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EXECUTIVE SUMMARY

Paul, L.J., Ó Maolagáin, C., Francis, M.P., Dunn, A. & Francis, R.I.C.C. 2000: Age, growth, mortality, and yield per recruit of butterfish (*Odax pullus*) in Cook Strait, New Zealand. *New Zealand Fisheries Assessment Report 2000/6.* 30 p.

This report addresses part of Specific Objectives 1, 2, and 3 of Project INS9802, namely: "To determine age and growth of ... butterfish in QMA 2 ...", "To estimate [the] natural mortality rate of ... butterfish ...", and "To estimate yield-per-recruit for butterfish".

Otoliths, scales, and fin spines were investigated for growth increment marks. All showed clear structures (growth zones, annuli, or rings), with good agreement among them. A combination of otolith and scale reading was used to determine ages. Within-reader and between-reader variability of counts was low. The ages are not validated, but seem reasonable given the level of agreement between structures and readers. A small innermost mark on all three structures was considered to be a non-annual check mark and was disregarded in age determination.

A von Bertalanffy growth curve was fitted to length at age data for 211 fish, using a procedure to correct for the selective sampling of fish by different sizes of setnet mesh. Von Bertalanffy parameters were $L_{\infty} = 51.8$, K = 0.23, $t_0 = -1.7$. Maximum age of the fish sampled was 11 years, though natural longevity is assumed to be greater, possibly 15 years.

Using Hoenig's regression method, natural mortality M was estimated as 0.38 for a maximum age of 11 years, 0.32 for 13 years, 0.28 at 15 years. Using Pauly's method, incorporating von Bertalanffy parameters and mean water temperature, M was estimated to be 0.40-0.45. The most plausible estimate of M was considered to be in the range 0.30-0.45.

The greatest yield-per-recruit was obtained when butterfish recruited at 2–3 years, at 30–35 cm fork length. An associated study on mesh selectivity suggests that this would be achieved by reducing the legal minimum setnet mesh size from its current 108 mm. However, with maturity occurring at 35–40 cm, this move would result in substantially more immature fish being caught. It would probably also result in proportionately more females being caught; some females change to males at or after maturity, and most males are larger than 40 cm. If the mesh size is reduced to maximise the theoretical YPR, it is not known what effect the removal of relatively more smaller fish will have on the sex ratio and reproductive viability of populations.

1. INTRODUCTION

Butterfish (*Odax pullus*) have been caught commercially in New Zealand for over a century (*see* Sherrin 1886), and annual landings of 50 t or more have been recorded from 1935 onwards, rising to 100–200 t in the 1990s. The main fishery is centred on the shores of Cook Strait, particularly adjacent to the Wellington Harbour entrance and in parts of the Marlborough Sounds. There is a smaller fishery around the Otago, Southland, and Stewart Island coasts (Paul 1997). The preferred size of fish is 40–55 cm fork length (FL).

Butterfish are caught almost exclusively by setnets from shallow (5–40 m) reefs covered with macroalgae. They are specifically targeted by commercial fishers who hold a permit for this species, and there is an associated bycatch of other shallow water reef-dwelling fishes. Butterfish are available throughout the year, but there are few if any full time fishers. Butterfish are essentially an alternative target species, sought when other fisheries (e.g., lobster potting, lining for groper, ling, school shark, etc.) cannot be pursued. General information on the commercial fishery was given by Ritchie (1969), Paul (1997), and Dunn & Paul (2000).

In southern New Zealand, setnet fishing by recreational fishers is directed at butterfish, blue moki, and other species on or near shallow reefs. Some recreational catch is also taken by spear. The size of the recreational catch is poorly known, but estimated to be equal to or larger than the commercial catch (Annala & Sullivan 1997). There is a further, even less well-defined, catch by Maori, by non-permitted commercial fishers, and by 'recreational' fishers who take more than the recreational quota for unrecorded sale or barter. The total annual catch of butterfish may be as much as 500 t.

A precise and reliable ageing technique is fundamental to any study of fish population dynamics. The most common application of an ageing technique is the derivation of growth curves, and estimation of growth rates. This in turn enables age-structured population models to be applied. Other important applications of ageing techniques are the estimation of ages at maturity and recruitment, longevity, population age structure, natural and fishing mortality rates, and recruitment strength and variability. An ageing technique also provides the opportunity for detecting density-dependent changes in various population parameters over time, such as growth rate and age-specific fecundity. The ability to age fish is a requirement for most fish population models, and for monitoring population responses to exploitation.

This study develops an ageing technique for butterfish, and applies it to a sample of fish from eastern Cook Strait to estimate growth rate, longevity, natural mortality rate, age at maturity, and age at recruitment. There has been little work on these aspects of butterfish biology, although a plausible plot of length against age was developed from unvalidated scale-reading by Ritchie (1969). The present study arises, in part, from a review of the knowledge about butterfish (Paul 1997) undertaken when it was proposed to bring this species into the Quota Management System. It was carried out in association with a study on the mesh selectivity of setnets for butterfish (Dunn & Paul), and uses the fish caught during fieldwork for that study.

The results of the ageing work reported here and the mesh selectivity work (Dunn & Paul 2000), are combined with a yield-per-recruit (YPR) analysis to assess the suitability of the current mesh size restrictions. The current mesh size for butterfish is 108 mm, which is larger than that for several other inshore reef species (100 mm), but smaller than the 114 or 115 mm used for blue moki, the species most often caught in association with butterfish.

2. BACKGROUND BIOLOGICAL INFORMATION

Butterfish are endemic to New Zealand. They occur from North Cape to the Snares Islands and at the Chatham, Bounty, and Antipodes Islands, and are most common around and south of Cook Strait.

They are not found at the Three Kings Islands, where the related bluefinned butterfish, Odax cyanoallix, occurs. The two other species in the genus Odax, rainbow cale and herring cale (weed whitings), are both restricted to southern Australia.

Butterfish inhabit rocky coastlines, their main habitat being moderately turbulent water with dense beds of macroalgae, predominantly the large brown seaweeds of the genera *Ecklonia* and *Carpophyllum*. They generally occur from the immediate subtidal zone to about 20 m, but appear to have a shallower depth range in the north (to 10 m) than in Cook Strait (to 20 m) and southern waters (to 40 m) (Ritchie 1975).

The number of butterfish stocks is not known. Some degree of geographical isolation is possible simply because butterfish have such restricted habitat requirements; their movement between reef areas where these are separated by long sandy coastlines or deep straits is likely to be limited. Ritchie's study found minor geographic variation in some taxonomic characters (vertebrae, scale rows, finrays), as well as some variation within regions, and came to no conclusion about stocks. Butterfish populations at offshore islands (Chathams, Antipodes, Bounties, and Snares), however, are likely to be distinct from the mainland population(s) because of their isolation. Where shallow reef complexes are not widely separated, however, local movements clearly occur; fishermen report that heavily fished reefs usually recover within a month.

Butterfish are almost certainly protogynous hermaphrodites, maturing first as females, with some fish later changing to males. This was suggested from strong circumstantial evidence by Ritchie (1969), and supported by work on gonad histology and sex-linked steroids by Crabb (1993), but the trigger for, and extent of, this change has yet to be elucidated. Butterfish are closely related to wrasses, Family Labridae, in which complex sex changes are well documented. As with wrasses, butterfish undergo colour changes with size, and sex. Juveniles, most common in shallow areas, are reddish brown, later golden yellow, with a pale midbody longitudinal stripe. At about 30 cm FL they become a deeper-bodied, brownish or greenish female phase which lasts to about 40 cm; these females are most common in depths < 10 m. Maturity is reportedly attained at 35–40 cm, and the silver body stripe breaks into paler blotches. At about 40 cm, some of the mature females transform into males, which are dark greenish to black above, paler below, with brighter fin markings. During the breeding season the depth ranges of the sexes overlap and males become territorial; at other times (autumn-winter) males tend to live deeper than 15 m. The sex ratio of the population is difficult to assess as it varies with locality, depth, and season.

A long spawning season has been reported, July to March in Cook Strait (Ritchie 1969), August to January, perhaps shorter in Otago (Robertson 1973, Crabb 1993).

Butterfish are almost exclusively herbivorous, feeding on a variety of the larger seaweeds, particularly *Macrocystis pyrifera* and *Ecklonia radiata*, but at times eat small invertebrates. Feeding activity is higher in spring and summer (Ritchie 1969, Clements & Choat 1993); it is also influenced by the tide, high tide apparently providing a greater choice of seaweeds.

3. PREVIOUS WORK ON AGE AND GROWTH

Although no definitive studies have been published, ages as well as sizes are often mentioned in association with accounts of reproduction. In his general study of butterfish biology, Ritchie (1969) covered age and growth only briefly, his study being restricted by a small sample (92 fish) with few juveniles. He described the otoliths as very small and delicate, difficult to locate, and the 'growth rings' on the six he examined as poorly formed, "irregular, often incomplete and intergrading". He noted that opercular and subopercular bones had "very well defined growth layers" but were difficult to obtain and prepare. He considered scale annuli to be relatively clear, and his ageing work centred on scale reading, using the increments between successive annuli to develop a back-calculated 'growth curve' to age 9, with mean lengths-at-age from age 1 of about 8, 15, 24, 32, 38, 43, 46, 48, and 50 cm total length.

Paul (1997) examined seven otoliths from adult butterfish (42–57 cm FL), four of which were sectioned. When viewed whole in oil, with reflected light and a black background, alternating dark and light bands were readily visible, the former being similar in appearance to the 'hyaline' otolith zones generally described as formed by fish in winter. Thin sections were viewed with reflected and transmitted light, and identical ring counts obtained. The zone counts of 6–9 agreed closely with Ritchie's interpretation of scales from fish of similar size.

4. METHODS

4.1 Fish sampling

Most of the fish for this study of age and growth were caught in an experimental study of setnet selectivity (Dunn & Paul 2000), where a series of setnets with different mesh sizes was fished on suitable shallow reefs outside Wellington Harbour. Some additional fish were collected opportunistically by spear-fishing.

There is an inherent problem in using setnets to collect a sample of fish from a population: the sample is almost certainly not random, and selectivity will bias any estimates that assume random sampling, such as length-weight regressions, sex ratios, capture-recapture estimates of population size, and calculations of growth and mortality (Hamley 1975). (Selectivity is considered to be the process behind the probability of capture, which varies with the characteristics of the fish, but usually involves selection by size.) This bias can be minimised by using a range of mesh sizes, as was done in this study, and by supplementing the sample with small and large fish taken by other methods. The four nets which took most (c. 90%) of the fish used in this study had modal selectivities for butterfish of 32–44 cm (Dunn & Paul 2000). Baranov (1948), quoted in the general review by Hamley (1975), suggested that gillnetted fish were retained at a length $\pm 20\%$ of the optimally selected size. Although the selectivity function is probabilistic rather than knife-edged (i.e., not all fish $\pm 20\%$ are retained), this generalisation implies that butterfish 25–52 cm long were reasonably well retained by the nets. However, there will have been a bias in the catch of each mesh size towards retaining the faster-growing small fish and the slower-growing old fish. A method for correcting growth estimates for selectivity is presented in Appendix 1.

Five fish 18–28 cm in length were taken by spear. They were used in the development of an ageing methodology, but were not included in the final calculation of a growth curve.

Fishing for the study of setnet selectivity was carried out from the research vessel *Rangatahi*, a 9.3 m outboard-powered aluminium catamaran. Sampling was carried out along the coastline outside Wellington Harbour (Figure 1) from December 1998 to February 1999; for details of the gear and fishing procedure, see Dunn & Paul (2000). Essentially, nets were set for between 1 and 20 h, in depths from 4 m to 20 m. The nets were constructed as standard butterfish nets, but with seven mesh sizes ranging from 50 to 125 mm (legal mesh size is 108 mm), and fished as sets of three mesh-panels each 20 m long (regulation nets are 60 m).

4.2 Data recording

Fish of all species were measured in the laboratory on the day they were brought ashore. Lengths were recorded as fork length (FL), to the nearest millimetre below actual length. In butterfish, FL is marginally less than total length, the caudal fin margin being only slightly concave. This measurement follows the convention of fisheries regulations, and was the procedure used by Hickford & Schiel (1995, 1996) but differs from the total length used by Ritchie (1969). The butterfish which had been damaged in the net by predation in such a way that length measurements would be unreliable were recorded by presence only.

Each intact butterfish was given a code-number, identifiable to the net panel in which it was caught, and frozen. On subsequent thawing, each fish was re-measured (as a check on its code-number) and sexed, with scales, otoliths, and fin spines collected. The butterfish undamaged by predation (95% of the catch) were weighed to the nearest gram. Girth measurements to the nearest millimetre were taken from a sub-sample of 64 butterfish, using a fine cord encircling the region of greatest girth, at the pelvic girdle. The initial measurements from freshly dead fish were used in all data analyses.

To avoid confusion when describing and discussing the concentric growth marks which may not be comparable in different structures, those in otoliths are termed *zones*, those in scales *annuli*, and those in fin spines *rings*.

4.3 Otoliths

Otoliths were collected by slicing off the top of the cranium, and using fine forceps to extract them from the semicircular canals. This region of the skull was lightly ossified, and the very small otoliths difficult to locate, as noted by Ritchie (1969). They were cleaned and stored dry in coded small plastic snaplock bags. For development of an ageing procedure, the whole otoliths were examined in both reflected and transmitted light, and some thin sections $(300 \pm 100 \mu m)$ were examined in transmitted light. For subsequent age reading the otoliths were immersed in a high refraction oil in a small black dish, and the distal (lateral) surface viewed whole using a compound microscope at various magnifications. Otoliths were read independently by two readers, and were then re-read by the two readers together viewing a digitally captured image on a screen display. A new reading was made by each reader, discussed, and compared with the earlier readings, the fish length, and a printed image of a scale (see below) from that fish. From this procedure a final agreed reading (zone count plus marginal category) was assigned to the otolith.

4.4 Scales

Scales were taken from the rear flank of the body, above the lateral line and below the rear half of the dorsal fin; scales from this area were subjectively judged "best" for size, shape, and annulus clarity by Ritchie (1969). After dry storage they were cleaned in sodium hypochlorite, and mounted between two microscope slides, 4-6 scales per fish. They were read independently by two readers, using different techniques. Reader 1 (LJP) used a library microfiche reader to project the scale image on to a screen at x23 magnification, and made an A4 paper print at the same magnification. All mounted scales were examined and the clearest chosen. The screen image was slightly clearer than the print, and fine focussing allowed different parts of the scale - which was seldom all in focus at once - to be examined in detail. Initial counts of annuli were made from the screen image. The print (Figure 2) brought all the scale into focus, and allowed the position of each annulus to be marked for growth zone measurement. Reader 2 (CÓM) viewed each chosen scale in dark field illumination at several magnifications (Figure 3), and recorded an annulus count. The scale print, in conjunction with viewing the screen image of the otolith, was used to assign the final "age" to the fish. The scale print was also used to take growth zone measurements, from the focus to annulus 1 and between successive annuli, for back-calculation of growth rate. Scales were read essentially following the procedure described by Ritchie (1969).

4.5 Fin spines

The first large dorsal and anal fin spines were removed and stored dry. Segments from near the spine base were embedded in epoxy resin, and sectioned using a dual-bladed diamond saw. After being

attached to a microscope slide with a thermoplastic cement, the sliced sections were ground to a thickness of $300 \pm 100 \mu m$ and polished. They were viewed under transmitted light using both brightand dark-field illumination, and a range of magnifications. A subsample of spines from 63 fish was read independently by two readers.

4.6 Age and growth

Reader 1 aged the otoliths twice (readings $R_{1,1}$ and $R_{1,2}$) and reader 2 aged them once (R_2).

Otolith zone counts were assessed for ageing bias and precision (between readers, and between readings by reader 1) using age-bias plots, and plots of the coefficient of variation (c.v.) against age, as recommended by Campana *et al.* (1995). These two plots show the means (and their standard errors), and the *c.v.s.*, respectively, of the zone counts made by reader y for each "age" as determined by reader x. For example, for all the butterfish that were judged by reader 1 to have five zones, the mean, standard error, and *c.v.* were calculated from the zone counts made by reader 2 for the same fish, and plotted at age 5 on the X-axis.

A growth curve was 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. For fish sampled by lengthselective methods, such as setnets, this growth curve might be biased by under-representation in the samples of faster-growing old fish and slower-growing young fish. We therefore re-fitted the von Bertalanffy growth curve making allowance for the selective effects of the nets used to sample butterfish in this study (Appendix 1).

4.7 Natural mortality

Estimates of the natural mortality coefficient (M) were obtained using two techniques that are based on observed empirical relationships between M and other more easily measured parameters: maximum age in the population (Hoenig 1983), and growth rate and water temperature (Pauly 1980).

Hoenig (1983) compared published estimates of mortality rates and life spans for fishes, cetaceans and molluscs. He found a significant negative relationship between the two variables that explained (for fishes) 68% of the variability in M:

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

where t_{max} is the maximum age reached by the species. The oldest fish in our aged samples was used as a minimum estimate of t_{max} . We also applied a commonly used "rule-of-thumb" based on Hoenig's equation:

$M = -(\log_e p)/A$

where p is the proportion of the population that reaches age A (or older) in an unexploited stock (Annala *et al.* 1999).

Pauly (1980) examined the relationship between reported values of M, the von Bertalanffy growth parameters (K and L_{∞}), and the mean annual temperature at the position where the fish were

caught (T). He obtained a multiple regression equation that explained 72% of the variance in M:

 $\log_{10}M = -0.0066 - 0.279 \log_{10}L_{\infty} L + 0.6543 \log_{10}K + 0.4634 \log_{10}T$

Our previous experience with this formula has shown that the estimate of M is not particularly sensitive to the value of T used. Nevertheless, it is difficult to estimate the mean annual temperature for a species, so we applied sensitivity tests to determine the effect of a range of plausible temperature estimates.

4.8 Yield per recruit

A yield per recruit analysis (YPR) was carried out using the software *pmod*: input parameters are shown in Table 1. Growth parameters were those derived in the present study, using a correction for setnet selectivity (*see* Equation (1) in Section 5.4 below). The parameters of the length-weight relationship were estimated by applying a linear regression to the log-transformed data collected during the mesh selectivity experiment (Dunn & Paul 2000):

 $\log(\text{weight}) = \log(a) + b \log(\text{length})$

where length is measured in centimetres and weight in kilograms¹. There is little information on age at recruitment to the commercial fishery. We assumed knife-edge recruitment for a range of ages, with a base value of 3 years. A base value of 0.37 was chosen for M, with a sensitivity range of 0.30–0.45 (see Results).

Туре	Parameter	Unit	Base value	Sensitivity (lower)	Sensitivity (upper)
Growth parameters	L_{∞} K t_0	cm, FL yr ⁻¹ yr	51.8 0.23 -1.7		
Length-weight relationship	a b		6.085 x 10 ⁻⁶ 3.239		
Recruitment age		yr	3	2	6
Natural mortality	М	yr ⁻¹	0.37	0.30	0.45

Table 1: Biological parameters used as input for the yield per recruit analysis

5. RESULTS

5.1 Selection of ageing structures

A total of 212 butterfish which could be measured were caught by setnet, and 25 were speared. Fin spines were available from all fish. A smaller number of fish (214) provided otoliths and/or scales which could be read. For a few of these fish suitable otoliths or scales could not be obtained (otoliths were missed or broken, scales were absent or "regenerated"), but the other structure gave an age that was considered reliable. Of the net-caught fish, 206 could be aged.

¹ Ritchie (1969) provided a length-weight relationship for gutted butterfish, but this is not comparable with our relationship for whole butterfish.

Otoliths, scales, and spines from a subsample of 63 fish were examined to determine the most appropriate structure, and methodology, for age determination.

5.1.1 Otoliths

When the whole otoliths were immersed in oil on a black background and viewed using reflected light, a concentric series of dark and light zones was clearly visible (Figure 3). With transmitted light, a similar series of zones was also visible, but they were less clearly defined, particularly in the otolith's thicker central region; the light 'illuminated' the otolith's interior, and the curved nature of the zones made their relative spacing at the otolith's surface difficult to determine. The four otolith thin sections read by Paul (1997) were re-examined; they gave similar zone counts to the whole otolith of the pair, but were generally less clear, showing more ambiguous zone splits and apparent checks. After initial comparisons, all otolith reading was done with whole otoliths under reflected light.

5.1.2 Scales

Most scales (Figures 2, 3) showed clear annuli, which could be counted along both the anterior and lateral axes. The scales were generally long and narrow (some broader scales were collected from some fish when the optimal site on the body was damaged), and the marginal increment was most clearly defined at the anterior margin. At the sides (dorsal and ventral margins), the outermost annulus was at or very close to the margin. A very small "first annulus", designated annulus "0", could usually be seen; it was relatively constant in position, but varied greatly in clarity.

5.1.3 Fin spines

Fin spine sections (see Figure 3) showed a very clear sequence of concentric dark and light zones or rings, surrounding a small hollow centre. There was usually a poorly-defined innermost ring (designated "0") immediately outside this central cavity.

5.1.4 Comparison of growth marks

Between readers comparison: With otoliths, there was good agreement between readers, with a slight tendency for reader 1 to read lower at low ages (Figure 4). With scales, reader 1 often read 1 higher, occasionally 2 at higher ages. With fin spines, both anal and dorsal, there was a clear trend for reader 1 to read 1 or 2 rings higher than reader 2 at all ages.

Between structures comparison: Both readers got very similar readings from the anal and dorsal fin spines (Figure 5). Anal spines were judged to be clearer, and were used in subsequent comparisons. Comparing otoliths with scales, reader 1 often counted more scale annuli than otolith zones (usually 1 more, occasionally 2), while reader 2 obtained similar counts. Comparing otoliths with anal spines, both readers counted fewer spine rings than otolith zones.

A review of these results suggested that the spines were the least likely to be reliable indicators of age. Although most spines had clear rings, the status of the innermost one was uncertain, and it was unknown whether the cavity enlarged with age and obscured the first ring. Spine ring counts tended to be lower than zone counts from otoliths and annulus counts from scales. From a practical viewpoint, spine sections were more time-consuming to prepare than a set of scales. It was also decided to read whole otoliths. These required no preparation time, but because they were small (1-3 mm) and fragile they were time-consuming to handle.

For the remainder of the sample, only otoliths and scales were read. The final age reading was based on an interpretation of both structures.

5.2 Defining the first growth mark

5.2.1 Otoliths

The otolith has a relatively large opaque central zone, or core. In the centre of this is a very small hyaline 'nucleus', often surrounded by one or more small and narrow check rings. These are clearly visible on the distal surface of most otoliths, but they form part of a confused grouping of zones and rings in the otolith's core when viewed in thin section. The nature of this central hyaline core and its associated small rings remains unresolved. Interpretation will probably require the examination of otoliths (entire and sectioned) from known-age 0+ fish, as these structures are assumed to be formed during the first few months of life.

Outside the central core, the hyaline zones are spaced at fairly regular intervals out to the otolith's margin, the space between them (the opaque zone) diminishing only slightly. The first of these zones ('0') is ambiguous in appearance and position. It is always less clear, and often narrower, than the other (later) hyaline zones, and it is always positioned close to the following zone, sometimes almost combining with it as a double zone. Its position relative to the centre of the otolith seemed 'reasonable' for zone 1, but its position relative to the next zone was such as to imply that growth in the first and third years was greater than growth in the second year. Both readers independently decided to record it separately from the main count of zones.

5.2.2 Scales

There was some difficulty in identifying the first annulus. Most scales had an annulus a very small distance out from the focus (labelled '0' in Figures 2 and 3). In some scales this was as clearly formed as the following annuli, but in most it was only moderately well formed, and in some it was barely visible. It was relatively constant in position, whereas the other annuli were variously spaced. Its position also implied that if it was interpreted as the first annulus, growth in the second (and often third) year would be greater than growth in the first year. Both readers recorded it separately from the main count of annuli.

5.2.3 Scale back-calculation

To clarify whether the small first ("0") annulus was a check ring or the first annual mark, a simple back-calculation procedure was used to determine theoretical fish lengths at the time of each annulus formation. The procedure followed that of Ritchie (1969), for comparability with his results, using the formula $L_n = (S_n/S) \times L$. The regression of scale size on fish length (Figure 6A) appears linear, and by projection would intersect the axes close to the origin (0,0). Although there are various subtleties in the back calculation procedure (Francis 1990), for the purpose of comparing growth curves with and without the "0" annulus this simple proportional relationship is considered appropriate.

The results (Table 2 and Figure 6B) show two different growth patterns, based on mean lengths at the formation of successive annuli. The growth pattern *without* annulus "0" has a reasonably standard

shape. The growth pattern with annulus "0" is almost linear for the first five annuli, and greatest growth in "year three" (L_2 to L_3); both features are unusual.

Ritchie (1969) included annulus "0" in his determination of a growth curve, and obtained a similar result, with low "year two" growth. He decided that the first small annulus was "anomalous" and likely to be a false check-ring, perhaps "...associated with changes of feeding habit in the early growth period ... from a planktonic or micro-epiphytic algal diet to feeding on macrophytic algae".

Table 2: Back-calculated fork lengths (mm) at the time of formation of successive annuli, and "annual" growth increments (mm), determined from scale measurements which interpret annulus "0" as the first true annulus, and which exclude annulus "0" from the count. n ("ages" 2-10) = 191

_	Including annulus "0"		Excluding annulus "0"		
Annulus no.	Length	Increment	Length	Increment	
1	74	74	150	150	
2	150	76	230	80	
3	230	80	303	73	
4	303	73	361	58	
5	361	58	400	39	
6	400	39	428	28	
7	428	28	449	21	
8	449	21	465	16	

When scale annulus "0" is omitted, the back-calculated first year growth of 150 mm seems high. However, butterfish are very slender when juvenile, attaining greater body depth as they grow (Ritchie 1969, Francis 1988). This morphometric change has not been quantified in any published account, but measurements taken from a sequence of fish drawings (plate 1 in Ritchie 1969) show an increase in relative body depth with size (Table 3) that – although they do not cover the critical size range of 50–150 mm – suggest it is not unreasonable to postulate an elongated juvenile reaching 150 mm in its first year, but growing only 80 mm during its second year as it became deeper-bodied.

Table 3: Increase in relative body depth with size in butterfish. Derived from measurements of drawings in Ritchie (1969, plate 1), hence lengths (fork length) are rounded to centimetres

Fish length (FL, cm)1731404953Body depth as % fish length1920222225

Another approach to interpreting annulus "0" is to examine the distribution of fish lengths backcalculated from each annulus (Figure 7), rather than consider only the mean size of each assumed age group. The size distribution of fish at L_{-0} " (at formation of annulus "0") is narrow, relative to that at L_{1-5} . There are too few fish at L_{6-9} to properly assess, and their size distributions almost completely overlap, as would be expected from the small mean increments at these "ages" (see Figure 6B). The narrow size distribution at L_{-0} " would be reasonable for a fish with a short spawning season, but is unlikely for butterfish which have an extended spawning season. It is considered more likely to represent the size (c. 7 cm ± 3 cm) at which butterfish undergo some biological change which creates a check mark on the scale.

5.3 Age readings

5.3.1 Otoliths

Alternating dark and light "growth zones" were visible around the whole otolith. They were more widely separated and sometimes clearest on the projecting anterior rostrum, but zone counts were made at several positions, particularly when there was some ambiguity. The dark ('hyaline') zones

were generally narrower than the white ('opaque') zones, although when the outermost hyaline zone was right on the margin it was often as wide or wider than the preceding opaque zone.

All samples were collected between December and February, i.e., summer. The margins were either hyaline, or had a very narrow opaque zone outside a wide hyaline zone. This last hyaline zone is interpreted as having formed during the preceding (1998) winter and/or spring, with summer growth (the opaque zone) having just started outside it. The final counts of the hyaline zones excluded the faint "0" zone.

5.3.2 Scales

Final age readings were taken as the count of annuli, excluding the "0" annulus recorded in the original count.

5.3.3 Scale and otolith readings compared

When otolith and scale readings were compared, there was a close correlation when the faint innermost otolith zone, and the small scale annulus "0", were both excluded (Figure 8). There would, naturally, be similar agreement if both were included, but the back-calculated lengths from scale annulus "0" appear anomalous, if not unreasonable (*see* Section 5.2.3), and the very small comparable ring on the anal spine (*see* Figure 3) also suggests that this first check does not represent the first year of growth.

5.4 Growth

The two otolith readings by reader 1 ($R_{1,1}$ and $R_{1,2}$) were strongly positively correlated ($R^2 = 88.2\%$), with the greatest absolute difference being 2 years (Figure 9A). There was no systematic bias between the two readings (Figure 9A. Note that the figure shows the mean ± 1 standard error; the 95% confidence limits of the mean are twice the range indicated by the error bars). Otolith readings by the two readers ($R_{1,1}$ and R_2) were also highly correlated ($R^2 = 79.5\%$), with only one otolith having an absolute difference greater than 2 years – one fish was aged as 11 years by Reader 1 and 7 years by reader 2 (Figure 9B). Reader 2 tended to age the young fish slightly older, and the old fish slightly younger, than did reader 1, but the bias usually fell within two standard errors of the mean and was therefore not significant (Figure 9B).

Ageing precision was high for butterfish aged four years and older (mean c.v. = 10.6%), both within and between readers (Figure 10). The low and variable precision for younger butterfish reflects the small sample sizes and the low absolute ages.

Based on the final, agreed age estimates, a high proportion of the sampled fish were 4 or 5 years old (Figure 11). Females outnumbered males by 2.1:1. The smallest male was 36 cm long, but most males were 40 cm or more. The youngest male was 3 years old, and all 1–2 year old fish were females. The oldest fish in the sample was an unsexed 11-year old. There was no systematic difference in length-at-age between the sexes (although sample sizes of older fish were small) so growth curves were fitted to both sexes combined. Von Bertalanffy growth curves fitted with and without corrections for setnet mesh selectivity produced very similar results (Figure 11). The corrected curve was described by the equation:

$$L_{t} = 51.8(1 - e^{-0.23[t+1.7]})$$

where length (L_t) is measured in centimetres and age (t) in years.

13

(1)

Back-calculated mean lengths agreed well with the lengths determined from the corrected von Bertalanffy growth for ages 4 and above. For ages 1–3, the mean back-calculated lengths differed from the von Bertalanffy values, and are presumably more realistic, because the von Bertalanffy growth curve is based on few fish younger than 4.

5.5 Natural mortality

For p = 0.01, Hoenig's rule-of-thumb method produced estimates of M that were consistently slightly greater than those obtained using Hoenig's regression method (Table 4). However, the rule-of-thumb method was sensitive to the value of p used – with p = 0.015, the rule-of-thumb and regression methods produce nearly identical results. Because of this sensitivity, only the regression method is considered further in this report.

The maximum age obtained in this study was 11 years, which is comparable with the 9–10 years reported by Ritchie (1969). Using a longevity of 11 years, M was estimated to be 0.38 (Table 4). However, considering the small sample size and the heavy fishing on the butterfish population in the Wellington region, true longevity is probably greater than 11 years. For longevities of 13 and 15 years, M would be 0.32 and 0.28 respectively (Table 4).

Table 4: Butterfish mortality rate estimates for three longevities using Hoenig's regression method and a rule-of-thumb approximation to it

		Long	Longevity (years)	
Estimation method	11	13	15	
Hoenig's (1983) regression	0.38	0.32	0.28	
Hoenig's rule-of-thumb (p=0.01)	0.42	0.35	0.31	

Using the von Bertalanffy growth parameters from Equation (1) and a mean Wellington water temperature of about 14 °C (Greig *et al.* 1988), Pauly's method produced an M estimate of 0.43. For temperatures between 12 and 16 °C, M would be in the range 0.40–0.45.

Pauly's method therefore produced higher estimates of M than did Hoenig's method. We consider the most plausible estimate of M to lie in the range 0.30-0.45.

5.6 Yield per recruit

Most of the YPR curves rose steeply and then flattened off (Figures 12–14). There was usually no optimum fishing mortality (F_{MSY}) beyond which yields began declining, but gains in yield were low for F greater than 0.2–0.3. The reference fishing mortality, $F_{0.1}$, increased considerably with age at recruitment and M (see Table 5). The greatest YPR was attained when butterfish recruited at ages 2–3; increasing the age at recruitment beyond 3 years resulted in a substantial decline in YPR. This was true regardless of the value of M used, because the increase in weight as fish grow beyond age 3 is negated by the high natural mortality rate. Mean lengths at ages 2 and 3 years are 30 cm and 34 cm respectively (see Table 5), suggesting that yields will be maximised if butterfish recruit at 30–35 cm. Recruitment at this length could be achieved using a setnet mesh size smaller than the current legal minimum of 108 mm, as that mesh size retains few fish less than 35 cm (Dunn & Paul 2000). However, this ignores the fact that butterfish mature at about 4–5 years. Recruitment to the fishery at a lower age (2–3 years) would result in an increase in the proportion of immature fish caught. Also, after maturity a proportion of fish change from female to male, but it is not known what biological factors or environmental conditions influence this. The overall sex ratio in butterfish populations is difficult to determine because the sexes have different, though overlapping, depth ranges. If the mesh

size is reduced to maximise the theoretical YPR, it is not known what effect the removal of relatively more smaller fish will have on the sex ratio and reproductive viability of populations.

	Age at recruitment (R _{age}) (years)				_{ge}) (years)
М	2	3	4	5	6
0.30	0.278	0.339	0.396	0.447	0.490
0.37	0.355	0.436	0.510	0.574	0.624
0.45	0.456	0.560	0.650	0.720	0.785
Mean length (cm)	30	34	38	41	43

Table 5: Estimated $F_{0,1}$ for a range of values of M and age at recruitment, and mean length-at-age

6. **DISCUSSION**

Age determination of butterfish proved to be reasonably straightforward, with good agreement between scale annuli, otolith zones, and fin spine rings. A possible problem with identifying the first annual growth mark was investigated. These three structures all displayed a very small and/or indistinct first growth mark or check. Its relative position on the otolith seemed appropriate for the first true growth zone, but its position on the scale produced an apparent anomaly in back-calculated mean lengths at age (also noted by Ritchie 1969), and this first ring in anal fin spines was very poorly developed. There is no available information on the size distribution and mean lengths of 0+ and 1+ fish from which the position of the first true annual growth mark could be determined. Small butterfish are cryptic weed-dwellers and not easily sampled. In this study it has been assumed that the first small ring is some form of growth check, and it has not been incorporated in the determination of growth rate and the subsequent calculations of mortality and yield per recruit. If subsequent work on butterfish shows that they do have an unusual pattern of early growth, in particular a short first growth season leading to a mean length of only 7–8 cm in their first winter, these calculations will need to be revised.

A correction was applied to the von Bertalanffy growth curve to allow for the selectivity of setnets in sampling butterfish. The corrected and uncorrected curves differed little, suggesting that the wide range of setnet mesh sizes used by Dunn & Paul (2000) produced an unbiased sample of the population for fish aged 4 years or older. However, back-calculated lengths indicated that fish younger than 4 years were not well sampled, so our growth curve (Equation 1) should not be used to represent their growth.

The range of M estimated here (0.30-0.45) is broad, reflecting uncertainty in the longevity of butterfish, and differences resulting from the Hoenig and Pauly estimation methods. The range suggests a higher value of M than the 0.30 proposed by Paul (1997).

Yield per recruit analysis showed that yield could be increased by harvesting butterfish as young as 2-3 years. This implies that a smaller mesh size than currently used in the fishery would *theoretically* generate maximal yields. However, the effects of a reduction in mesh size on the age structure, sex ratio, and reproductive viability of the butterfish population, and on the bycatch of non-target fish species (especially blue moki and wrasses), are not quantified. Such effects may, in the longer term, negate any gains obtained from increased butterfish yields.

7. ACKNOWLEDGMENTS

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Figure 1: Sampling localities outside Wellington Harbour.



Figure 2: Butterfish scale, directly printed through a microfiche reader. Annuli, dark in transmitted light, were identified on both the anterior (top) and lateral edges. Focus-to-annulus measurements were made along the longest (anterior-posterior) axis. In the December to February samples, the outermost annulus was at or very close to the lateral scale margins, and close to the anterior margin. This scale has five annuli, plus a faint small "0" annulus which is considered to be a non-annual check ring (see text).





Figure 3: Scale, otolith, and fin spine from a 406 mm butterfish, showing five annuli, growth zones, or rings respectively, plus an inner ("0") check ring. Top, scale photographed with reflected light, the annuli showing as light structures parallel to the lateral margins, dark structures parallel to the anterior (left) margin. Lower left, otolith photographed with reflected light, showing indistinct "0" zone, and five dark (hyaline) growth zones, the outermost very close to the margin. Lower right, thin section of anal fin spine photographed in transmitted light with dark field illumination, showing concentric growth zones or rings; the dark zones are interpreted as 'hyaline', with the outermost one close to the edge, and an indistinct inner "0" ring close to the central cavity.



Figure 4: Butterfish age estimates by readers 1 and 2, initial sample of 63 fish; comparison between readers, by structure. Data points dithered for clarity, diagonal lines indicate equality of age estimates.



Figure 5: Butterfish age estimates by readers 1 and 2, initial sample of 63 fish; comparison between structures, by reader. Data points dithered for clarity, diagonal lines indicate equality of age estimates.



Figure 6: Back-calculation of growth from scale annulus dimensions. A, Fish length/scale size relationship; points marked with an open circle were considered to be abnormally small and were excluded from the linear regression, an extension of which almost passes through the origin. B, Mean lengths-at-age: (i) calculated using the annulus "0" as marking year 1, (ii) omitting annulus "0" from calculations, (iii) from table 32 in Ritchie (1969) who included annulus "0" and used fish total length rather than fork length.



Figure 7: Size distribution of "age groups" back-calculated from scale annulus dimensions. Annulus "0" provides L_{10} , annulus 1 provides L_1 , etc., the fish lengths at the time these annuli were formed. Based on scale measurements from 195 fish.



Figure 8: Comparison of otolith hyaline zone counts with scale annuli counts. Reader 1, second reading. The faint innermost otolith zone and the scale annulus "0" are not included.



Figure 9: Comparison of actual (open circles) and mean (dots) butterfish age estimates between (A) the two otolith readings of reader 1 ($R_{1,1}$ and $R_{1,2}$), and (B) the otolith readings of readers 1 and 2 ($R_{1,1}$ and R_2). Diagonal lines indicate equality of age estimates. Numbers along the top axis are sample sizes for age estimates by $R_{1,1}$. N, total sample size.



Figure 10: Precision of butterfish age estimates of reader 2 (R_2) and reader 1 ($R_{1,2}$), plotted against the ages determined for the same fish by reader 1 ($R_{1,1}$). The data points are the coefficients of variation of the data in Figures 9A and 9B.



Figure 11: Relationship between butterfish length and age based on the final age estimates agreed by both readers. Data points for males are slightly offset from the axis ticks for clarity. Von Bertalanffy curves were fitted to the data for both sexes combined, with and without a correction for setnet mesh selectivity.



Figure 12: Yield per recruit curves for butterfish, with M = 0.30. $R_{age} = age at$ recruitment.



Figure 13: Yield per recruit curves for butterfish, with M = 0.37. $R_{age} = age at recruitment$.



Figure 14: Yield per recruit curves for butterfish, with M = 0.45. $R_{age} = age at recruitment$.

Appendix: Fitting age-length data with allowance for gillnet selectivity

R.I.C.C. Francis

With a very selective sampling method (like gillnets) the distribution of lengths in a sample may be quite different from that in the population from which the sample is drawn. This means that, unless some adjustment is made for selectivity, mean length at age curves estimated from data from gillnet samples may be biased (because they describe mean length at age in the sample, and not in the population). This Appendix describes a method for correcting for that bias.

I first describe the general theory, and then a specific application of that theory for the butterfish data.

The theory underlying the correction of a length distribution for selectivity is straightforward. If f_S and f_P are the probability density functions (pdfs) for the sample and population length distributions, and S is the selectivity function of the sampling gear then

$$f_{S}(L) = \frac{f_{P}(L)S(L)}{\int f_{P}(l)S(l)dl}$$

where the integral is calculated over the domain of f_P .

This is the simple form which ignores age and assumes that there is only one sampling device (i.e., one selectivity function). With the butterfish data we have several sampling devices (mesh sizes) and wish to describe the length distribution at each age. For this purpose we generalise the above equation to

$$f_{S}(L \mid A, m) = \frac{f_{P}(L \mid A)S(L \mid m)}{\int f_{P}(l \mid A)S(l \mid m)dl}$$

where A denotes age, and m denotes mesh size, so that

 $f_S(L|A,m)$ is the sample pdf for the length distribution of fish of age A caught with a gillnet of mesh size m

 $f_P(L|A)$ is the population pdf for the length distribution at age A, and S(L|m) is the selectivity of a gillnet of mesh size m.

For the butterfish data the selectivity functions derive from a gamma distribution,

$$S(L \mid m) = \left(\frac{L}{\alpha_m \beta_m}\right)^{\alpha_m} \exp\left(\alpha_m - \frac{L}{\beta_m}\right)$$

and it was assumed that the population distribution of length at age A was gamma distributed with mean μ_A and standard deviation (s.d.) σ_A , which means that

$$f_P(L \mid A) = \frac{L^{a-1}b^a e^{-bL}}{\Gamma(a)}$$

where $a = (\mu_A / \sigma_A)^2$ and $b = \mu_A / \sigma_A^2$. The gamma distribution was used for f_P , rather than the more conventional normal, because it leads to a simple form for $f_S(L|A,m)$. It is straightforward to show that this is gamma distributed with

mean =
$$\frac{\beta(\alpha + a)}{(1 + \beta b)}$$
 and variance = $\frac{\beta^2(\alpha + a)}{(1 + \beta b)^2}$.

Mean length at age was assumed to follow the von Bertalanffy function,

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

and $\sigma_A = \sigma$ for all ages. Thus four parameters were estimated: L_{∞} , k, t_0 , and σ .

More complicated models were fitted in which μ_A followed the four-parameter function of Schnute (1981) and σ_A was a linear function of age. However, these provided no significant improvement in fit. Estimation was by maximum likelihood and significance tests were by likelihood ratio.