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Age and growth of brill (*Colistium guntheri*) and turbot (*C. nudipinnis*) from the west coast South Island

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Final Research Report

Report title:	Age and growth of brill (*Colistium guntheri*) and turbot (*C. nudipinnis*) from the west coast South Island
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7. Executive summary:

Brill and turbot collected from the west coast of South Island were aged by counting opaque growth zones in whole and sectioned otoliths. Zones counts from whole otoliths were poor indicators of age compared with counts from thin otolith sections. Agreement between thin section zone counts made by the same reader was good, but agreement was lower between readers. This is thought to be at least partially due to the inexperience of one reader. Analysis of the state of the otolith margin tentatively supported the hypothesis that one translucent and one opaque zone are formed each year in brill up to 10 years old. Similar analysis for brill greater than 10 years of age, and for turbot, were inconclusive. However, 2-year old captive reared turbot showed similar zone structure to wild caught fish and most individuals deposited two opaque zones in two years. It is therefore likely that one translucent and one opaque zone are deposited each year in both species.

Both species grow rapidly for the first 3 years of life before growth slows down appreciably. Growth rates in fish older than 5–7 years are minimal. Maximum observed ages were 21 years for brill and 16 years for turbot. However both species grow considerably larger than the maximum sizes available in this study, and longevity is likely to be higher. Based on maximum ages of 21 and 16 years for brill and turbot, estimates of natural mortality are 0.20 and 0.26 respectively.

8. Objectives:

To determine age and growth of turbot and brill.

9. Methods:

See attached report.

10. Results:

See attached report.

11. Conclusions:

See attached report.

12. Publications:

Nil.

13. Data storage:

The age and growth data have been stored on the Ministry of Fisheries database *age* (maintained by NIWA).

1. Introduction

The genus *Colistium* contains only two species, both of which are endemic to New Zealand. Brill, *C. guntheri,* and turbot, *C. nudipinnis* are found throughout mainland New Zealand on sand and mud bottoms to 100 m depth, but they are patchily distributed (Ayling & Cox 1987; Anderson et al. 1998). They occur in greatest numbers on the west coast of the South Island, where they are commercially important. The closest relatives of brill and turbot belong to the South Australian genus *Ammotretis*.

Brill and turbot are large flounders, reaching at least 700 mm total length. They have well developed rostral hooks, which unlike in *Peltorhamphus* sp., fail to cover the mouth from the ocular surface (Ayling and Cox, 1987). Brill differ from turbot in having at least nine ocular pelvic rays, a shorter rostral hook, and a grey-brown and black ocular surface. The turbot has seven ocular pelvic rays, a longer rostral hook, and a brown mottled ocular surface (Ayling and Cox, 1987).

Both species command a high price in local markets, and are thought to have 'great aquaculture potential' ((Graham 1953; Tait and Hickman, 1997). A pilot aquaculture scheme was recently initiated at the NIWA Aquaculture Research Centre at Mahanga Bay, Wellington, to investigate their aquaculture potential.

Brill and turbot are managed in the New Zealand Quota Management System in a species complex that includes six other flatfish species: yellow-belly flounder, *Rhombosolea leporina;* sand flounder, *R. plebeia;* black flounder, *R. retiaria;* greenback flounder, *R. tapirina;* lemon sole, *Pelotretis flavilatus;* and New Zealand sole, *Peltorhamphus novaezeelandiae.* The current flatfish TACC of 6670 t was introduced in the 1990-91 fishing year. Total landings have fluctuated considerably, and the 1999-00 landings were the lowest recorded since the 1983–84 fishing year (Annala et al. 2001). The commercial species studied to date are fast growing and short lived, generally only surviving to 3–4 years of age (Rapson 1940; Colman 1974; Kirk 1988). Adult stocks generally consist of one or two year classes and stock size appears to be recruitment driven for most species (Annala et al. 2001).

There is little biological information on brill or turbot, and in particular on their age and growth. Otoliths and scales of both species were read with little success in the late 1920's, although two brill otoliths examined by Finlay (in Paul 1992) suggested ages of 2 and 4 years at 25 and 38 cm respectively. Colman (1985) reported that brill and turbot may survive to maximum ages of 7–8 years. Tait and Hickman (1997) provided preliminary age estimates for both species from whole otolith readings.

Brill and turbot are less abundant than most other commercial flatfish species, and may be less productive. As a result, they may be more prone to overfishing. The purpose of this study was to investigate the age and growth of these species from the west coast of the South Island. In particular, we aimed to determine whether brill and turbot are fast-growing and short-lived like many other flatfish species.

2. Methods

2.1 Otolith collection

NIWA staff collected monthly samples from Talley's Fisheries Ltd fish processing sheds in Greymouth between June 1996 and December 1997 as part of a study to determine gonado-somatic indices. Samples were unavailable from January to March 1997 when the commercial fleet did not target flatfish. Otoliths were also collected during this sampling programme (Appendix 1).

A small number of otoliths were available from juvenile turbot collected from Lyall Bay, Wellington from January 1996 to January 1997. An additional 40 otolith pairs were extracted from 766-day old captive-reared (and spawned) turbot on 28th October 2000.

2.2 Otolith asymmetry

Flatfish (Pleuronectiformes) are unique among the actinopterygians (ray-finned fishes), in having asymmetrical left and right otoliths (Nolf 1985). The pronounced asymmetry of the skull and body is reflected in the external and internal morphology of the otoliths (Stevens 1993). It has been suggested that this asymmetry could be a "mechanical consequence of a 90° shift in body orientation or a functional modification to facilitate hearing and balance control" (Sogard 1991).

The sagittal otoliths of brill and turbot are moderately asymmetrical (Figure 1). The left sagitta is broader, slightly shorter, and less strongly curved distally than the right. Internally, opaque zones are more uniform and increment clarity is greater in the left sagitta , reflecting more regular epitaxial growth. In this study, we used only the more symmetrical left sagitta.

2.3 Otolith weight

Each otolith was immersed in fresh water in a petri dish, and cleaned of endolymphatic sac remnants with fine forceps. Broken, chipped, or extremely aberrant otoliths were rejected. Cleaned otoliths were oven dried at 50 °C for 3 hours before weighing to the nearest 0.1 mg. Scales were re-calibrated after every 50 otoliths.

2.4 Otolith preparation

Three methods were used to prepare otoliths for ageing:

- baking, embedding, and sectioning;
- thin sectioning;
- sectioning of juvenile turbot otoliths with thermoplastic cement.

Baked and embedded transverse sections were prepared following the methodology of Horn & Sutton (1996). Sections were prepared from 12 brill and 12 turbot otoliths to compare increment resolution and zone interpretation with those in thin otolith sections.

Most thin otolith preparations were sectioned transversely following the methodology of Stevens & Kalish (1998). However, initial experiments were conducted to determine an optimal sectioning plane. This involved sectioning 6 otoliths per species transversely and 4 otoliths per species longitudinally. The longitudinal sections were of two types: from the antirostrum through the centre of the nucleus (2 otoliths) and rostrum through the centre of the nucleus (2 otoliths).

Thin transverse sections were prepared from 218 brill and 220 turbot otoliths for the adult age series. An additional 40 otoliths were thin sectioned from reared 766-day old (2+) turbot to provide information on the appearance and identification of the first two opaque zones. Measurements of the first and second opaque zones were taken from these sections with the aid of image processing software.

Thermoplastic medio-lateral sections of 20 juvenile turbot otoliths were prepared for micro increment counts as follows: A small portion of thermoplastic cement was placed on a slide and heated on a hot plate until almost molten. An otolith was then placed on the cement (sulcus side uppermost) and gently pressed into the cement with a pair of fine forceps. The slide was taken from the hot plate and allowed to cool. If the otolith was not positioned correctly the cement was reheated and the otolith repositioned. The sulcal surface was then gently ground and polished with a series of fine carborundum papers (400, 1200, and 4000 grit) until the surface of the section was almost level with the nucleus. The slide was then reheated, the otolith flipped over, and the polished surface gently pressed into the cement. After cooling the otolith section was reground until increment resolution was optimised (section thickness ca. 150 μm).

2.5 Otolith reading protocol

Otoliths were examined whole, as baked transverse sections, thin transverse sections, or as medio-lateral sections. Whole otoliths were immersed in water in a petri dish and read with transmitted light under a binocular microscope (x16 and x20). Polarised light filters were used to enhance zone clarity. A pattern of white translucent and dark opaque zones was visible in some otoliths. Baked transverse sections were coated with paraffin oil and read with reflected light under a binocular microscope (x40). A pattern of light brown (translucent) and dark brown (opaque) zones was visible. Thin otolith sections were read with transmitted light under a compound microscope (x40). A pattern of clear (translucent) and dark (opaque) zones was visible.

The dark opaque zones in the whole otoliths corresponded with the dark brown zones on the baked cross sections and thin otolith sections, with the exception of the nuclear region, which was dark (opaque) in whole otoliths and thin sections but light brown (translucent) in baked cross sections.

For ageing purposes, counts on baked and thin transverse sections were made of opaque zones in the regions either side of the sulcus where growth zones were clearest. Increment measurements derived from the captive reared 2 year old turbot were used as a guide to the position of the first two opaque growth zones. Where possible, counts were taken from both the dorsal and ventral axes. If there was a discrepancy between counts they were re-checked. Easily read zones were followed along the proximal face to help ensure zones were not omitted or split zones misinterpreted. Each otolith count was given a readability score from 1 to 5, where a 1 was considered to be 100% reliable and 5 reading was considered to be unreadable. All grade 5 readings were omitted from further consideration.

2.6 Age and growth

2.6.1 Progression of juvenile length frequencies

To estimate the growth of juvenile turbot in Lyall Bay, a time series of eight samples, ranging from 44 to 60 days apart, was taken between 14/1/96 and 28/1/97. As catch rates were low and sampling was weather dependent, sampling continued until approximately 70 turbot were caught (maximum sampling duration for a single sample was 7 days). All sampling was completed during daylight hours.

A 10 m long, 12 mm mesh, modified beach seine was used for sampling. Further details of the net configuration can be found in McPhee (1997). The net was towed by two people parallel to the shoreline. The tow parameters varied, but generally the warps were about 10 m apart, the water was about 1 m deep, and the tows were around 50–75 m in length. At the end of each tow the net was gradually turned and pulled on to the shore at right angles to the shoreline, where the catch was sorted. Juvenile turbot were placed in buckets of seawater and taken to the NIWA Aquaculture Research Centre at Mahanga Bay for measuring.

The total length (TL) of each turbot was measured (to 0.1 mm) with vernier callipers. TL was taken from the anterior edge of the rostral hook, not including dorsal fin rays, to the posterior edge of the caudal fin. The length measurements are subject to some error as the rostral hook is flexible and in very small turbot (less than 30 mm TL) the end of the caudal fin is transparent and sometimes difficult to detect.

To avoid recapture, all fish were then held at the Aquaculture Research Centre until the sampling for that period was complete, i.e. until approximately 70 turbot were caught and measured. The fish were then returned alive to Lyall Bay.

2.6.2 Microincrement counts

To provide additional information on the growth of juvenile turbot in Lyall Bay, microincrement counts were attempted from thin medio-lateral otolith sections. Counts were made from the central core to the otolith margin in any axis where the microincrements were relatively clear and a count could be obtained.

2.6.3 Marginal state analysis

To determine if one translucent and one opaque zone were deposited each year, the state of the otolith margin was recorded when thin otolith sections were read. The otolith margin was graded as narrow (a discrete, relatively narrow, translucent zone visible at the edge), wide (a wide translucent zone visible at the edge), or line (a discrete opaque zone visible at the edge). After an initial evaluation at x40 magnification, a magnification of x100 was often used to help clarify the marginal state.

2.6.4 Ageing variability and growth rate estimation

To assess the level of within-reader variability, each otolith was read twice by an experienced reader (Reader 1), two weeks apart. Each thin otolith preparation was also read by a less-experienced reader (Reader 2) to assess the level of between-reader variation.

The final age assigned to each fish was the mean of the two age estimates made by Reader 1 on thin sections, adjusted by adding the fraction of the year elapsed between 1 August (the hypothetical birthday) and the date of collection. Growth curves were fitted to the 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_∞ is the asymptotic maximum length, K is the von Bertalanffy growth constant, and t_0 is the theoretical age at zero length.

2.6.5 Mortality estimates

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

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

where $t_{\max}$ is the maximum age reached by the species in an unexploited population.

3. Results

3.1 Otolith interpretation

The whole brill and turbot otoliths were small, thick, and narrow compared with those from other flounders (e.g. *Rhombosolea* spp.), which are usually read whole (e.g. Mundy 1968, Colman 1974). Zone resolution was poor, particularly near the dark (opaque) nuclear region and near the thin otolith edge (Figure 2). Baked preparations were difficult to read. The small size of the sections and poor contrast between the light (translucent) and dark (opaque) zones made age estimation difficult.

Thin otolith transverse sections were the best method of otolith preparation. Greater confidence was placed in the zone counts derived from this method due to enhanced increment resolution and clarity (Figures 3–4). The optimal sectioning plane was a dorsoventral (transverse) axis through or close to the nucleus and the straightest, most uniform dorsal lobe.

The correct interpretation of the first 2–3 years of growth was essential for accurate age readings. This region often had poor increment clarity and split opaque zones (Figure 4). These split zones were often particularly difficult to distinguish in otoliths from younger fish, and may have accounted for higher counts in some specimens. By following increments along the proximal edge, split opaque zones were often readily distinguished. The increment measurements from the captive reared fish (*see* Section 3.4) helped this process considerably. Often the opaque zones were wider than the measurements, but the measurements did provide a useful comparison and point of reference.

3.2 Progression of juvenile length frequencies

Length-frequency histograms of juvenile turbot from Lyall Bay show four clear periods of juvenile recruitment over one year (Figure 5). There appeared to be strong recruitment in January, July, and October 1996, and a weaker cohort in March 1996. In January 1997, the first recruits for the next year were captured. In each case, juveniles were first captured at 25–60 mm TL and grew rapidly, particularly over the warmer months. Juveniles recruited in

January 1996 (mean TL = 38.9 mm) had doubled in length by March (77.4 mm), and were half as big again by May (114.9 mm). Juveniles recruited in July 1996 (44.6 mm) grew slower, but were half as big again by September (64.8 mm) and again by October (84.2 mm). Growth rates were about 0.5 mm/day for much of the year.

3.3 Micro-increment counts

The juvenile turbot otoliths were small, generally 400–800 µm long, and difficult to prepare. Microincrements were narrow (4.0–4.5 µm) and resolution was generally poor (Figure 6). The finest increments, and the most difficult to resolve, were those surrounding the central core (Figure 6a). It is likely that counts from this region in particular were underestimated.

It was difficult to find an axis with clear microincrement patterns and as a result only nine thin medio-lateral sections were read. Each section was read three times and the three counts were averaged. Counts ranged from 51 for a 27 mm TL fish to 185 for a 130 mm TL fish (Appendix 2). Eight otolith preparations were from new recruits, 27–60 mm TL, and the readings ranged from 51to 80. The remaining fish, a January recruit, was killed in late June at 130 mm TL and had a count of 189. Growth rates (assuming microincrements are laid down daily and estimated as TL/mean count) were 0.53–0.76 mm/day and were higher for the larger, older fish. All estimated growth rates exceeded the estimate of 0.5 mm/day obtained from the juvenile length-frequency data.

3.4 Captive reared turbot

A number of the captive reared turbot contained post-metamorphic abnormalities, such as head deformities (incomplete eye migration and rostral hook development) and aberrant pigmentation (excessive brown coloration, pseudoalbinism and ambicoloration). Diggles (2000) found abnormally pigmented juvenile turbot to be slower growing and more susceptible to disease than their healthier siblings. In the current study, the otoliths of abnormal fish were often small and/or aberrant in shape. When thin sectioned, the otolith preparations were difficult to interpret and increment resolution was poor. For this reason only thin otolith sections from the 10 largest, normally pigmented fish were used for opaque zone interpretation and measurements (*see* Appendix 3 for zone measurements).

Two relatively clear opaque zones were visible in the ten selected thin otolith sections (Figure 4a). In general, opaque zones were lighter in colour and less distinct than in otolith preparations from wild caught fish (Figure 4b). Opaque zones often appeared to be split into two zones separated by a narrow translucent region. This pattern of split opaque zones was common in the otoliths of wild caught brill and turbot, particularly in the first three opaque zones, and care had to be taken with otolith readings to ensure zones were correctly interpreted.

3.5 Marginal state analysis

Although the contrast between the wide translucent zones and relatively narrow opaque zones was often poor, particularly in otoliths from older fish, the marginal state was generally visible. All sections with low readability (score 4-5) were removed from the dataset (23% of brill and 39% of turbot otoliths). The marginal state was more difficult to determine in older fish of both species. To help alleviate this problem the brill sample was divided into two groups of age classes (0+ to 10+, 11+ to 21+). The turbot sample was not divided, as there were only six fish over 10 years of age.

There appears to be a trend for more brill otoliths to have an opaque margin from May to August (for brill < 10 yrs) (Figure 7a). These data provide tentative support for the hypothesis that brill deposit one translucent zone and one opaque zone each year up to 10 years of age. The marginal state analysis for brill over 10 years of age (Figure 7b) was inconclusive. This discrepancy is likely to be due to interpretation of the outer increments of older fish, which are thinner and difficult to discern than those closer to the nucleus.

The marginal state analysis for turbot was also inconclusive (Figure 8). Thin sections were difficult to interpret and both readers experienced difficulty in zones counts and the interpretation of the marginal increment.

3.6 Ageing variability and growth rate estimation

3.6.1 Whole otoliths versus thin transverse sections

Of the 161 brill otoliths that were read whole and as thin transverse sections by Reader 1 (first reading), 14.3% of readings were identical, 44.1% were within 1 year, and 66.5% were within 2 years (Figure 9a). Whole otolith readings were often substantially lower than thin section readings, particularly in older fish (Figure 9b).

Of the 154 turbot otoliths that were read whole and as thin transverse sections by Reader 1 (first reading), 37.7% of readings were identical, 61% were within 1 year, and 69.5% were within 2 years of the first reading (Figure 10a). Whole otoliths were slightly easier to read in smaller fish but in older fish were likely to be under-aged relative to the thin section readings (Figure 10b).

3.6.2 Within-reader comparison

Of the 169 brill thin sections that were read twice by Reader 1, 62.7% of readings were identical, 91.7% were within 1 year, and 97% were within 2 years of each other (Figure 11a).

Of the 163 turbot thin sections that were read twice by Reader 1, 63.2% of readings were identical, 90.2% were within 1 year, and 95.7% were within 2 years of each other (Figure 12a).

Thus the within-reader agreement was high for both species, though a few old fish were aged slightly higher on the first reading (Figures 11b and 12b).

3.6.3 Between-reader comparison

Of the 174 brill thin sections that were read by both readers, 43.1% of readings were identical, 77% were within 1 year, and 92.5% were within 2 years of each other (Figure 13a).

Of the 161 turbot thin sections that were read by both readers, 33.5% of readings were identical, 67.1% were within 1 year, and 85.1% were within 2 years of each other (Figure 14a).

There was relatively poor within-reader agreement for both species. Brill thin sections were generally easier to read than turbot sections and this is reflected in the higher between-reader agreement. Reader 2 often aged young turbot one year older than did Reader 1 (Figure 14b). This is probably partly due to the inexperience of Reader 2.

3.7 Growth parameters

On the west coast of the South Island, female brill and turbot have an extended spawning season from May through to January, with a major spawning peak in late winter (late July to early August) and a secondary one in late spring (October to November) (B. Hickman, NIWA, pers comm.). A 'birthday' of 1 August was chosen to represent the approximate midpoint of the main spawning period. The opaque zone appears to be completed by August-September so fish spawned during winter are approximately one year old at the completion of the zone. Fish spawned during spring may be up to 3 months younger than their theoretical age.

Length at age data, with fitted von Bertalanffy growth curves, are presented for male and female brill and turbot in Figures 15 and 16 respectively. Growth curve parameters for each species are presented in Table 1.

The oldest male brill was 19.1 years old, and 26% of fish were greater than 10 years old. The oldest female brill was 21.0 years old, but a plot of age against otolith weight shows this fish to be an outlier; it is possible that the sex was wrongly recorded and it was in fact a male (Figure 17). Because of this uncertainty, this fish was not included in the estimation of growth curves. The next oldest female was 15.5 years old, and 27% of fish were greater than 10 years old. Females were larger than males at a given age, and in both sexes, there was little growth beyond 5 years. Because of the lack of small female brill in the sample, the female Von Bertalanffy growth curve was poorly defined and the parameter estimates were unrealistic and had large standard errors.

The oldest male turbot was 13.7 years old, and 13% of fish were greater than 10 years old. The oldest female was 16.4 years old, 17% of which were older than 10 years. Females grew faster and larger than males, and in both sexes growth slowed dramatically beyond 7 years.

Otolith weight at age data for brill and turbot (Figures 17 and 18) show relatively poor correlation for both species. Males of both species have lighter otoliths at a given age than females, and the difference increases with age. This probably reflects the difference in size of male and female fish.

3.8 Mortality estimates

Using maximum observed ages for brill and turbot of 21 and 16 years respectively, the natural mortality rates are estimated to be 0.20 and 0.26 respectively. However, our sample sizes were small, and both species have been fished intensively off the west coast South Island for decades, suggesting that true longevity could be substantially greater than we observed. For maximum ages of 30 and 25 years, the estimated values of M are 0.14 and 0.17 respectively.

4. Discussion

Brill whole otolith readings were substantially lower than those from thin transverse otolith sections. Turbot whole otolith readings were lower in older fish compared with thin section readings, but ageing precision for whole otoliths was poor. Because we achieved partial validation of thin section readings (see below), we believe that whole otolith readings provide unreliable estimates of age in brill and turbot.

Baked transverse otolith sections were difficult to read. Baked otoliths were small and the contrast between light (translucent) and dark (opaque) zones was poor. However zone counts derived from this method are likely to be more accurate than counts from whole otoliths. Thin transverse otolith sections were superior in zone resolution and clarity to other methods, and this is the preferred method of otolith preparation for brill and turbot.

The correlation between the two readings of thin sections by Reader 1 was high for both species and there was no apparent ageing bias. The correlation between readers was relatively poor for both species. Brill thin sections were easier to read than turbot thin sections and this was reflected in a slightly higher between-reader agreement. The poor correlation between readers is likely to be at least partially due to the inexperience of the second reader. For this reason, we used the mean of the two age readings by Reader 1 for our final age estimate.

Our age estimates are only partially validated. Analysis of the state of the otolith margin tentatively supported the hypothesis that one translucent and one opaque zone are formed each year in brill up to 10 years old, but the data were inconclusive for brill over 10 years old. The state of the margin was difficult to determine in older fish due to reduced clarity and the narrow margin. However, it seems likely that the growth zones are also annual in older brill.

Analysis of the otolith marginal state in turbot was inconclusive, reflecting the difficulty experienced in identifying zones in this species. However, zone counts on captive reared 2+ turbot supported the hypothesis of annual zone formation. Opaque zones were less pronounced in captive reared fish than wild fish, but two opaque zones were clearly visible in some preparations.

Attempts to age brill and turbot from scales and otoliths were first made in the late 1920's but were largely unsuccessful. Finlay (in Paul 1992) suggested ages of 2 and 4 years respectively for otoliths from 25 and 38 cm brill. Colman (1985) reported that brill and turbot may reach 7–8 years of age, but there were no further ageing studies until Tait and Hickman (1997) presented age estimates from whole otolith readings. The preliminary zone counts in the latter study were made by one of the present authors (DWS), and highlighted the problems with reading whole otoliths.

Based on the thin otolith section readings in the current study, both *Colistium* species grow rapidly for the first 3 years of their lives. Thereafter, growth slows down appreciably, and in fish older than about 5–7 years it is minimal. The reason for the abrupt change in growth rate is unknown but may be due to the onset of sexual maturity, or migration to adult feeding or spawning grounds.

Brill and turbot are relatively long lived, particularly for flatfish, with maximum ages of 21 years for brill and 16 years for turbot. However, both species grow considerably larger than the largest specimens aged and longevity is likely to be higher. The largest brill aged in this study was 47 cm TL but they are reported to grow to 70 cm TL. The largest turbot aged was 62.5 cm TL but they are reported to grow to over 80 cm TL (Ayling & Cox 1987).

The length at age data are likely to be biased towards faster growing young fish. With the exception of a few 1+ turbot collected from Lyall Bay, our samples were all caught by commercial trawlers off the west coast of the South Island. Only the larger 2+ and 3+ brill and turbot are likely to be of commercial value, so length at age of these age classes may have been overestimated.

The Lyall Bay juvenile turbot length-frequency data indicate a rapid initial growth rate and a prolonged breeding season. Juvenile turbot grow rapidly for at least the first 6 months after settlement. New recruits averaged 39 cm TL in January 1996, 77 cm in March, and 115 cm in May. Growth rates of 0.5 mm/day or higher were achieved in all but the coldest months of the year.

Like many teleosts, including commercially important species of flatfish, male brill and turbot are considerably smaller at a given age than their female counterparts.

Previous otolith-based ageing studies of New Zealand flatfish have reported fast growth rates and low maximum ages. *Rhombosolea* species are highly productive, grow rapidly and most live to about 3 years, with maximum reported ages of 4 years for *R. leporina* and *R. retiaria,* and 6 years for *R. plebeia* (Colman 1974, Paul 1992, Stevens 1993). The lemon sole, *Pelotretis flavilatus,* is also fast growing with a maximum age of over 5 years (Rapson 1940). The common sole, *Peltorhamphus novaezeelandiae,* is reported to a maximum age of 6 years (James in Paul 1992). All of these studies, with the exception of Rapson (1940), used whole otoliths for age determination. Rapson (1940) ground the more difficult otoliths with a fine carborundum paste to improve resolution.

Brill and turbot are unique among New Zealand's commercial flatfish species. They are our largest and longest-lived flatfish, and therefore, have lower productivity than many, if not all, of the other flatfish species with which they are jointly managed. Although their initial grow rates are rapid, there is an abrupt slowing of growth at about 3–5 years of age. Information on size at first maturity is needed to determine if this change in growth rate is due to the onset of sexual maturity. Brill and turbot may therefore be more vulnerable to overfishing than other flatfish species and should be managed outside of the current flatfish (FLA) quota.

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Table 1: Von Bertalanffy growth curve parameters for male and female brill and turbot. SE, standard error

Species	Sex	Sample size	L_∞ ± SE (cm)	K ± SE (years^{-1})	t_0 ± SE (years)
Brill	Female	98	43.76 ± 3.71	0.10 ± 0.12	−15.87 ± 16.92
Brill	Male	69	38.41 ± 0.39	0.37 ± 0.07	−1.70 ± 1.04
Turbot	Female	92	57.08 ± 0.73	0.39 ± 0.03	0.30 ± 0.14
Turbot	Male	69	49.22 ± 1.05	0.34 ± 0.04	−0.09 ± 0.23

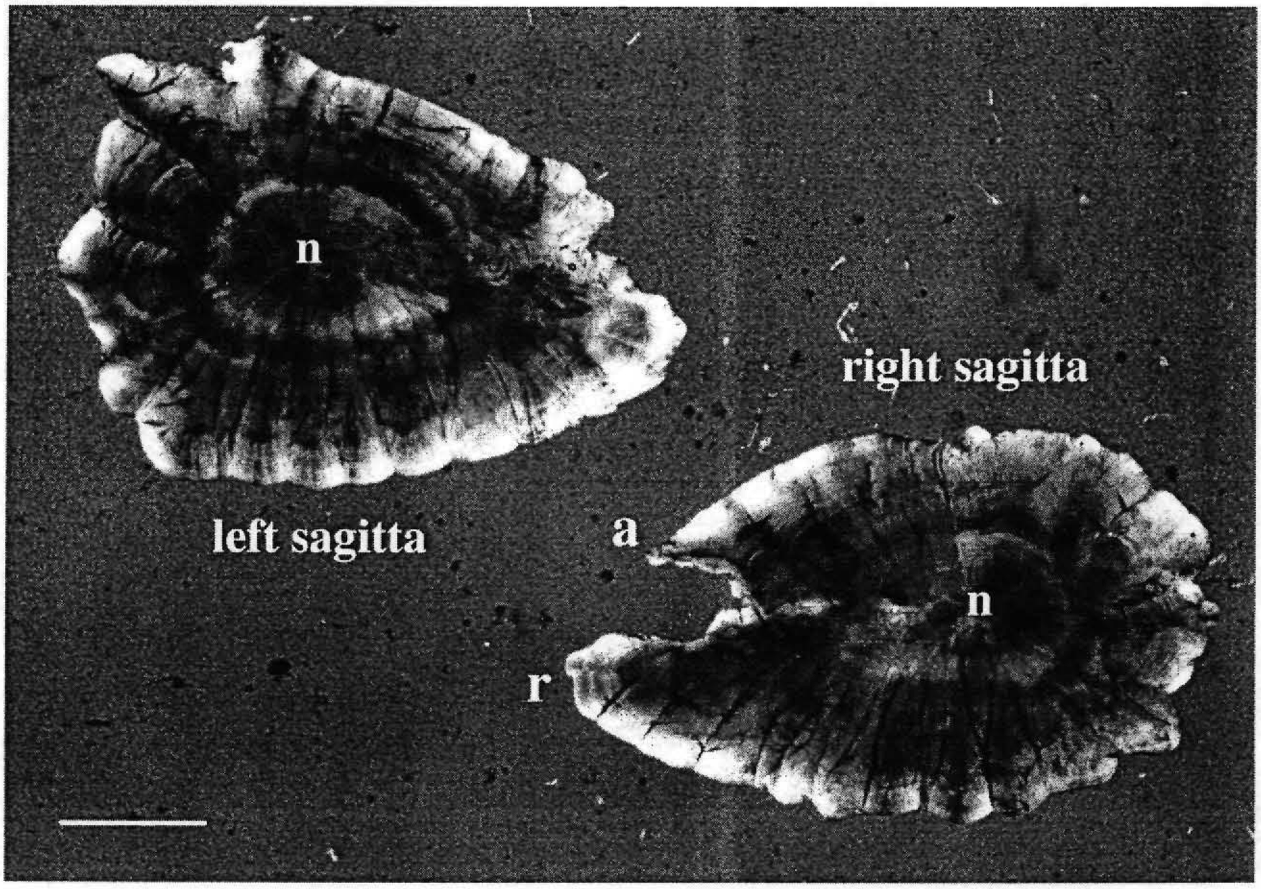
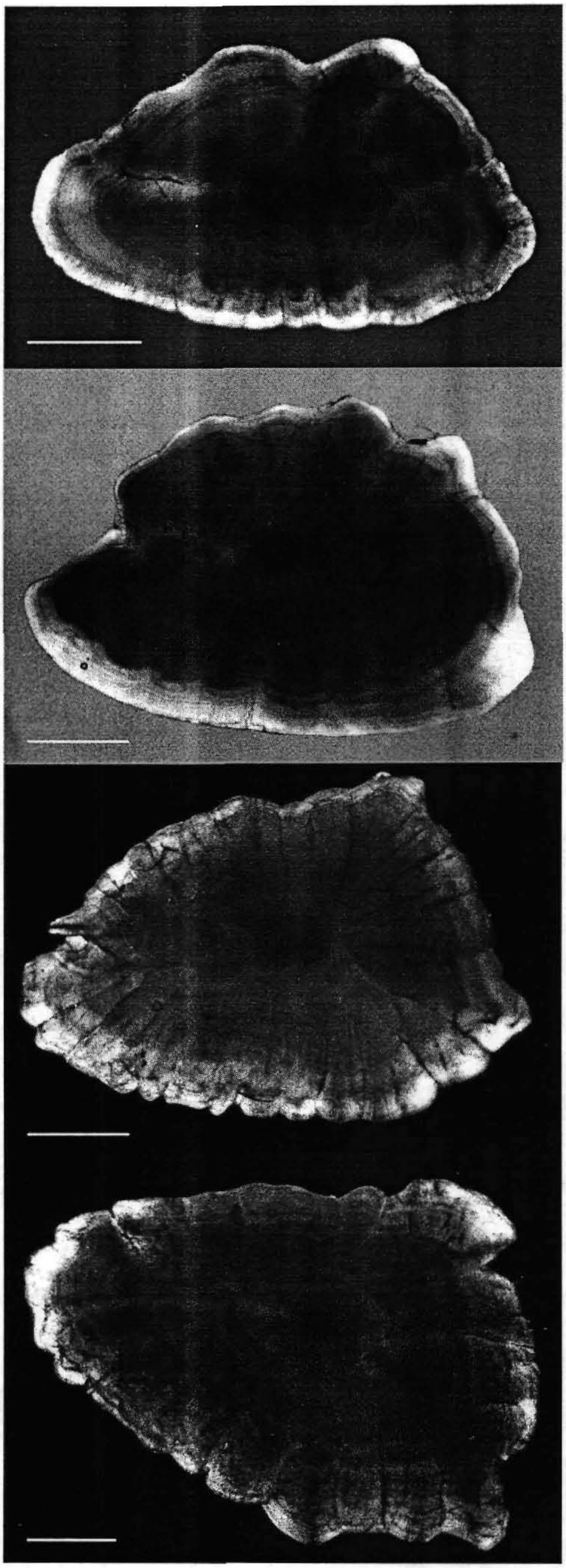


Figure 1: Otolith asymmetry in a partially ground turbot sagitta pair (517 mm TL female) (x10). a, antirostrum; n, nuclear region; r, rostrum; scale bar represents 1 mm.

Figure 2: Whole brill and turbot sagittae viewed under transmitted polarized light. scale bar represents 1 mm, zone counts are below fish details.



2a: 365 mm TL female brill (x16) (3 narrow whole, 4 narrow thin section)

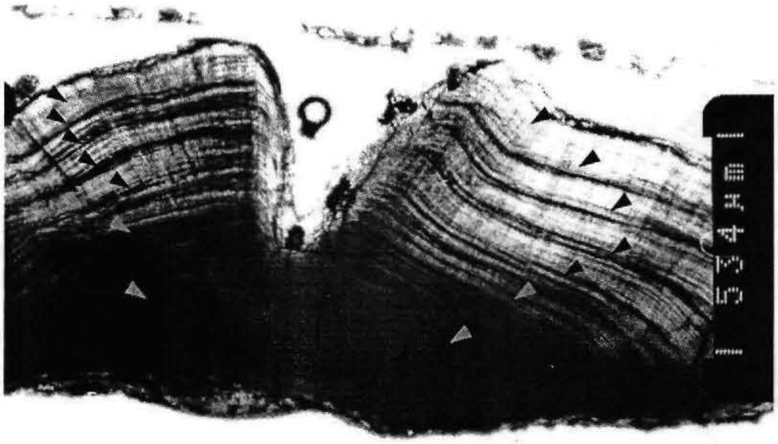
2b: 403 mm TL female brill (x16) (8 line whole, 11 line thin section)

2c: 477 mm TL female turbot (x16) (5 line whole, 5 line thin section)

2d: 625 mm TL female turbot (x14) (10 line whole, 9 line thin section)

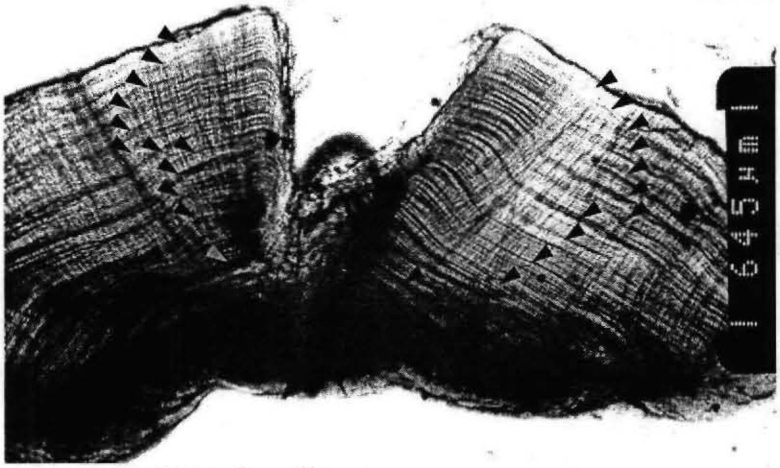
Figure 3: Brill – thin transverse otolith sections.

3a: 384 mm TL female (x60)
(7+ years old) arrows
denote opaque zones.



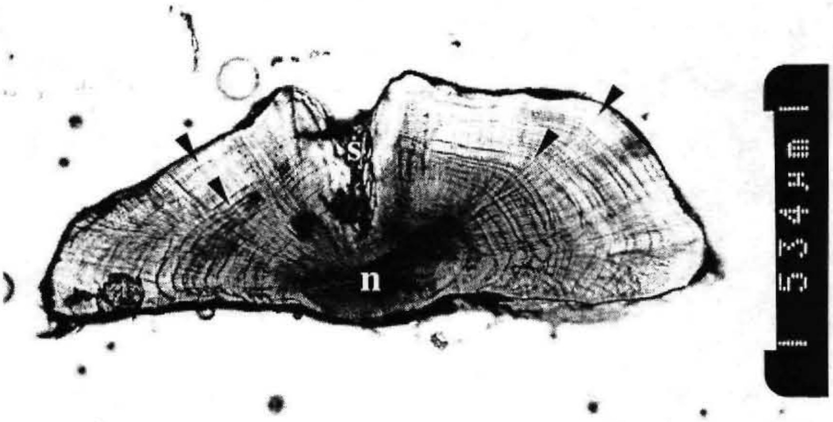
3b: 378 mm TL male (x60)
(7+ years old)

3c: 428 mm TL female (x50)
(12+ years old)



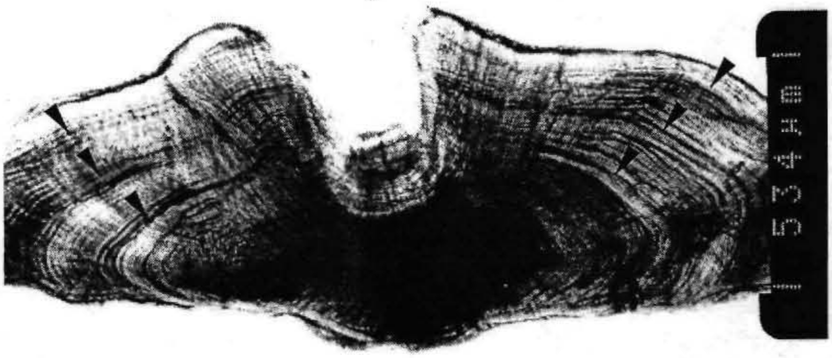
3d: 383 mm TL male (x50)
(14+ years old)
- inner zones
were measured
on section.

Figure 4: Turbot – thin transverse otolith sections (x60).



4a: 211 mm TL captive-reared female (2+ years old). n, nucleus; s, sulcus, arrows denote opaque zones

4b: 385 mm TL wild-caught female (2+ years old). Note: this a fast growing early recruit.



4c: 435 mm TL wild-caught female (3+ years old). Note: this a fast growing early recruit.

4d: 570 mm TL wild-caught female (6 years old)

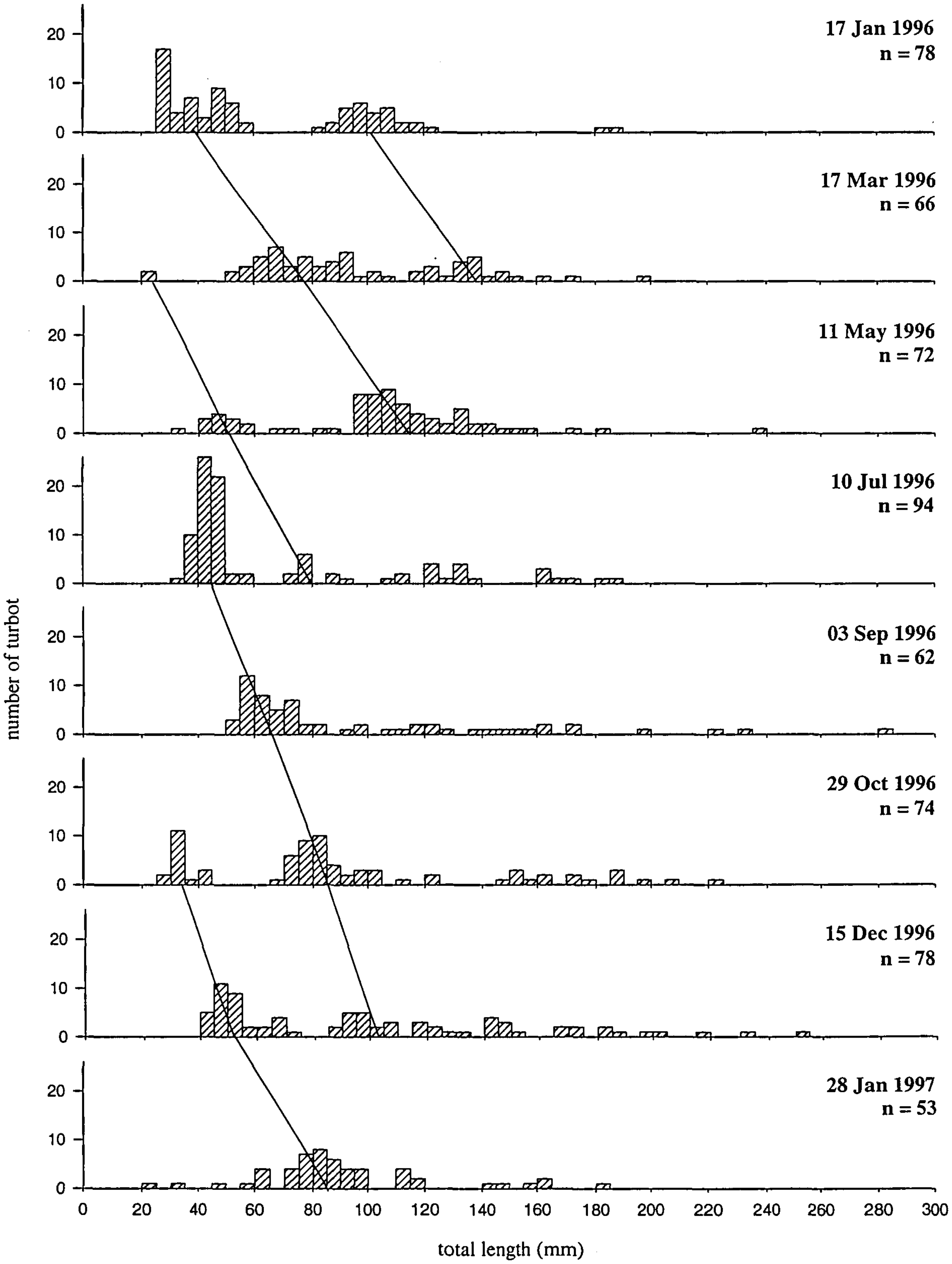
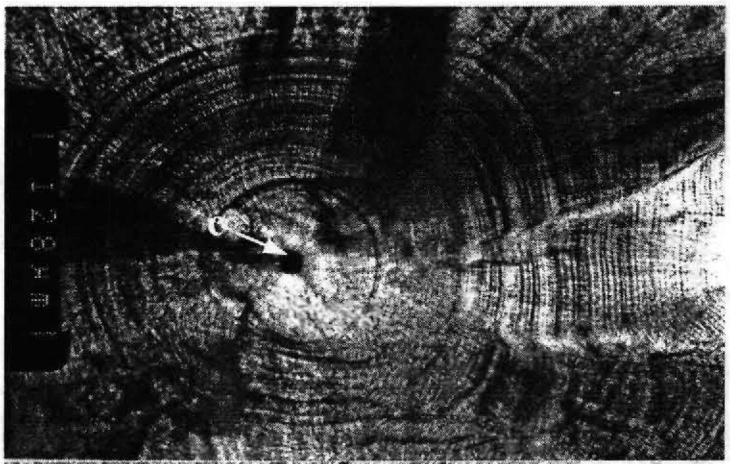


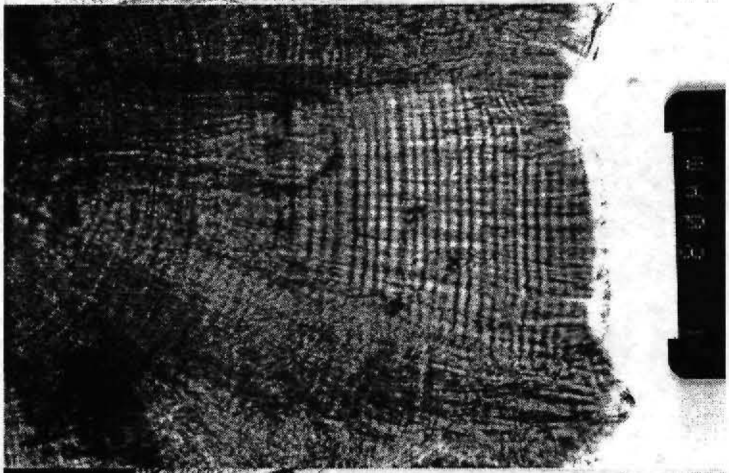
Figure 5: Length frequency histograms of juvenile turbot caught by beach seine from Lyall Bay, Wellington from January 1996 to January 1997.

Figure 6: Thin medio-lateral juvenile turbot sagitta sections.

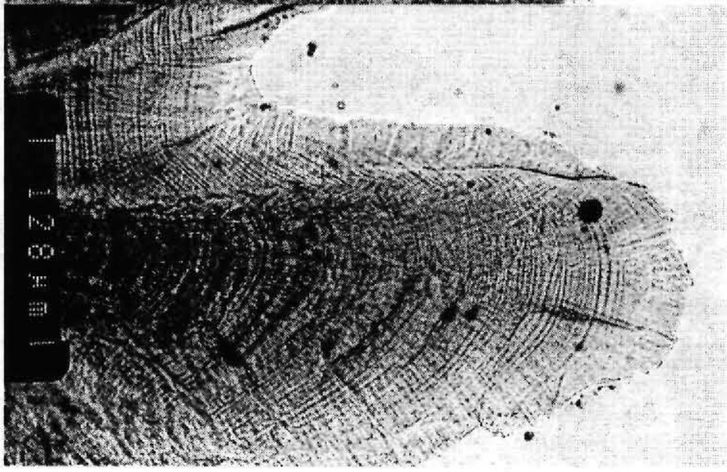


6a: Nuclear region showing otolith core, c. (78 mm TL) (x250)

6b: Nuclear region and micro-increments patterns (31 mm TL) (x300)

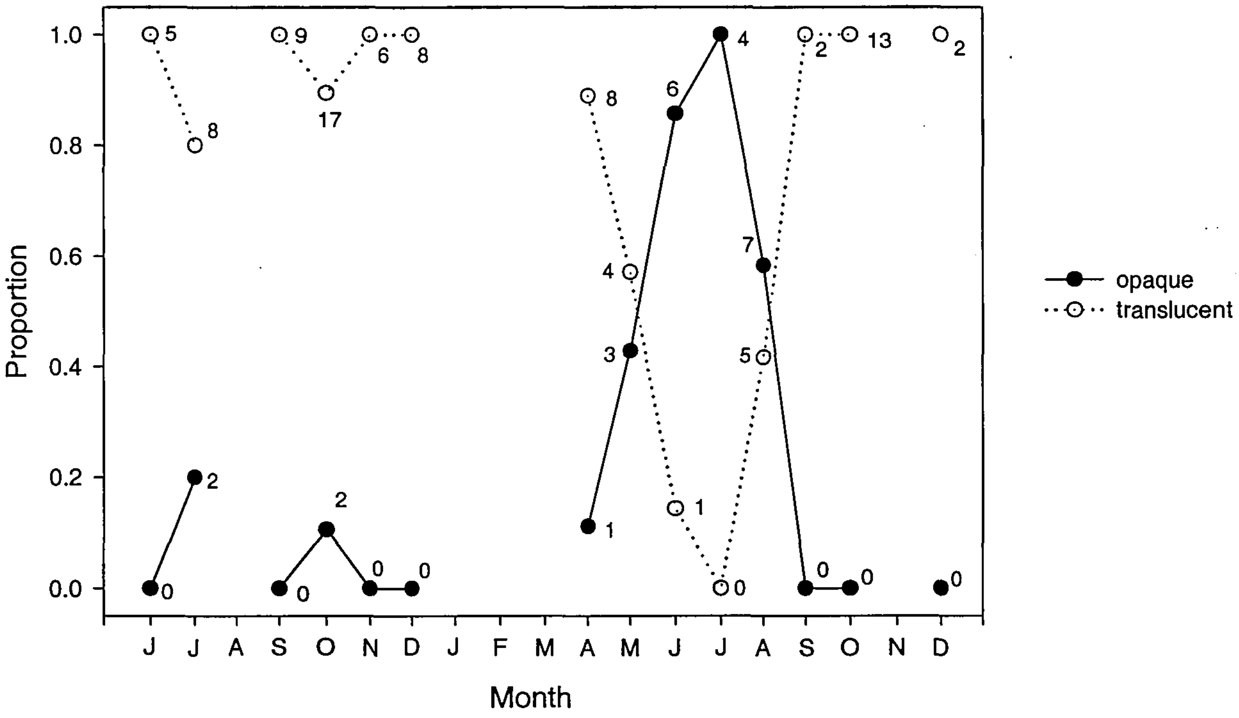


6c: Microincrement patterns in the sulcal region (45 mm TL) (x400)



6d: Microincrement patterns in the rostrum. (78 mm TL) (x250)

a. Brill less than or equal to 10 years old (n = 113)



b. Brill greater than 10 years old (n = 34)

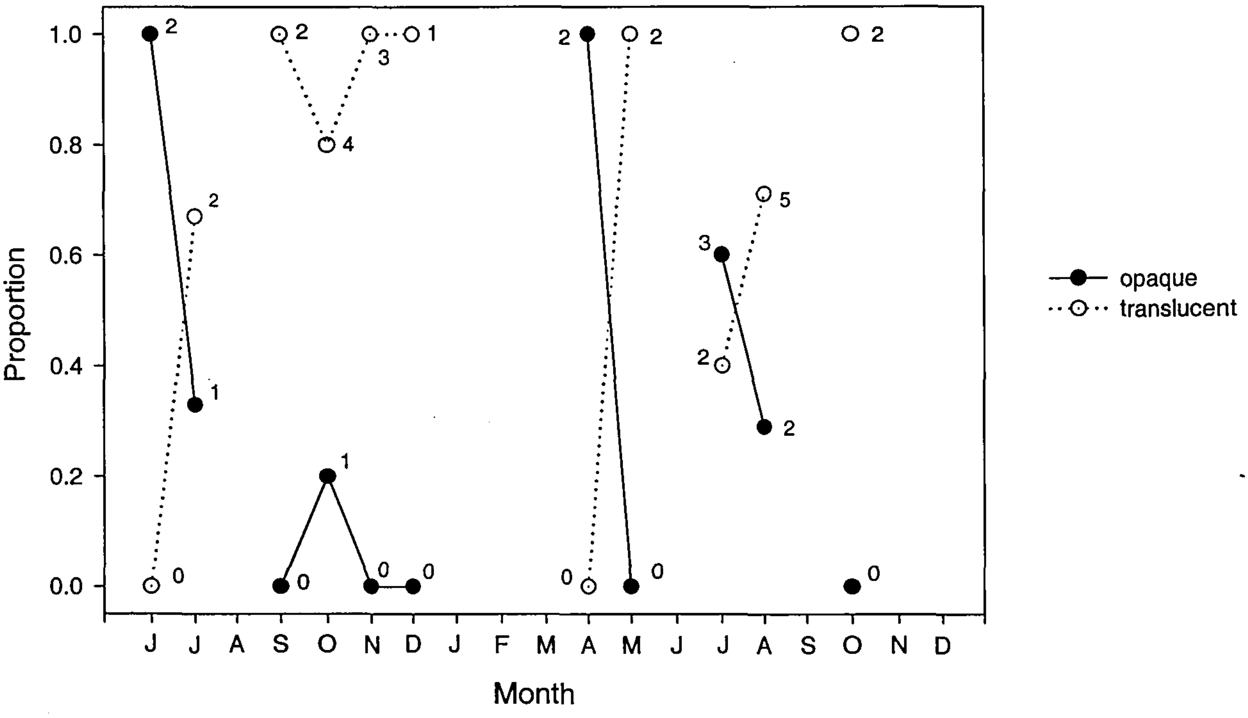


Figure 7: Proportion of brill thin otolith sections with a translucent or opaque margin (n = 147). Sample sizes are shown next to data points.

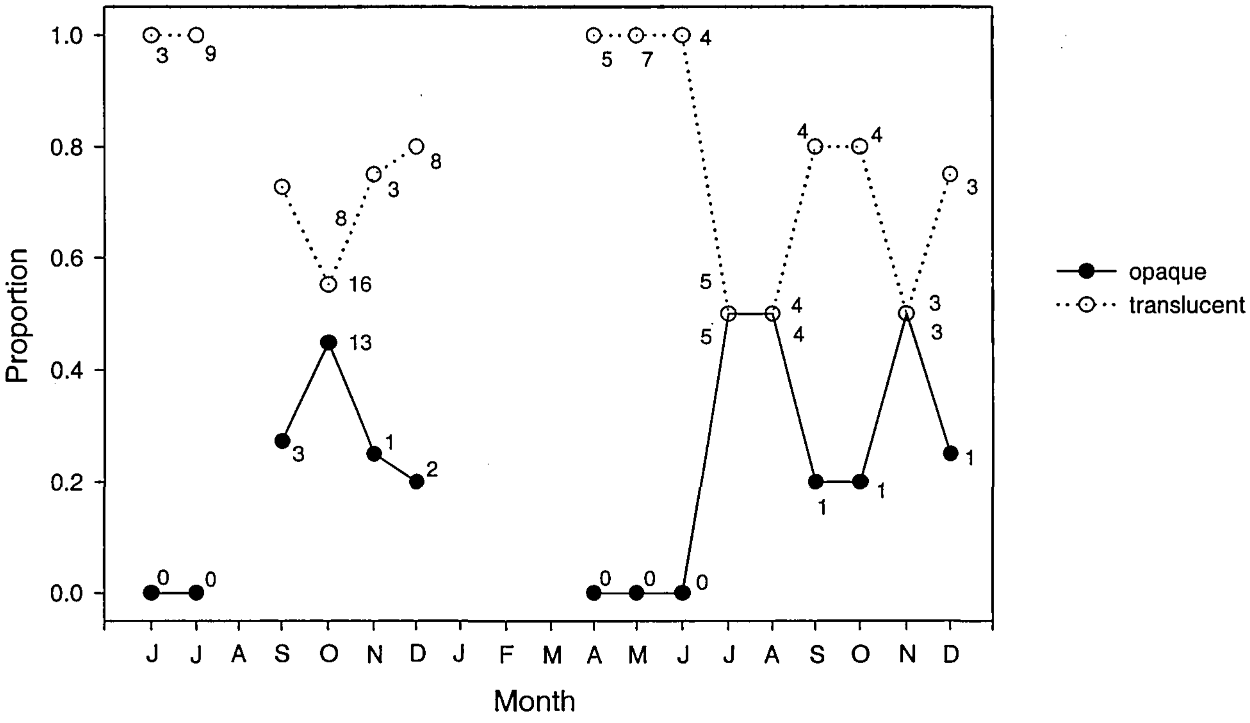


Figure 8: Proportion of turbot thin otolith sections with a translucent or opaque margin (n = 120). Sample sizes are shown next to data points.

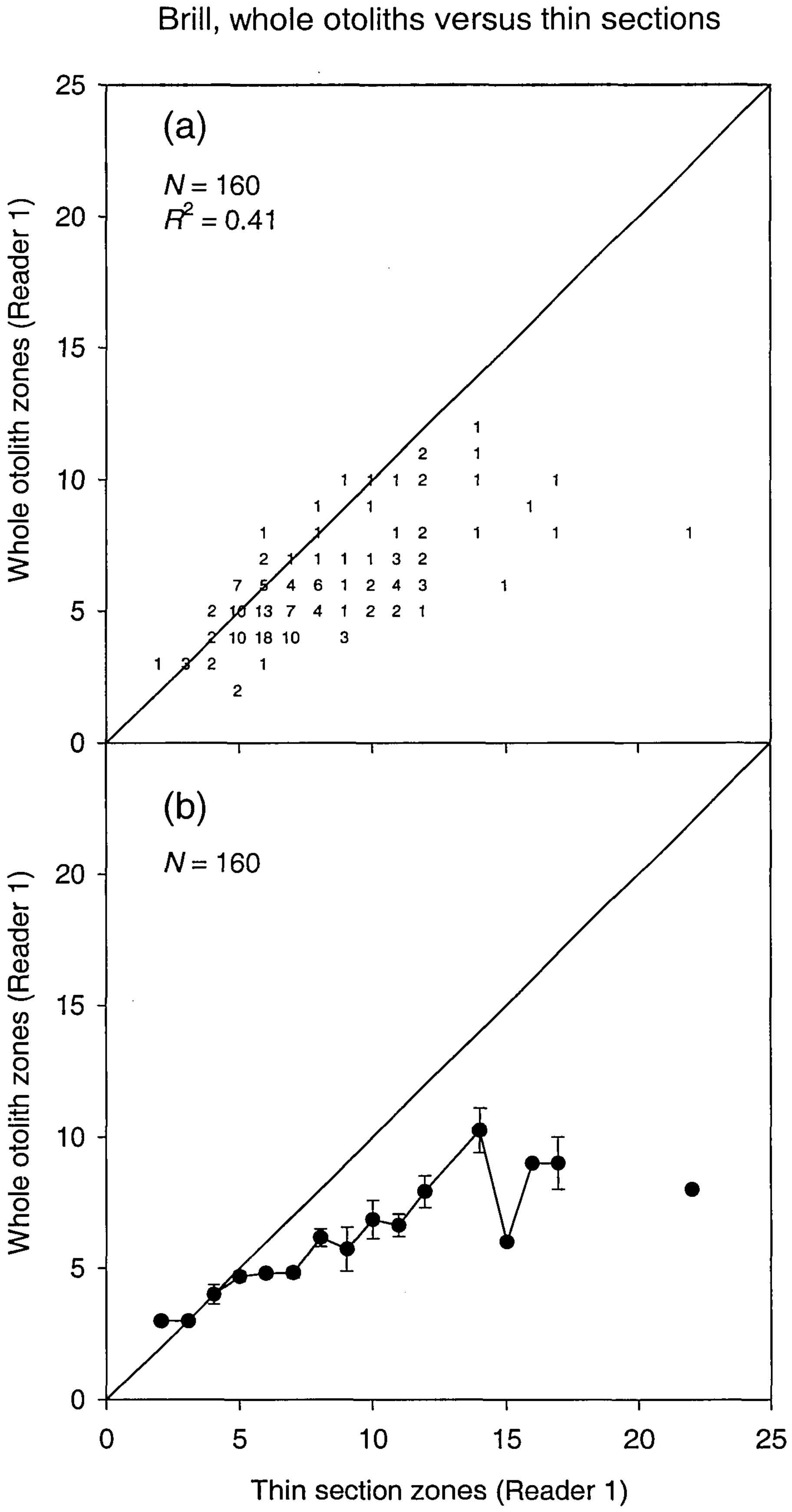


Figure 9: Comparison of whole otolith and thin section readings for brill made by Reader 1: (a) Actual counts (numbers represent number of fish); and (b) mean count ± 1 standard error. Diagonal lines indicate the expected relationship. *N*, total sample size.

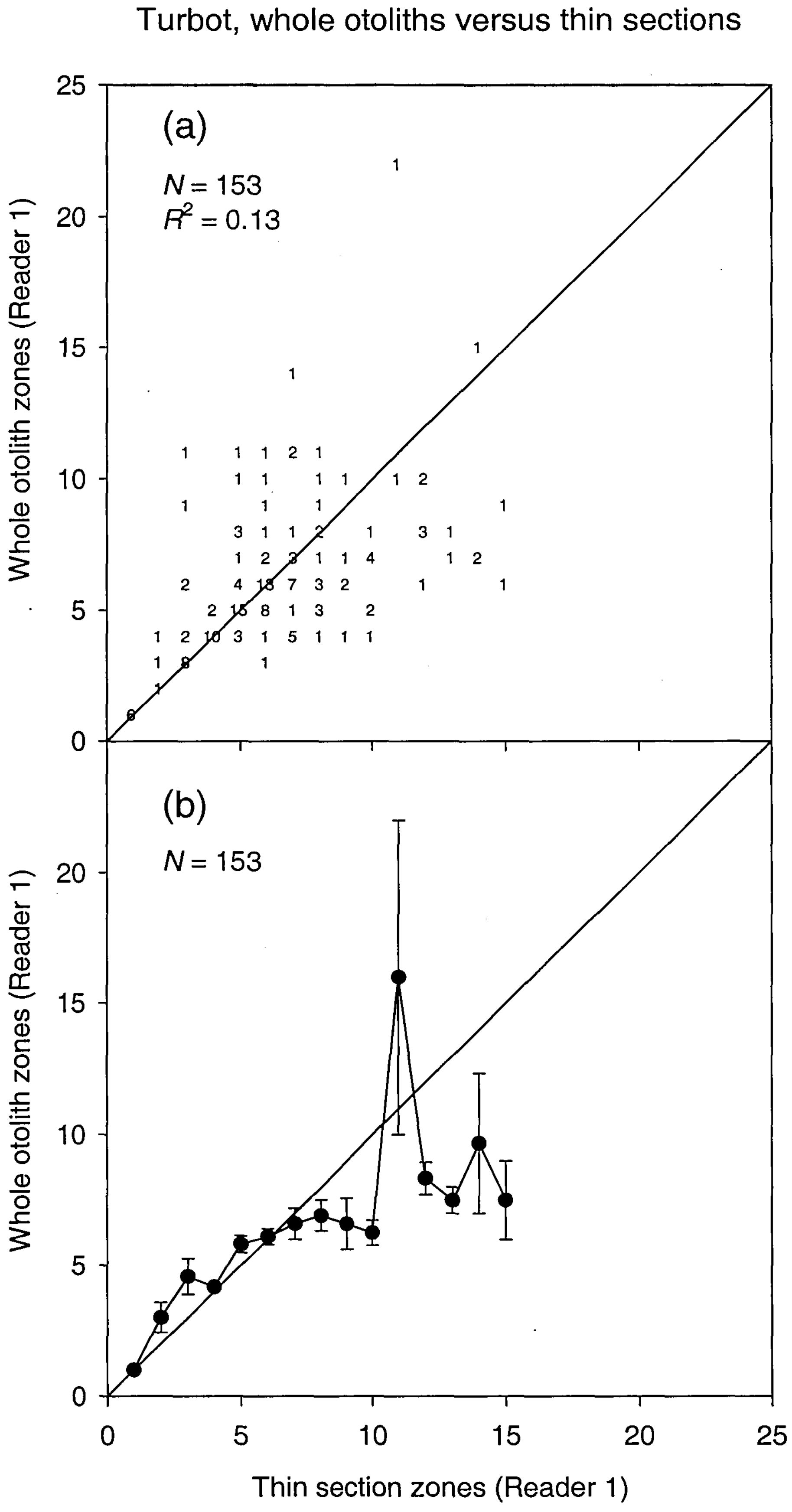


Figure 10: Comparison of whole otolith and thin section readings for turbot made by Reader 1: (a) Actual counts (numbers represent number of fish); and (b) mean count ± 1 standard error. Diagonal lines indicate the expected relationship. *N*, total sample size.

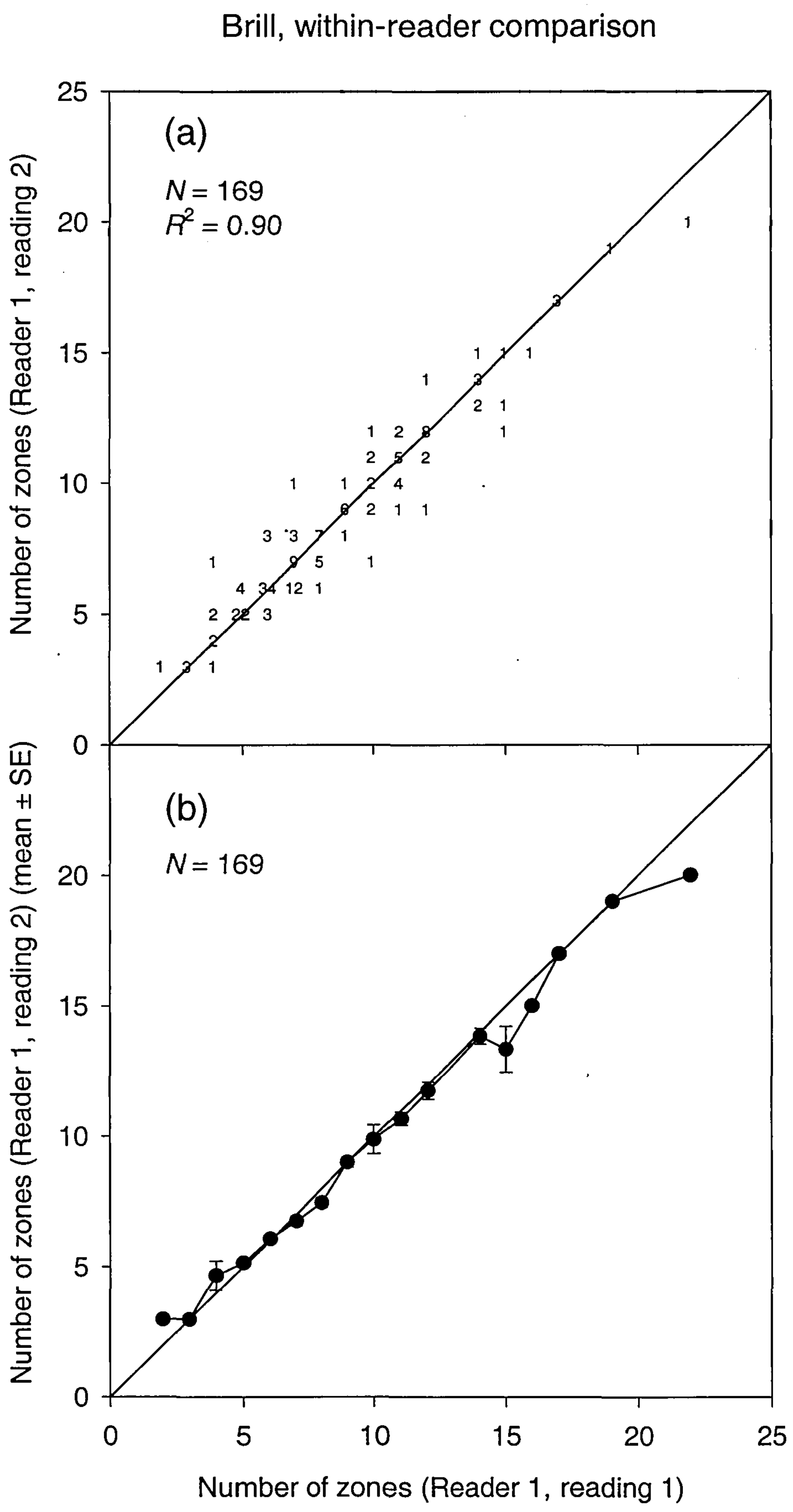


Figure 11: Comparison of the two readings of brill otolith thin sections made by Reader 1: (a) Actual counts (numbers represent number of fish); and (b) mean count ± 1 standard error. Diagonal lines indicate the expected relationship. *N*, total sample size.

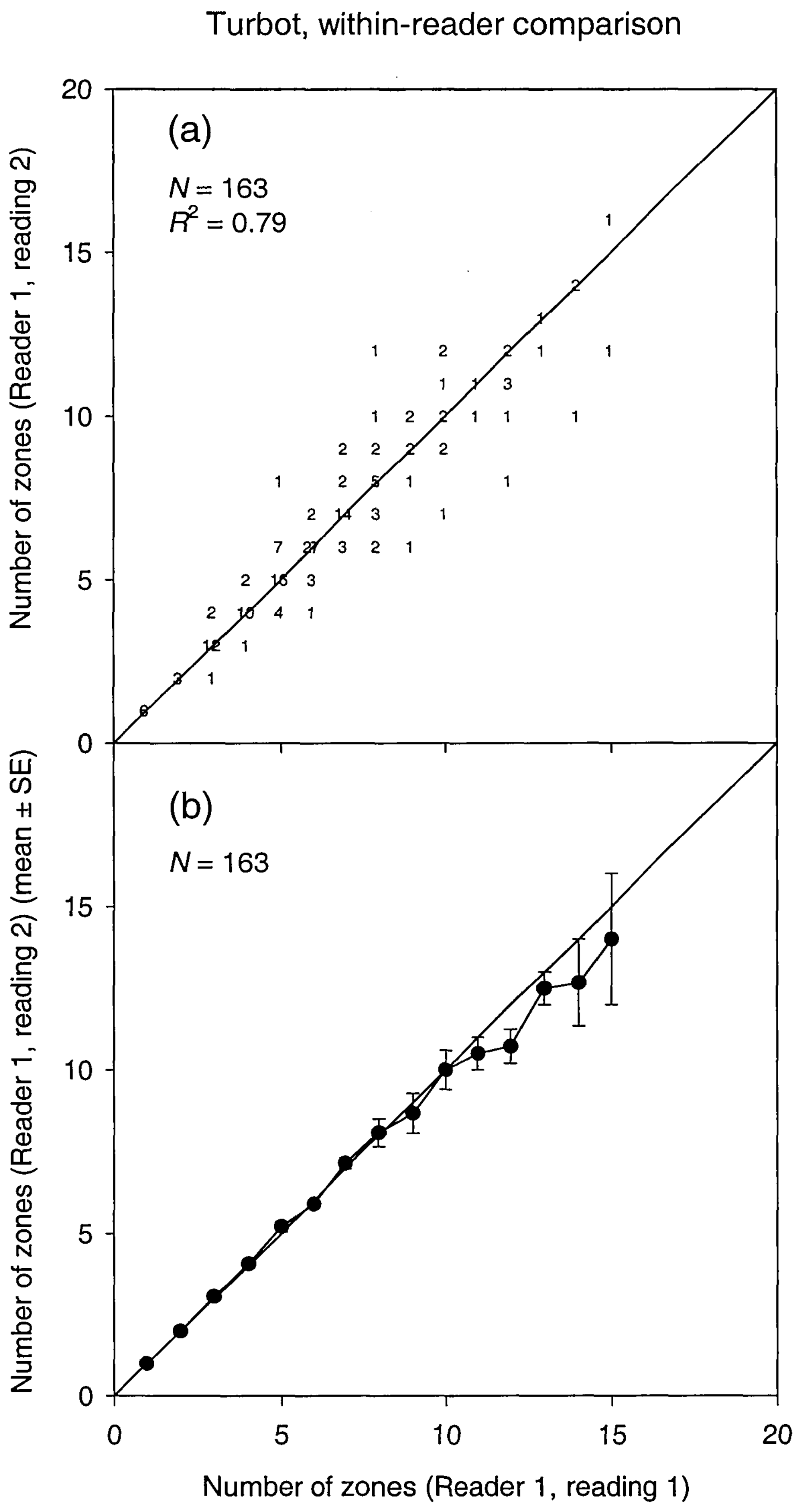


Figure 12: Comparison of the two readings of turbot otolith thin sections made by Reader 1: (a) Actual counts (numbers represent number of fish); and (b) mean count ± 1 standard error. Diagonal lines indicate the expected relationship. *N*, total sample size.

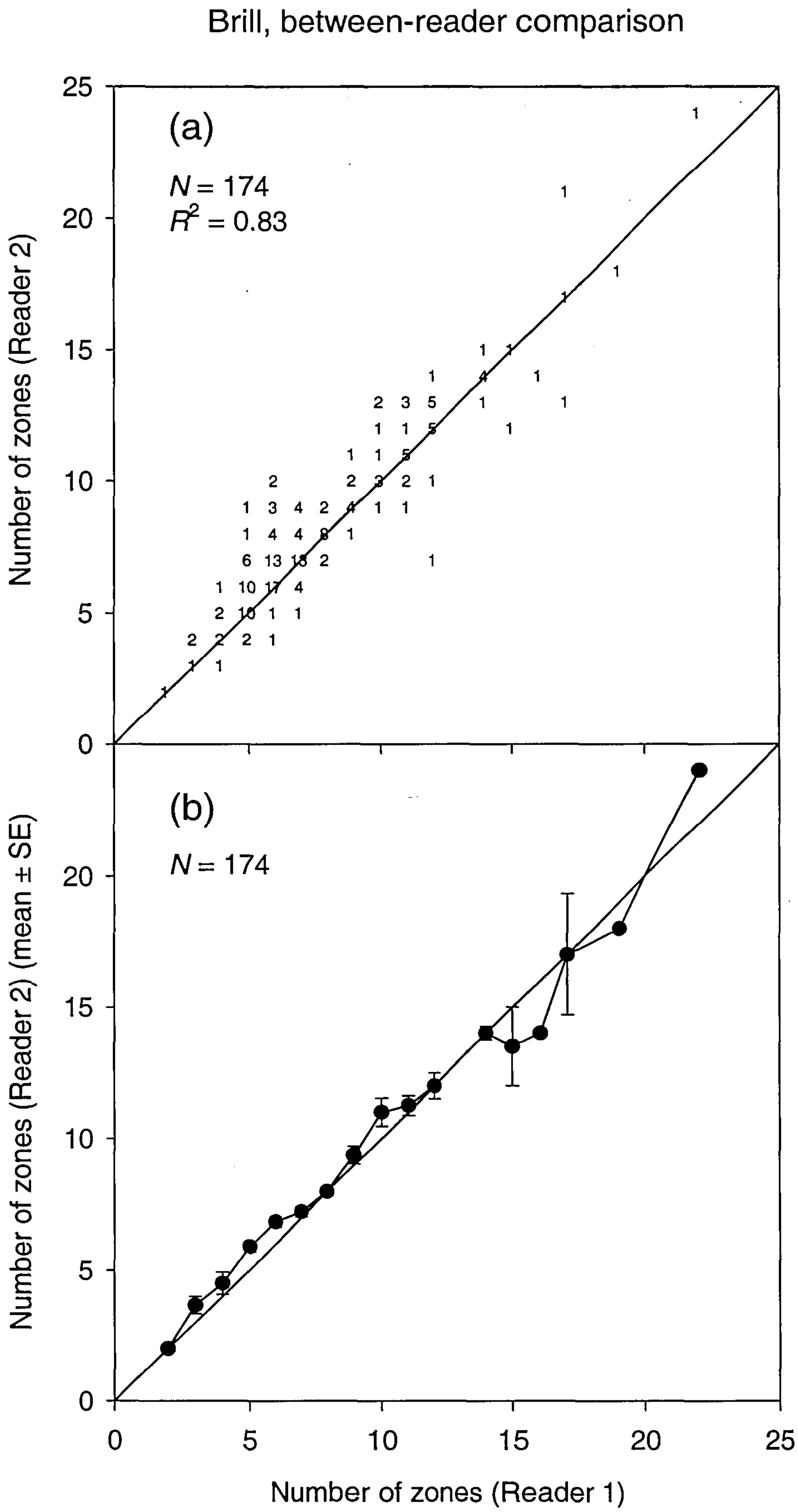


Figure 13: Comparison of the readings of brill otolith thin sections made by Reader 1 and Reader 2: (a) Actual counts (numbers represent number of fish); and (b) mean count ± 1 standard error. Diagonal lines indicate the expected relationship. *N*, total sample size.

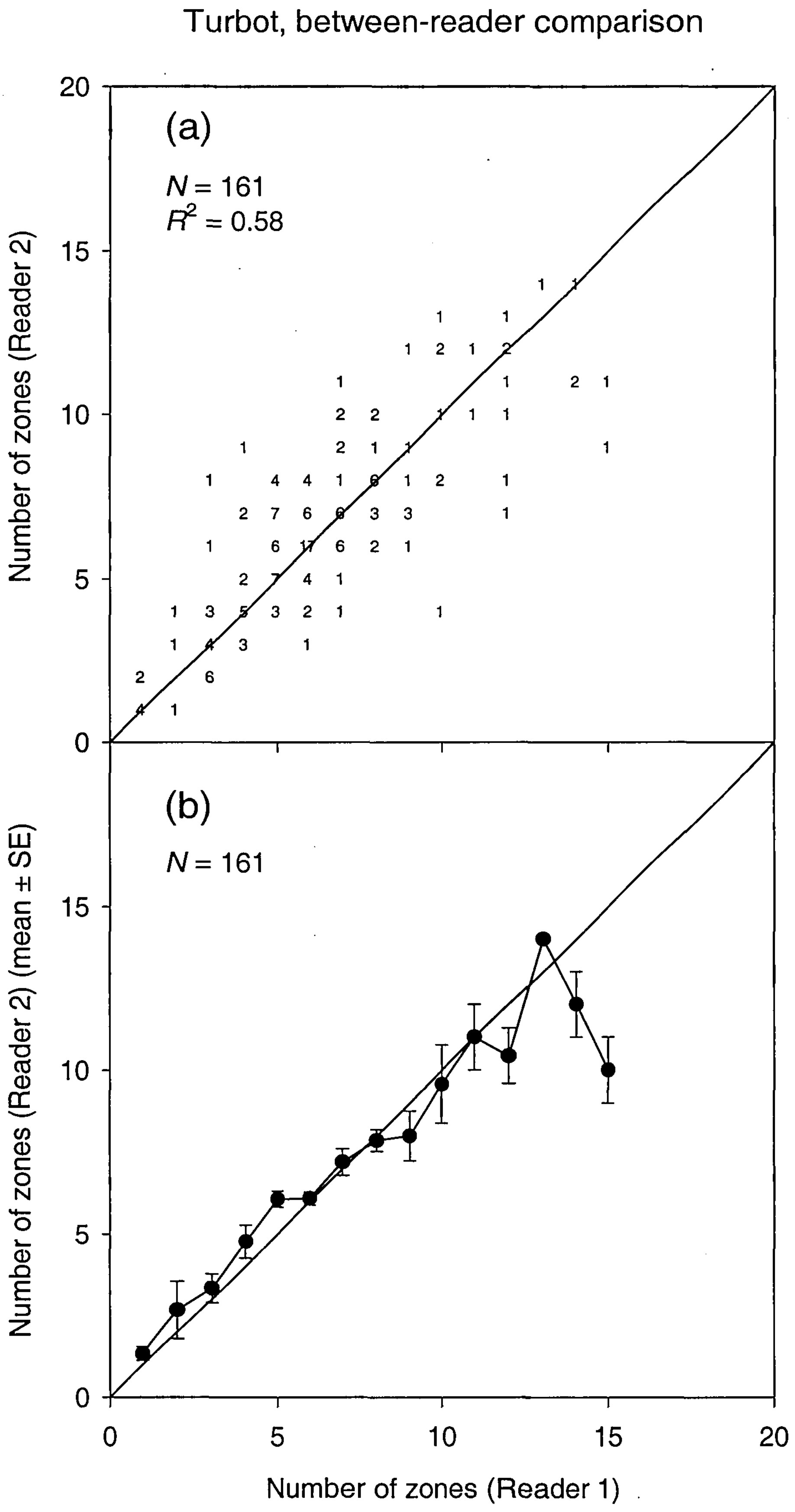


Figure 14: Comparison of the readings of turbot otolith thin sections made by Reader 1 and Reader 2: (a) Actual counts (numbers represent number of fish); and (b) mean count ± 1 standard error. Diagonal lines indicate the expected relationship. *N*, total sample size.

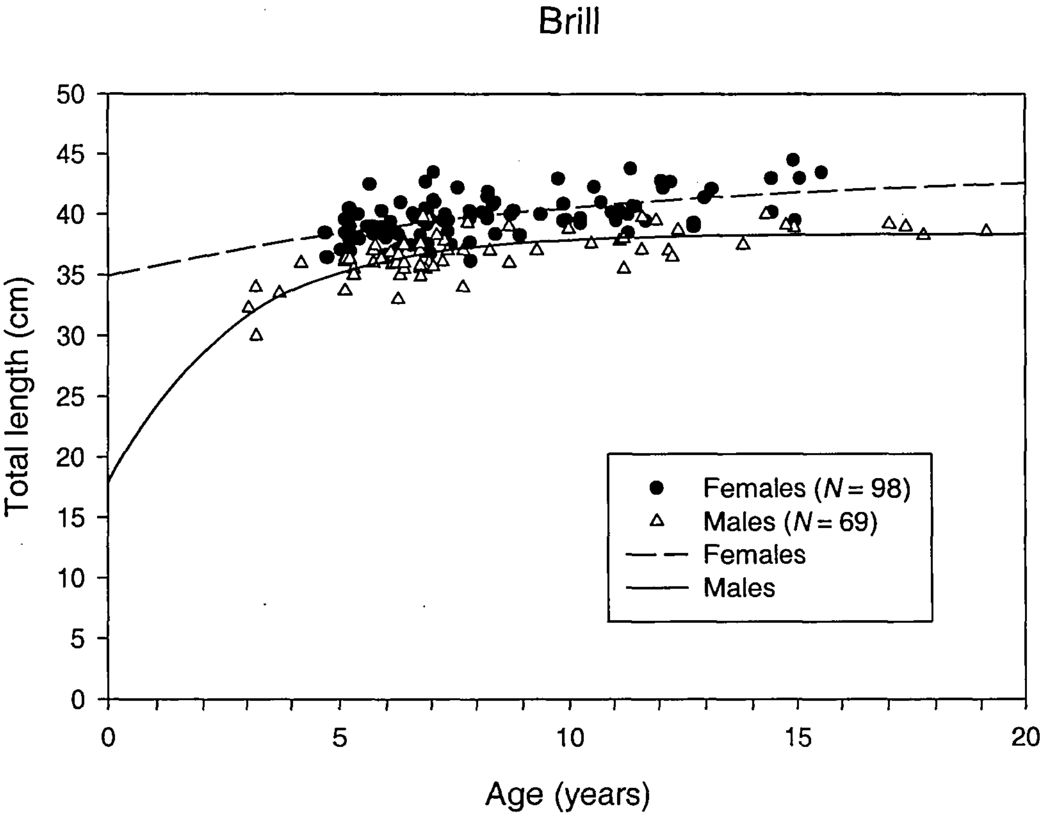


Figure 15: Length at age data for male and female brill with fitted Von Bertalanffy growth curves. *N*, sample size.

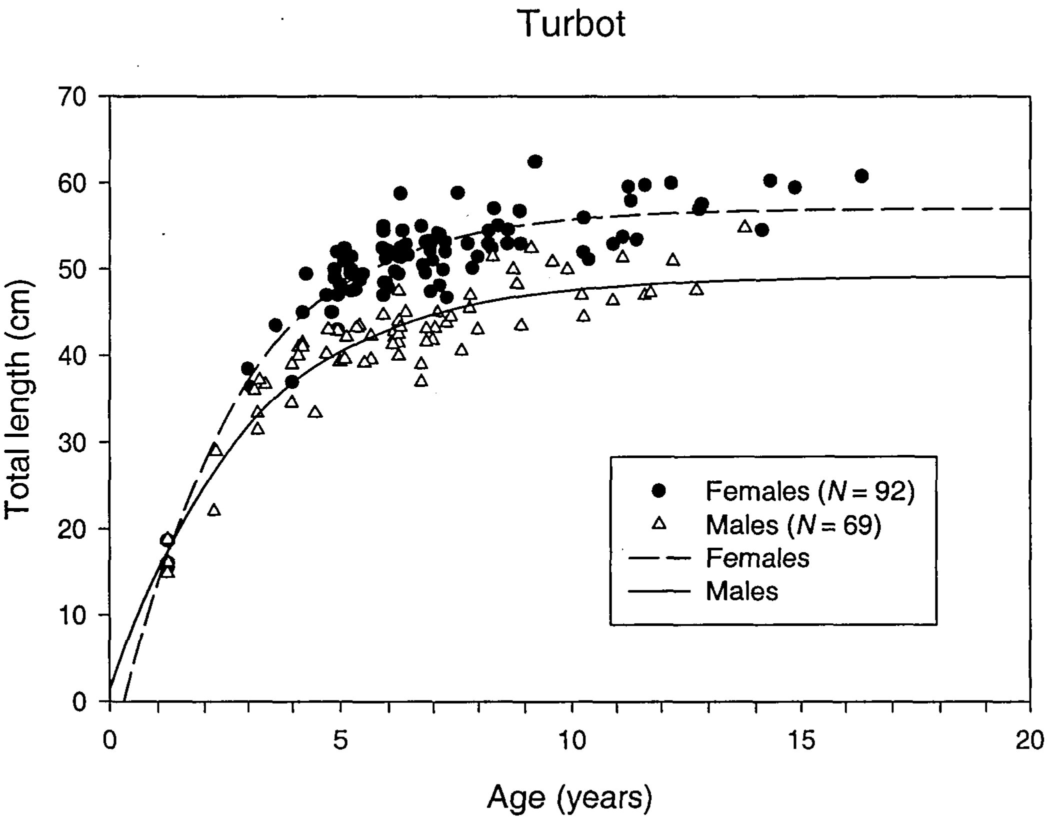


Figure 16: Length at age data for male and female turbot with fitted Von Bertalanffy growth curves. Fish shorter than 25 cm were beach-seined at Lyall Bay, Wellington. *N*, sample size.

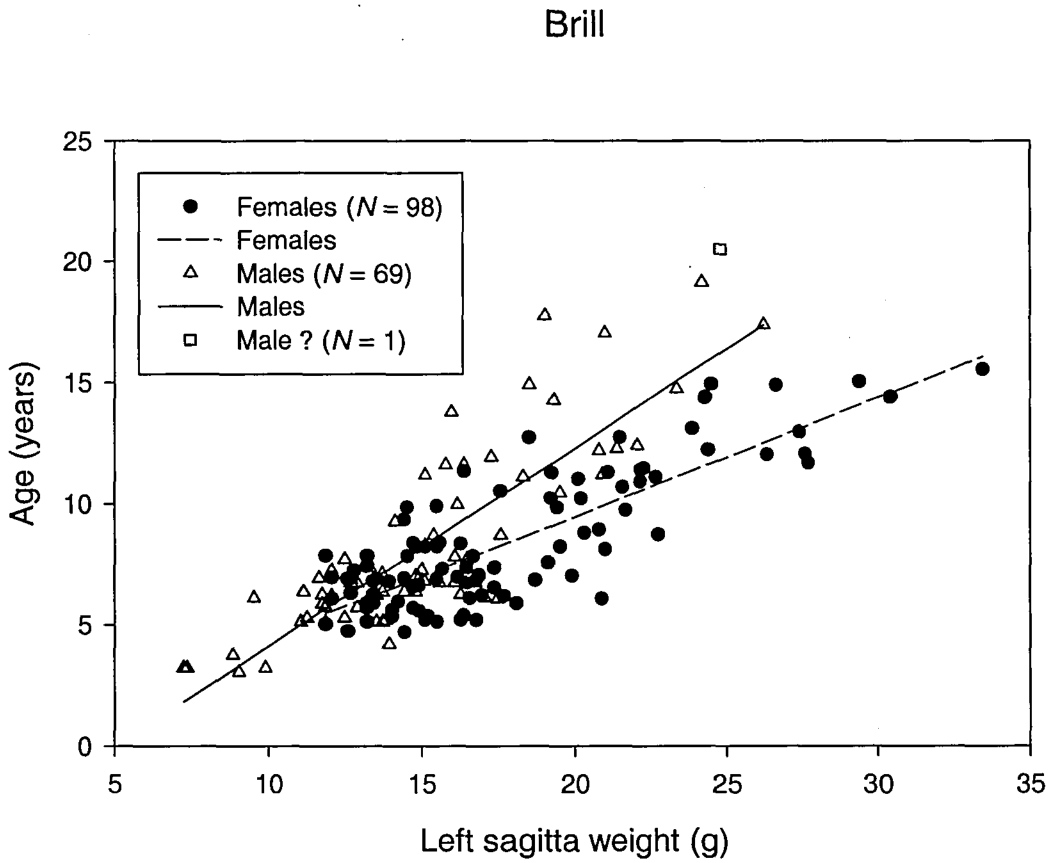


Figure 17: Relationship between age and sagitta weight for male and female brill. One fish recorded as a female was an outlier, and may have been incorrectly sexed. *N*, sample size.

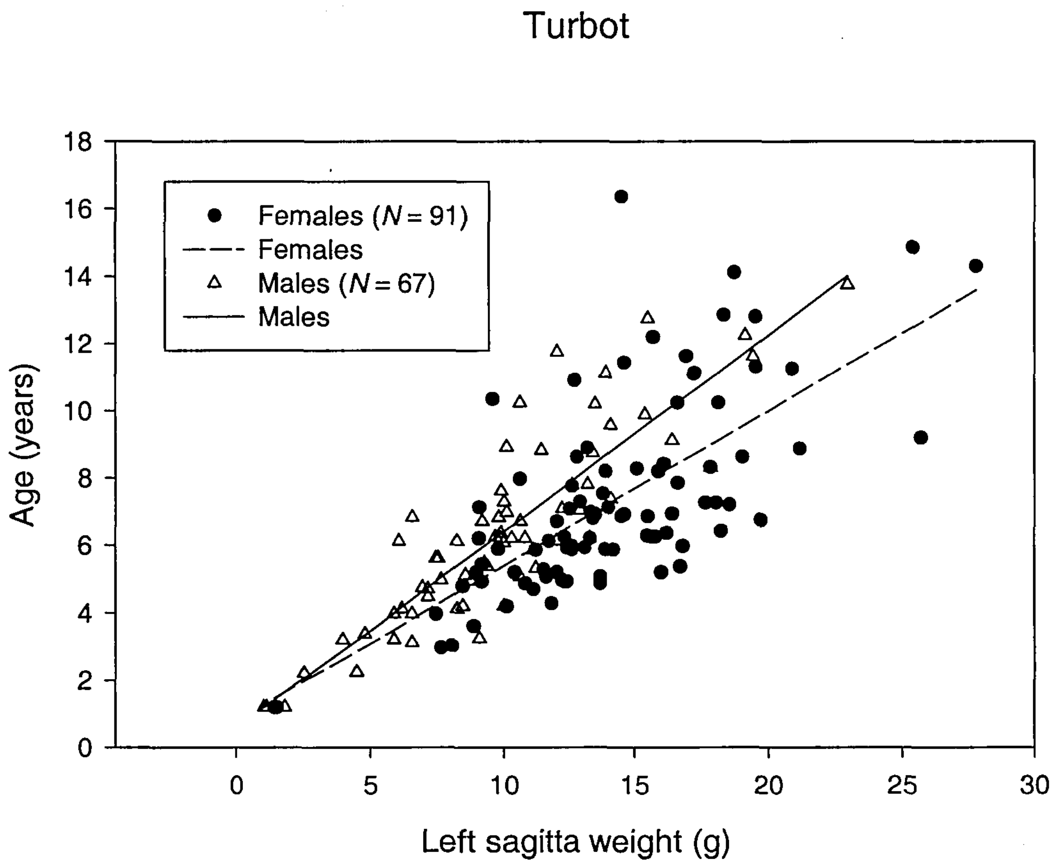


Figure 18: Relationship between age and sagitta weight for male and female turbot. *N*, sample size.

Appendix 1: Month of capture, sex and length distribution of brill and turbot used in the otolith age sample. All fish were obtained from the west coast South Island (Talley's Fisheries Ltd., Greymouth) except for 4 small male and 5 small female turbot in the October 1996 sample that were beach-seined from Lyall Bay (*). N, sample size.

	Brill				Turbot			
	N	Mean	Min	Max	N	Mean	Min	Max
June 96								
Male	0	-	-	-	3	46.5	43.0	50.0
Female	14	41.0	38.0	46.6	5	51.0	45.0	57.4
July 96								
Male	6	38.1	36.0	39.6	4	41.7	39.0	43.0
Female	13	38.3	31.7	41.4	16	48.0	37.0	53.5
September 96								
Male	12	37.2	33.7	40.6	12	42.7	39.6	52.5
Female	6	39.4	37.8	41.2	9	50.2	43.5	59.8
October 96								
Male	18	35.7	30.0	39.0	22*	37.2	14.9	15.6
Female	11	38.9	37.0	41.0	23*	44.6	47.5	62.5
November 96								
Male	10	36.7	35.0	40.0	4	42.3	40.0	45.5
Female	0	-	-	-	6	49.9	46.8	54.5
December 96								
Male	7	37.0	35.5	39.0	3	41.6	36.7	44.5
Female	4	39.4	38.0	40.0	8	51.0	47.0	56.8
April 97								
Male	3	36.4	33.5	38.3	6	48.4	43.0	54.8
Female	11	39.8	36.5	43.0	4	52.8	50.5	56.0
May 97								
Male	2	39.6	39.3	39.8	2	49.3	47.0	51.5
Female	9	39.3	37.0	41.0	8	53.6	45.0	60.3
June 97								
Male	3	36.7	35.5	37.5	1	45.0	45.0	45.0
Female	8	40.7	37.7	43.8	5	56.2	50.2	60.8
July 97								
Male	2	38.8	38.7	38.9	6	38.9	33.4	43.5
Female	9	39.6	37.6	41.4	16	50.1	38.5	55.1
August 97								
Male	5	36.4	32.3	39.2	9	42.1	38.2	50.9
Female	21	40.3	37.1	43.5	6	51.1	36.4	58.9
September 97								
Male	4	37.3	34.7	39.1	7	37.9	30.7	51.4
Female	8	39.6	36.8	42.5	6	52.4	47.4	54.6
October 97								
Male	10	36.0	33.0	39.1	6	42.1	29.0	49.9
Female	14	39.3	31.3	42.7	1	58.8	58.8	58.8

Appendix 1 *continued*

	Brill				Turbot			
	N	Mean	Min	Max	N	Mean	Min	Max
November 97								
Male	0	-	-	-	4	44.1	41.6	48.3
Female	0	-	-	-	10	53.6	45.2	59.6
December 97								
Male	1	37.2	37.2	37.2	1	44.7	44.7	44.7
Female	5	39.0	36.2	40.9	5	52.5	51.2	53.3
Total								
Male	83	36.7	30.0	40.6	90	41.3	14.9	54.8
Female	133	39.7	31.3	46.6	128	50.1	15.6	62.5

Appendix 2: Microincrement counts from thin medio-lateral otolith sections of juvenile turbot beach-seined from Lyall Bay.

Fish no.	Date collected	TL (mm)	Otolith length (µm)	Microincrement count				Growth (mm/day)
				1	2	3	Mean	
13	30-10-96	27.1	-	53	51	50	51.3	0.53
1	27-01-96	30.6	412	53	56	54	54.3	0.56
14	30-10-96	32.6	436	57	59	59	58.3	0.56
7	03-05-96	45.3	608	74	78	73	75.0	0.60
20	27-01-97	58.1	-	85	85	83	84.3	0.69
12	18-09-96	58.7	724	82	79	77	79.3	0.74
9	13-05-96	58.8	719	77	80	76	77.7	0.76
22	27-01-97	60.0	779	86	78	76	80.0	0.75
10	22-06-96	130.2	1 564	185	192	190	189.0	0.69

Appendix 3: Increment measurements (in transverse otolith sections) of the opaque zones for the first and second year of growth from ten, 766-day old (2+) captive reared turbot. The dorsal axis measurements are on a line from the nucleus to the tip of the dorsal margin. The sulcal axis measurements are on a line from the nucleus to the proximal surface, immediately adjacent to the sulcus. TL, total fish length; Total length, total otolith length.

			Dorsal axis					Sulcal axis				
Fish no.	**Sex**	**TL (mm)**	**1st yr (mm)**	**% of total**	**2nd yr (mm)**	**% of total**	**Total length**	**1st yr (mm)**	**% of total**	**2nd yr (mm)**	**% of total**	**Total length**
18	F	202	0.498	62.5	0.740	92.9	0.796	0.343	75.5	0.428	94.1	0.455
20	F	213	0.629	60.6	0.977	94.3	1.037	0.366	66.5	0.518	94.1	0.551
21	F	214	0.637	69.9	0.854	93.8	0.911	0.403	72.4	0.523	93.9	0.557
24	F	228	0.476	66.2	0.709	98.5	0.719	0.338	75.8	0.428	95.9	0.446
25	M	234	0.532	61.0	0.780	89.6	0.871	0.324	73.6	0.409	92.8	0.440
26	F	211	0.581	73.0	0.745	93.6	0.796	0.362	74.0	0.455	93.0	0.489
28	F	219	0.565	72.8	0.703	90.6	0.776	0.339	78.8	0.400	93.0	0.430
29	M	229	0.640	73.3	0.812	93.0	0.872	0.350	76.6	0.426	93.2	0.457
33	F	239	0.613	73.7	0.771	92.7	0.831	0.387	81.3	0.456	95.6	0.477
39	M	234	0.506	62.7	0.751	93.1	0.807	0.317	75.2	0.374	88.8	0.422
Mean		222.3	0.567	67.6	0.784	93.2	0.842	0.353	75.0	0.442	93.5	0.472
Stdev		12.18	0.062	5.52	0.082	2.35	0.088	0.027	3.93	0.048	1.95	0.047
Min		202	0.476	60.6	0.703	89.6	0.719	0.317	66.5	0.374	88.8	0.422
Max		239	0.640	73.7	0.977	98.5	1.037	0.403	81.3	0.523	95.9	0.557