (1993) that maturity was attained at 30–31 cm would imply an age of about 11.

12.5 Remaining uncertainties

Despite the uncertainty both readers gave to their final counts of growth zones on otolith thin sections, the results were in moderate agreement and yielded a plausible growth curve (in contrast to the results of White et al. (1998) whose age at length data did not fit a Von Bertalanffy growth equation or any other growth function). The growth curve was supported by a growth rate estimated independently from modal progression in a sequence of length frequencies from trawl surveys, and the mean size at age of one and two year old fish was supported by length frequency modes of juveniles, albeit from a different region of New Zealand. The growth curve almost precisely matched a growth curve derived for *Helicolenus percoides* in Australia, also based on otolith thin sections, and was similar in shape to growth curves for *H. dactylopterus* in the North Atlantic. Given our present understanding of the species, it appears reasonable.

However, some uncertainties remain in otolith interpretation. The first zone is difficult to distinguish in most sections, often being part of a large dense core. Also, the nature of the alternating dark and light growth zones needs more investigation. In normal thin sections the
dark (considered to represent slow-growth) zones seem typical of those in many fish species, but in very thin sections these zones broaden to become wider than the light (assumed fast-growth) zones and can be seen to comprise several fine lines or bands. This broadening may be an optical artefact, but it is not known what the fine bands represent.

Determining the size and nature of the marginal increment, in order to establish the timing of zone formation, is problematic. The new growth zone appears to form at different times around the otolith; in very thin sections the relatively narrow light zone is difficult to distinguish when it is at the edge; and during preparation (grinding and polishing) of very thin sections some parts of the edge can be lost.

The attempt to define the position of the first growth zone by counting what appeared to be daily increments must be regarded as tentative. Although the result was plausible, it was based on three assumptions: (1) a birthdate of 1 January, from limited information on time of spawning; (2) first dark zone formation commencing in May, from information on the time of formation of much later zones; (3) unvalidated daily growth increments. It reinforces the desirability of knowing something of the general biology of a species when undertaking detailed age and growth studies. There is considerable value in understanding the reproductive cycle, and in investigating the pattern of daily growth increments during the 0+ year.

This study treats sea perch as one species, *Helicolenus percoides*, with a very large depth range. Trawl surveys reveal it to be common between 100 m and 800 m, extending down to at least 1200 m (Anderson et al. 1998), and diver observations and catches by recreational and commercial fishers show it to be common in less than 5 m on rocky shorelines (Paulin & Roberts 1992, NIWA unpublished records). Paulin (1989) subdivided the “sea perch” into a shallow (to c. 40 m) species (*Helicolenus percoides*) and a deepwater species (*H. barathri*), based on eye size and body coloration, formalising earlier recognition of shallow (orange/brown) and deep (red/orange) forms. These features are now considered to vary, mainly with depth, and genetic analysis has not been able to show that there is more than one species (P.J. Smith, NIWA, pers. comm.). There is unpublished evidence that in Australia the very similar ocean perch, nominally *H. percoides*, comprises either two forms (shallow and deep), or two species (Gomon et al. 1994; P.J. Smith, NIWA, pers. comm.). If future analysis subdivides New Zealand *H. percoides*, the work reported in this study is predominantly based on the form commonly present in 50–600 m.

Caution must be used when extrapolating the results of this ageing study to other species. Unless more than one species of sea perch exists (see above), the extensive depth range recorded for *Helicolenus percoides*, 0–1200+ m, with habitats ranging from rocky shorelines to the open deepwater seafloor, suggest that it is a highly adaptable species, and not necessarily typical of either shallow or deepwater species. The influence of its viviparity on otolith growth, in females at least, is not known. The reason for the subdivision of the otolith’s dark zones into fine bands is unknown; it might reflect viviparity, a prolonged spawning season, or be an inherent feature of scorpaenid otoliths. The variation in the extent of this zone subdivision might be a function of depth, a possibility that could not be investigated in this study because most of the fish in the main sample came from the depth range 50–200 m.
13. Relevance to fisheries

The results presented here suggest that the sea perch has growth and longevity characteristics comparable with many other fish species of the mid to outer shelf and upper slope. They have a "moderate" growth rate; the exploited population predominantly comprises age groups 5 to 20, with some evidence of variability in year class strength; and maximum age is in the range of 40 to 50 years. Age at maturity of 5–7 years is similar to other New Zealand shelf and middle depth species which have been studied (but earlier than usually reported for Helicolenus populations elsewhere).

14. Acknowledgments

We thank all those persons who measured sea perch during trawl surveys targeted at other species; their accumulated data have proved very useful. We also thank those who took the additional trouble to collect otoliths. Michael Stevenson and his team on the ECSI survey kah0014 went one step further and recorded gonad stage as well, adding to our knowledge of the complex reproductive cycle of this species. Neil Bagley collected shallow water sea perch from Cook Strait, and the west coast South Island trawl survey samples. We thank C. Ó Maolagáin for the otolith and spine sections, and other structures, for photomicroscopy (Figures 8–14), and for being a major participant in age-reading. Peter Horn contributed useful suggestions when reviewing the manuscript. This project was funded by the Ministry of Fisheries under project code SPE2000/01.

14. Data Storage

Data extracts and analyses have been stored by NIWA in accordance with the current Data Management contract with the Ministry of Fisheries.

15. Publications

None.
16. References


Figure 1: Length frequencies for sea perch, by region, vessel, and sex, South Island. Data combined from standardised trawl surveys in each region during the 1990s. Codend mesh sizes: r.v. Tangaroa, 60 mm; r.v. Kaharoa, 74 mm (west coast and east coast winter), 28 mm (east coast summer). 'All fish' (line plots) include unsexed immature fish; males and females (histograms) comprise a sexed subsample. N, sample size; all fish, and (sexed subsample).
Figure 2: Length frequencies for sea perch, east coast South Island, by trawl survey (r.v. Kaharoa) 1990 to 1996; winter time series (May/June). Codend mesh size, 74 mm. N, sample size.
Figure 3: Length frequencies for sea perch, east coast South Island, by trawl survey (r.v. Kaharoa) 1996 to 2000; summer time series (December/January). Codend mesh size, 28 mm. N, sample size.
Figure 4: Length frequencies for sea perch, east coast South Island, by 50 m depth zone, all r.v. Kaharoa trawl surveys (i.e., winter and summer) combined. $N$, sample size.
Figure 5: Length frequencies for sea perch, North Island regions, by season, all r.v. Ikaterere and r.v. Kaharoa coastal trawl surveys combined (as listed). Summer = Jan-Mar; autumn = Apr-May; winter = Jun-Sep; spring = Oct-Dec. N, sample size.
Figure 6: Length-frequency distributions (both sexes combined) of sea perch sampled during trawl surveys of the Chatham Rise, 1992-93 to 2000-01. Arrow heads indicate estimated modal lengths of two cohorts that recruited in 1992-93 and 1996-97. N, sample size.
Figure 7: Modal lengths of two sea perch cohorts (both sexes combined) estimated from Chatham Rise length-frequency samples (symbols). Also plotted for comparison are the east coast South Island Von Bertalanffy growth curves derived from the mean otolith ages of both readers.
Figure 8: Whole otolith, in transmitted light; anterior (rostral) tip to the left, dorsal edge to top. From 24 cm female, west coast South Island.

Figure 9: SEM images of lateral surface of otolith; anterior tip to the left. From 29 cm male, Cook Strait.

Figure 10: Cross section of baked otolith, in reflected light; ventral edge to the right. From 24 cm female, west coast South Island.
Figure 11: Thin sections of two otoliths, in transmitted light; dorsal edge to the top, lateral surface to the left, sulcal (medial) surface to the right. Left otolith from 21 cm female, right otolith from 24 cm female, both west coast South Island.
Figure 12: Fine structure visible in otolith thin sections, in transmitted light. (A) Very thin section showing the innermost growth zones; 15 cm male, east coast South Island. Arrows show inner and outer margins of first two growth zones, see text on daily growth increments. (B) Segment from the sulcus to the ventral edge of a thicker section, showing a ‘typical’ pattern of growth zones; apart from along the ventral axis, the dark zones are narrower than the light zones; 21 cm female, west coast South Island. (C) Very thin section of sulcal ridge (crista), showing subdivision of dark zones into fine bands. (D) Very thin section of medial edge on other (ventral) side of sulcus, also showing the relatively broader dark zones which are subdivided into fine bands, and the relatively narrow pale zones. (C) and (D); 24 cm female, west coast South Island.
Figure 13: Growth marks visible in scales, fin spines, and other structures. (A) Scale, transmitted polarised light; 21 cm female, west coast South Island. (B) Dorsal spine section, transmitted light; 29 cm male, Cook Strait. (C) Anal spine section, transmitted light; 29 cm male, Cook Strait. (D) Pectoral spine section, transmitted light; 26 cm male, Cook Strait. (E) Pelvic spine section, transmitted light; 26 cm male, Cook Strait. (F) Opercular bone, transmitted light; 33 cm male, Cook Strait. (G) Branchiostegal ray section, transmitted light; 24 cm female, west coast South Island. (H) Vertebral centrum, reflected light; 20 cm male, Cook Strait. (I) Vertebral centrum, reflected light; 21 cm female, west coast South Island.
Figure 13 (continued): Growth marks visible in scales, fin spines, and other structures.
Figure 14: Otolith thin sections from two sea perch injected with oxytetracycline (OTC). Left, viewed in UV light; right, viewed in transmitted light. Top, 31 cm fish, aged from otolith thin section at 19 years, otolith segment shown is the dorsal edge. Bottom, 30 cm fish, aged at 21 years, otolith segment shown is from the medial edge midway between the sulcus and dorsal edge. Both fish were captured in Otago coastal waters in May 2000, injected, held in a large outdoor tank at Portobello Marine Laboratory, and sacrificed and sampled in May 2001. Comparative measurements taken from enlargements of these and other photographs show that the OTC mark (arrow) lies just inside the outermost narrow dark growth zone of both otoliths.
Figure 15: Within-reader comparison of otolith zone counts for sea perch: (A) Actual counts (numbers represent number of fish). (B) Mean count of Reader 1, reading 2 (± 2 standard errors (SE)) relative to the counts of Reader 1, reading 1. Diagonal lines indicate the expected relationship. $N$, sample size.
Figure 16: Between-reader comparison of otolith zone counts for sea perch: (A) Actual counts (numbers represent number of fish). (B) Mean count of Reader 2 (± 2 standard errors (SE)) relative to the counts of Reader 1. Diagonal lines indicate the expected relationship. \( N \), sample size.
Figure 17: Length at age data from three otolith readings for east coast South Island and Chatham Rise sea perch. N, sample size.
Figure 18: Growth curves derived from three otolith readings for east coast South Island and Chatham Rise male and female sea perch.
Figure 19: Final growth curves for east coast South Island sea perch, derived from the mean otolith zone counts of Readers 1 and 2.

Figure 20: Otolith weight versus mean age for east coast South Island and Chatham Rise sea perch. 

*N, sample size.*