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EXECUTIVE SUMMARY

Dunn, A. & Paul, L.J. 2000: Estimates of butterfish (*Odax pullus*) setnet selectivity. *N.Z. Fisheries Assessment Report* 2000/2. 22 p.

This report addresses part of Objective 3 of Project INS9802: "To estimate yield-per-recruit for butterfish (*Odax pullus)* and assess the suitability of current mesh size limits used in the fishery". This report investigates the relative selectivity of mesh sizes for commercial and amateur setnets, and compares this with the suitability of the legal minimum mesh size (108 mm) for selecting butterfish of the current minimum legal size of 350 mm (35 cm). A subsequent paper will consider the choice of mesh size in relation to the optimal length of butterfish derived from maturity and growth parameters, and yield per recruit analyses.

We present the results of a gill setnet selectivity experiment on butterfish, and estimate the relative length based selectivity of the gill setnets. Experimental catch data were generated from gill setnets with a range of different sized mesh for both butterfish and their associated bycatch. We apply the method of Kirkwood & Walker to estimate the relative selectivity of different mesh sizes in gill setnets on butterfish. In addition, we develop two extensions of the Kirkwood Walker methodology: (1) we relax the strong assumption of proportionality between length at maximum selectivity and mesh size and allow a linear relationship; and (2) we assume that the distribution of the selectivity curve follows a normal, rather than a gamma, distribution. We found little difference in fit between these models, and conclude that the standard Kirkwood Walker model provides an adequate fit to the data.

Estimated Kirkwood Walker selectivity model parameters were $\theta_1 = 4.5$ (with 95% confidence intervals of 4.4–4.6) and $\theta_2 = 2544$ (2014–3098), and the estimated probability of catching a sub-legal fish (of length less than 350 mm) was estimated as less than 0.5% for the current legal minimum mesh size.

This report briefly considers issues relating to bycatch within the butterfish fishery, and shows that a wide range of species may potentially be caught as bycatch. However, we do not estimate the relative selectivity for any bycatch species, or draw any substantive conclusions on relative selectivity of these bycatch species.

1. INTRODUCTION

Butterfish (*Odax pullus*, also known as greenbone in southern New Zealand) have been caught commercially for over a century, and there are records of landings from 1935 onwards. Butterfish are present 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. Both of these species are restricted to New Zealand. There are two other species in the genus *Odax*; they are both restricted to southern Australia, known there as cale or weed whitings.

Butterfish inhabit rocky coastlines, their main habitat being moderately turbulent water with dense beds of macroalgae. 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).

The main, and most stable, fishery is centred on the shores of Cook Strait, particularly from the Wellington Harbour entrance east to Palliser Bay and west to Makara, and in parts of the outer Marlborough Sounds. A smaller fishery occurs around the southern Otago, Southland, and Stewart Island coasts. Small and sporadic landings are made as far north as Auckland. Total annual landings were 50–75 t from the mid 1930s until the late 1950s, then more variably 50–100 t until the early 1980s. From 1984 until 1995 landings have fluctuated between 100 and 200 t.

Butterfish are caught almost exclusively by gill setnets from shallow weed-covered reefs, usually in depths less than 40 m, and often much shallower. They are specifically target-fished, and there is a bycatch, varying by depth and locality, of several other shallow water reef-dwelling fishes. Butterfish are believed to be very vulnerable to capture by gill setnets. Hickford & Schiel (1996) stated "... the shape of the body allows even large individuals to enter the mesh of a gill net to about half their body length. Their sinuous swimming motion and weak pectorals do not allow them to swim backwards out of a gill net or to stop quickly." (Figure 1).

There have been few management measures until recently, apart from those applying to the commercial and recreational setnetting in general (Fisheries (Amateur Fishing) Regulations 1986, and Fisheries (Commercial Fishing) Regulations 1986). There is a setnet mesh size of 108 mm and a minimum fish size of 350 mm (for both commercial and recreational fishers), with some regional variation in netting restrictions. In the Cook Strait region (QMAs 2 and 7), since 1986, fishing permits for butterfish have been re-issued only to existing holders. In FMA (= QMA) 5, there is a competitive quota for butterfish of 30 t, though it was exceeded several times during the mid 1990s. Recreational fishers have daily bag limits, set at 30 fish in 1986 (Amateur Fishing Regulations 1986, 1986/221) and subsequently reduced to 20 (Northern, Central, Challenger regions, 1995) or 15 (Southern, 1993). Butterfish are not currently included within the Quota Management System (QMS), although recently there have been proposals for their inclusion.

Although the commercial and recreational setnet fisheries for butterfish use similar nets set in similar localities, there are distinct differences between the two fisheries. The main commercial fishery for butterfish is centred on Cook Strait, but moderate catches are made up the east coast to at least Hawkes Bay, and the on west coast up to Paremata. Fishing occurs throughout the year, but often has a winter peak. There are two main categories of commercial fishers, and for both the fishing operation is highly weather-dependent (because the main grounds are very close to exposed coastlines).

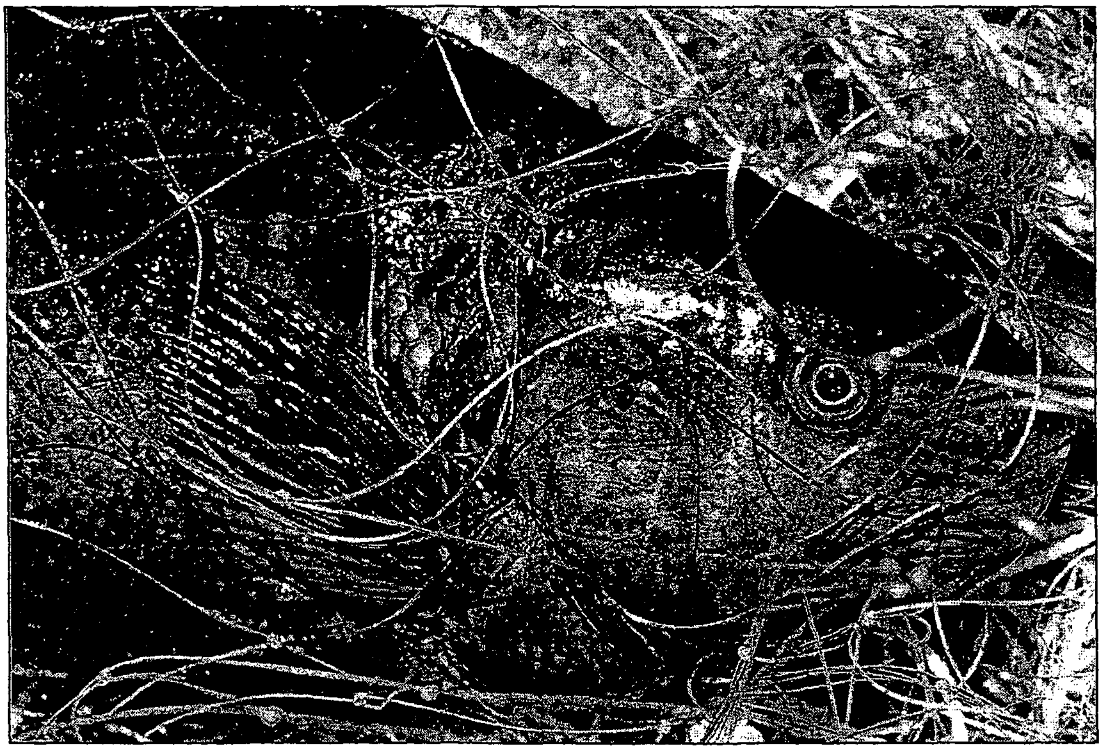

Figure 1: The typical placement of the gill setnet around the nape, preoperculum, and pectoral fins of a butterfish.

One group operates (usually) small, fast marina-based or trailer-launched boats. They choose calm days to set their nets, leave the gear in the water through at least one tide change, and, in good weather, leave the gear fishing overnight. Nets are usually 60 m long, and each boat sets between 5 and 15 nets, with each net positioned across or closely adjacent to a shallow reef. The depth range is 5–20 m, but may extend to as shallow as 2 m in sheltered areas, and out to over 30 m in a few localities where some of the largest fish occur. On some of the larger vessels which regularly setnet for butterfish (or other species) a simple net hauler may be used. On the vessels which work setnets less regularly, the nets are set and hauled by hand or are set from the main vessel and retrieved by hand from a dinghy (this is often an easier and safer method when working in swell in shallow water).

The other group of fishers, mainly working larger vessels, also target butterfish, but generally only when they have caught their quota of other species, or when market prices make butterfish a more attractive option. Target species for this group also include rock lobster (potting), groper, ling, school shark (lining), and warehou and blue moki (netting). Butterfish are a less valuable, but still useful, species for them; it is one of the few non-quota target species that can still be taken under licence.

Fishing for butterfish often occurs in potentially hazardous locations (where a change in weather and/or sea conditions may result in gear loss or damage). Therefore the nets are usually retrieved rapidly and cleared of fish some time later — perhaps on return to shore or to the larger fishing vessel when a dinghy is used. Much of the catch is already dead when the nets are initially hauled, and the most of the remainder die between hauling and clearing. The few fish that are not meshed, but are only lightly entangled in net folds, drop out as the nets are lifted from the water; their subsequent survival is not known. Consequently, there is unavoidable fishing mortality of sub-legal butterfish. Most bycatch of legal and sub-legal size is also killed; a proportion of this is retained by fishers as saleable fish, as bait for other fishing operations (e.g., potting or lining), or is discarded at sea.

The seasonality of Cook Strait butterfish catches may be related to seasonality of activity in the rock lobster fishery, as first suggested by Ritchie (1969). Because the fishery is a near-shore one, Cook Strait can be divided into eastern (southern North Island) and western (northeastern South Island) (see Paul 1997 for detail). The winter peak in butterfish landings is strongest and most regular in western Cook Strait; here the pattern is for the butterfish landings to peak at the beginning of the lobster season (April–September) before large catches of lobster landed in October. The butterfish fishery does not appear to be a true alternative fishery to lobster potting, but a supplementary one when lobster catches are low. In eastern Cook Strait the seasonality of both lobster and butterfish landings is less marked; lobster landings also peak during spring months, but butterfish landings are much more erratic, sometimes coinciding with peak lobster months and sometimes with a small peak in the low season for lobster. This seasonal pattern becomes less clear when considering the total New Zealand data from about 1988, possibly the result of a change in fishing strategy by Cook Strait fishers after introduction of the QMS. Although the seasonality of other target species is probably the major feature, there are other complicating factors. Port prices for rock lobster, in particular, change with supply and demand, and fishers may seek alternative target species (including butterfish) if lobster prices are low, even when they still hold quota. Much lobster quota is leased, and the changing margin between the leased value and port price through the lobster season dictates whether lobster or alternative species are targeted. Also, although butterfish are popular with consumers, the market is relatively small, and even in Wellington one or two moderate to large landings will saturate it for up to a week. Consequently, the seasonality of butterfish landings is not a guide to variations in the availability of this species.

Relationships between the timing of butterfish landings and the landings of other species (groper, ling, school shark) from Cook Strait (likely to be caught by the same fishers, though not in direct association) have not been investigated. Landings of butterfish in the smaller southern fishery (Dunedin to Stewart Island) are too irregular to show a seasonal pattern.

Anecdotally (and borne out during this study), butterfish are very patchily distributed. From a series of identical nets set at similar times in the same area, depth, and habitat, most of the catch will be taken in a few nets, some fish will be caught in a few others, and perhaps half or more of the nets will have no butterfish catch at all.

Recreational fishers are restricted to one 60 m net. They net the same grounds used by commercial fishers, though tend not to work as far afield, and probably work the shallower portion of the depth range. They tend also to be less concerned in directing their effort only at butterfish, and also fish for those other species that can be legally taken in their region with 108 mm mesh. Consequently, their bycatch of sub-legal and legal fish of other species is almost certain to be proportionately higher, though there is no quantitative information available. The total recreational catch of butterfish may exceed the commercial catch, but the proportions taken by setnet and by spearing, by region, are unknown.

Although there is an overall setnet mesh size of 108 mm and a minimum fish size of 350 mm in force for commercial and recreational fishers, there are some regional variations in the netting restrictions (i.e., prohibitions on netting certain localities or limitations on the size and/or operation of nets). Although setnet fisheries for other species often use nets slightly larger than the legal size to catch large fish and minimise the bycatch of sub-legal fish and unwanted small species, fishers targeting butterfish claim that moving to a mesh size larger than 108 mm would substantially reduce the number of legal-sized butterfish caught. (One group of fishers on the east coast of the North Island uses 114 mm mesh, but the reason for this is unknown.)

A mesh size of 4.25 inches (= 108 mm) has been in force for many years. In 1984 there was a review of mesh sizes and minimum fish lengths for a number of species, including butterfish. The intention of the minimum fish size was to allow each fish to breed at least once before recruitment into the fishery, and the mesh size was chosen to allow the escapement of a high but unspecified percentage of immature and "illegal" fish. The minimum size of butterfish was increased from 330 mm (originally 13 inches) to 350 mm; it was proposed to increase the mesh size to 115 mm — in line with that for blue moki (114 mm or 115 mm, depending on the area and net type) and for red moki (115 mm) on the grounds that butterfish and both moki species were either caught together or at least in fairly close association. There was opposition from within the industry to the proposed mesh size increase, and 108 mm was retained for butterfish.

Although commercial butterfish netting is a very directed and specific fishery, with nets set in shallow water within the weed-beds on and close to reefs, there is some interaction with other fish and fisheries. In the target butterfish fishery, there is a bycatch of other shallow reef fishes. Conversely, in other shallow water setnet fisheries butterfish could be taken as "bycatch". Butterfish are more likely to be taken as "bycatch" in setnets used by recreational fishers to take a range of species, including butterfish. While the minimum mesh size for moki and elephantfish (150 mm) is larger than for butterfish, most other species have a minimum mesh size of either 100 or 90 mm (with some exceptions of 114 or 125 mm in southern New Zealand). Fishing regulations state that butterfish caught in nets with a mesh less than 108 mm are to be released alive, but in practice this is unlikely to occur. However, in most other fisheries the nets are not set close enough to shallow weed-covered reefs to take more than an occasional butterfish.

Commercial and recreational setnets for the three small pelagic species (yelloweyed mullet, garfish, and pilchard) have 25 mm mesh. They would not normally be set near butterfish reefs, but accidental catches of small juvenile butterfish have been observed in such nets (NIWA, unpublished data).

In this experimental study, a series of setnets with different mesh sizes was used on suitable shallow reefs outside Wellington Harbour to determine setnet mesh selectivity for butterfish. Fish of all species captured were recorded to obtain some indication of the bycatch composition for different mesh sizes. It was anticipated that insufficient numbers of bycatch species would be taken for their respective mesh selectivities to be calculated. We report the estimates of gill setnet selectivities for butterfish from the results of this experiment using Kirkwood Walker estimates of selectivity, and report the bycatch associated with butterfish setnets.

2. METHODS

2.1 Experimental design

Fishing experiments were carried out from the NIWA research vessel *Rangatahi*, a 9.4 m outboard-powered aluminium catamaran. Nets were set from the open stern deck and retrieved using a net hauler on the port bow. It was intended to complete the fieldwork in December 1998, but problems with weather and vessel logistics extended the sampling period through until February 1999. Weather also played a large part in the selection of fishing locations. Southerly winds in Cook Strait during December and January precluded fishing in open coastal areas; harbour localities were judged to be too heavily worked by recreational fishers to be worth fishing — catches could be low and there was a greater risk of interference with unattended nets. At other times the wind tended northwesterly, so sampling was concentrated on suitable reefs between Fitzroy Bay and the western end of Palliser Bay (Figure 2), rather than along Wellington's more exposed south coast. On one day when Cook Strait's weather was worse than anticipated the nets were set at sheltered localities at the western harbour entrance, but these data are not used in this report (due to interference with the nets before retrieval).

Butterfish nets must often be set extremely close to a rocky shoreline because the swell must be low and the wind must be light and preferably offshore. On some of the fishing days during this experiment the weather and sea conditions were marginal. The original intention was to leave the nets fishing overnight, but the risk of an adverse weather change, the damage to meshed fish from predators (conger eels, crabs, etc.) in some early sets, and our finding that short sets (over one tide change) could catch as many fish as longer sets, prompted a change to setting and retrieving the nets in the same day. Consequently, there was some variation in fishing time of different sets.

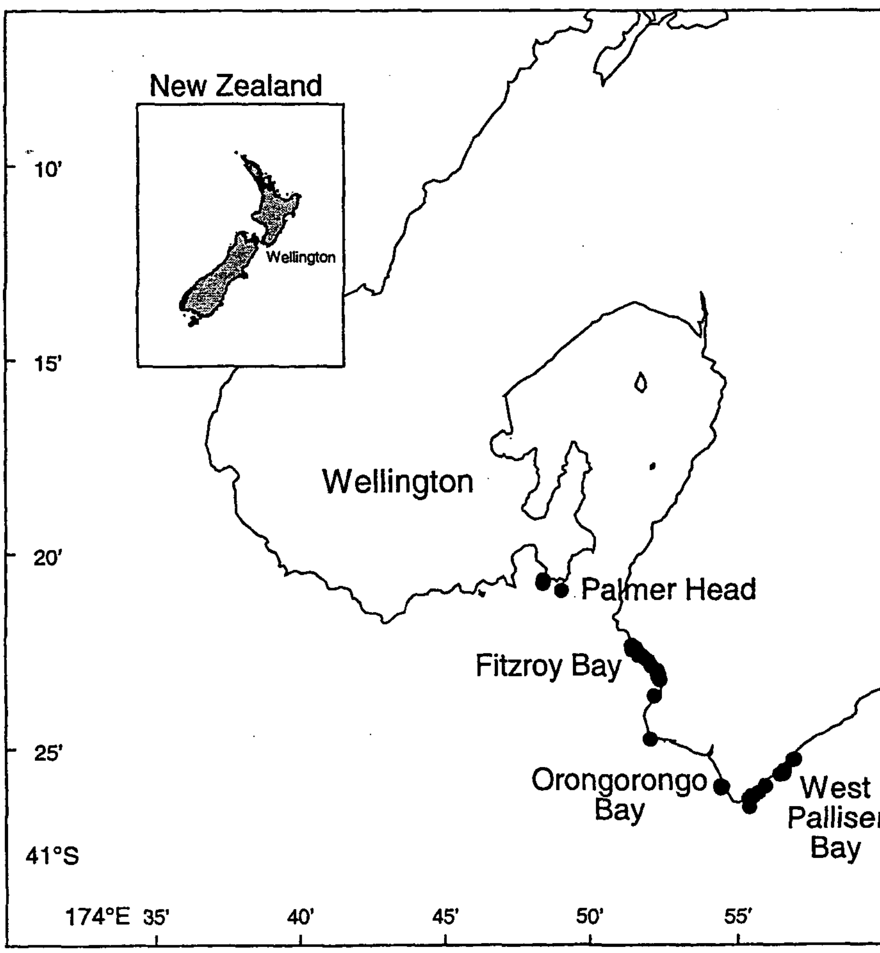

Figure 2: The south Wellington coastline and harbour showing the location of sites where nets were set.

The nets used were based on the standard butterfish nets used by both commercial and recreational fishers in Cook Strait, so that the results of this experimental fishing project were relevant to actual fishing practices. They were constructed by a commercial net-maker, some being cut from commercial nets already made up. Leadline weighting and headrope flotation were standard for butterfish nets. All nets were monofilament nylon. Filament colour, size, and breaking strain of the netting material was constrained by what was currently available, but was typical of most nets made commercially and sold in the region. It was not possible to standardise colour, but the netting (for different mesh sizes) was mid to pale green, pale blue, or white, and not dark green, red, or brown, which are some of the other colours commercially available. Sizes and breaking strains were not measured, but diminished with mesh size. The hanging coefficient was 50%, as commonly used in butterfish nets.

The essential differences between the experimental nets used and those used by commercial and recreational fishers were in length and in the use of both larger and smaller mesh sizes. Standard commercial and recreational nets are typically 60 m long.

The experimental nets were used in panels of 20 m, linked in threes to form a 60 m net. The three panels in each net were always of a different mesh size and the arrangement of panels was determined at random. In theory, each net was to be disassembled after only one set, and the panels reassembled into new nets, so that the same combination of panels was used only once. However, a finite number of panels, some losses through damage, and the need to optimise fishing activity during the relatively few days of at-sea sampling, required occasional re-setting of nets that had previously been used.

The net mesh sizes used were dictated by the sizes commercially available and ranged from a nominal 2 inches (50 mm) to 5 inches (127 mm), covering the legal mesh sizes used in setnet fisheries. Actual mesh sizes were measured by calliper, inside knot to knot, with the net under tension from a 1 kg weight; the means of 10 measurements for each mesh size are listed in Table 1. Actual, not nominal, mesh measurements have been used in all calculations.

Table 1: The mean measured, and nominal (in imperial and metric units) mesh size for each size of net

Mean measured mesh size (mm)	Nominal mesh size (mm)	Nominal mesh size (inches)
50.0	50.00	2.00
64.7	63.50	2.50
89.6	88.90	3.50
93.7	95.25	3.75
107.6	107.95	4.25
113.9	114.30	4.50
125.0	127.00	5.00

The nets were set following the standard procedure of commercial and recreational fishers. Suitable localities were chosen from prior knowledge, and the specific location of reefs confirmed by echo-sounder. The nets were set in three-panel units, buoyed at each end. To maximise fishing time, several groups of nets were set over each reef complex. The reef complexes usually had a restricted depth range, so the groups of nets were set in fairly similar depths along a few hundred metres of coastline. Time limitations, coupled with smaller catches made in a few deeper sets (at about 20 m), restricted most fishing to depths of 5–10 m where butterfish were both anticipated, and found to be, more abundant.

The nets were retrieved over a net-hauler. The net roller was about 2 m above the water, but the length of time the fish were suspended in the air, and hence more likely to drop out of the net, varied with the angle at which the net was retrieved; in wind gusts it was difficult to keep the boat directly above the net. A few butterfish fell out of the nets, and some were retrieved by dip-net (about 10 were retrieved in this manner, and a similar or slightly greater number were observed lost). No estimate of the number lost from the net before it reached the surface is available. Occasionally, a few fish were observed to be dislodged or disentangled from the net as it was lifted to the roller, sliding along but remaining within the panel in which they were originally caught. Dip-netted fish were incorporated into the catch for the associated panel.

Each net panel with its fish was packed in a separate plastic fish crate. Usually the panels were cleared of fish shortly after capture, all fish from each panel being put in a labelled plastic bag. Otherwise, the net panels plus fish were put into large plastic bags and brought ashore to be cleared.

On the early trips most of the nets were left fishing overnight. On later trips several factors led to the nets being set and lifted the same day: the weather was unsettled and there were few guaranteed two-day breaks without wind or swell; there was some damage to the catch by crabs, sea-lice, and fish (e.g., conger eels); and same-day catches in a few nets left for a few hours over a tide change proved to be as high as overnight catches.

Fish of all species were measured in the laboratory on the day they were brought ashore. Lengths were recorded as fork length, to the nearest millimetre below. In butterfish this is marginally less than total length, the caudal fin margin being only slightly concave. This measurement follows the convention of fisheries regulations and was used by Hickford & Schiel (1995, 1996), but differs from the total length used by Ritchie (1969). The fish which had been damaged in the net by predation in such a way that length measurements would be unreliable were recorded by presence only (5%). Girth measurements to the nearest millimetre were taken from a sub-sample of 64 (30%) of the butterfish, using a fine cord encircling the region of greatest girth, at the pelvic girdle. Some fish with full guts were "fatter" at a position behind this, but were judged able to squeeze this soft part of the body through a mesh.

Each intact butterfish was given an individual code-number, identifiable to net panel, and frozen for subsequent detailed processing for a study on age and growth (Paul *et al.* 2000). On subsequent thawing, each fish was remeasured and sexed; scales, otoliths, and fin spines were collected. The butterfish undamaged by predation (95% of butterfish catch) were weighed to the nearest gram.

2.2 Estimating mesh selectivity

Kirkwood & Walker (1986) outlined a method using the gamma distribution to estimate mesh selectivity by maximum likelihood (and referred to below as the Kirkwood Walker method). They modelled the selectivity, S_{ij}, by assuming that for each net i and length-class j (with length l_j), the number of fish n_{ij} caught are independent observations from a Poisson distribution with mean $\mu_j S_{ij}$,

$$\Pr\left(N_{ij}=n_{ij}\right)=\frac{\exp\left(-\mu_j S_{ij}\right)\left(\mu_j S_{ij}\right)^{n_{ij}}}{n_{ij}!} \qquad [1]$$

And hence showed that the log-likelihood can be expressed as

$$LL=\sum_{i=1}^{I}\sum_{j=1}^{J}\left[n_{ij}\ln\left(\mu_j S_{ij}\right)-\mu_j S_{ij}\right] \qquad [2]$$

Further, if we assume S_{ij} has a gamma distribution, then

$$S_{ij} = \left(l_j / \alpha_i \beta_i\right)^{\alpha_i} \exp\left(\alpha_i - l_j / \beta_i\right) \quad [3]$$

Kirkwood & Walker (1986) went on to assume that the maximum selectivity for net i was proportional to mesh size, i.e., $\alpha\beta = \theta_1 m_i$, and that the variance, $\theta_2 = (\alpha + 1)\beta^2$, was constant over all mesh sizes. This resulted in an equation for β,

$$\beta = -\tfrac{1}{2}\left(\theta_1 m_i - \sqrt{\theta_1^2 m_i^2 + 4\theta_2}\right) \quad [4]$$

The parameters θ_1 and θ_2 of Equation [2] can be found by maximising

$$\mu_j = \sum_{i=1}^{I} n_{ij} \Bigg/ \sum_{i=1}^{I} S_{ij} \quad [5]$$

We present two extensions of the formulation of Kirkwood & Walker (1986). In the first, we relax the strong assumption of proportionality between the length at maximum selectivity and mesh size, and assume a linear relationship instead (here-after called the linear Kirkwood Walker method). Second, we extend the linear Kirkwood Walker method with the assumption that the shape of the selectivity function follows a normal distribution instead of a gamma (here-after called the normal Kirkwood Walker method).

Both extensions can be fitted using a derivation of the Kirkwood Walker methodology. We add an additional parameter for the linear Kirkwood Walker method, θ_3, and set $\alpha\beta = \theta_1 m_i + \theta_3$. Then, solving for β,

$$\beta = -\tfrac{1}{2}\left(\theta_1 m_i + \theta_3 - \sqrt{(\theta_1 m_i + \theta_3)^2 + 4\theta_2}\right) \quad [6]$$

The parameters $(\theta_1, \theta_2, \theta_3)$ can be found by maximising Equation [5] as earlier.

The normal Kirkwood Walker method assumes that the selectivity is normally distributed, i.e.,

$$S_{ij} = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x_{ij} - \mu_i)^2}{2\sigma^2}} \quad [7]$$

where each net has parameters mean $\mu_i = \theta_1 m_i + \theta_3$ and constant variance $\sigma^2 = \theta_2^2$. As earlier, the parameters $(\theta_1, \theta_2, \theta_3)$ can be found by maximising Equation [5].

Mesh specific selectivity was calculated directly using the appropriate equation (Equation [3] and Equation [7]) with model fits for all three models evaluated by inspecting residual plots. Bootstrap error estimates and bootstrap 95% confidence intervals are presented for all estimated parameters and are based on 1000 bootstrap samples. All models were fitted using purpose written programs in S-Plus (MathSoft 1997).

3. RESULTS

3.1 Summary of the catch of butterfish and associated bycatch

The numbers of observed butterfish by length class, and respective mesh size are given in Table A1 in Appendix A. A total of 564 fish of 21 species were caught, including 212 butterfish. As the nets were set over shallow reefs, most species taken were typical of a reef, particularly a weedy reef, habitat (Table 2). However, some species more typical of other habitats were also caught. It is assumed that either these species strayed into the weed-reef habitat or some nets were set, at least partially, a short distance from away from the weedy reefs. As prior anecdotal information suggested, there was considerable variation in the numbers of fish caught by separate nets, regardless of mesh size, which had been set in similar areas. When net panels are considered as independent units (although fished in sets of three) the preponderance of panel-sets with small to zero catch is clearly apparent (Table 3), with 20% of panels set catching no fish.

The distribution of all species caught by mesh size is given in Table 4. Numerically, butterfish accounted for slightly more than one third of the total catch, and the most dominant bycatch species, blue moki, accounted for 21%. Other important bycatch fish were marblefish (9%), banded wrasse (7%), blue cod (6%), blue warehou (4%), and tarakihi (4%). A total fishing time of almost 1000 hours was recorded from all panels combined. While there was some difference in the total fishing time between each of the mesh sizes (*see* Table 4), we ignore this difference in the estimation of relative selectivity.

The butterfish caught ranged in length from 265 to 538 mm, with a broad mode at 350 to 470 mm — undoubtedly the result of the choice of nets and their relative selectivity, and not representative of the populations size structure (*see* Figure A1 in Appendix A). Almost all butterfish were sexed (the sex of 14 was unable to be determined, mainly due to effects of predation). The reproductive biology of butterfish is complex and not fully understood. There is strong evidence that they are sequentially hermaphroditic, with some fish changing from functional females to functional males (protogyny) during their life history (Graham 1939, Ritchie 1969, Crabb 1993), but the nature and extent of this change within a population are not understood. Ritchie (1969) described a long spawning season (July to March) for butterfish in Cook Strait, based on adult reproductive state and the presence of planktonic eggs. Female fish predominated in the present study, the sex ratio of the fish for which sex could be determined being 1 male to 1.9 females.

Immature butterfish, for which sex could not be precisely determined and were assumed to be female, reached at least 350 mm in length and possibly 400 mm. Maturity was assessed from macroscopic examination of the gonads from a sub-sample of 49 females. The fish which were assessed as Stage 1 (immature or resting) are all considered to be immature (32%) (slight enlargement of some ovaries but no visible eggs) and being unlikely to spawn. There was one Stage 2 female (some hyaline eggs present), and the remainder (65%) were Stage 3 or 4 (many hyaline eggs present, ripening to ripe). No running ripe fish, or spent fish, were taken; it is possible that the former may be in deeper water — where larger males are thought to be.

Male fish had a larger median size than females, 440 mm compared with 390 mm. The smallest male was 360 mm, but the largest males were similar in size to the largest females. The length frequencies of male and female butterfish are shown as Figure A2, where the lack of smaller males is apparent.

The growth rate of males and females at this size is essentially similar (Paul *et al.* 2000), though this comparison is compromised by the probability that an unknown proportion of the larger females become males. Clearly, though, not all large females become male.

The distribution of the lengths of the butterfish catch for each mesh size is shown in Figure 3. A clear pattern of increased mean length for increased mesh size was observed, suggesting that mesh size plays an important part in the length based selectivity of butterfish. In contrast, Figure 4 shows similar distributions for blue moki; although there is still some indication of length based selectivity by mesh size for blue moki, the data suggest that this is less obvious. Relative selectivities for all bycatch species have not been calculated because data are sparse.

Table 2: Species and numbers caught during the experimental netting, grouped according to the habitat they normally occur in, and ranked by numbers caught

Weedy reef		Rocky reef		Sandy seafloor		Pelagic/Semi-pelagic	
Butterfish	212	Blue moki	116	Red gurnard	3	Blue warehou	21
Marblefish	49	Blue cod	35	Spotted stargazer	2	Kahawai	16
Banded wrasse	37	Tarakihi	20			Jack mackerel	13
		Spotty	9			Rig	8
		Scarlet wrasse	9			Spiny dogfish	1
		Bastard red cod	5			School shark	1
		Telescopefish	2				
		Redbanded perch	2				
		Red moki	2				
		Rock cod	1				
Total	298		201		5		60

Table 3: Numbers of the top six species taken per net panel. There were 120 panel-sets, of which 23 caught no fish

Number of fish per panel	Number of panels					
	Butterfish	Blue moki	Marblefish	Banded wrasse	Blue cod	Blue warehou
0	64	67	88	104	110	108
1	23	28	20	9	5	7
2	10	10	8	5	0	4
3	8	8	4	0	3	0
4	2	1	0	1	0	0
5	1	1	0	0	0	0
6	2	3	0	0	0	1
7	2	0	0	0	0	0
8	1	1	0	0	0	0
9	0	1	0	0	1	0
10+	7	0	0	1	1	0
Total panels	120	120	120	120	120	120

3.2 Estimates of butterfish setnet selectivity

Of the 212 butterfish caught, 6 of these were excluded in estimating mesh selectivity because damage from predators during overnight sets prevented accurate measurement of length. The 50 mm mesh size net caught only two butterfish, and although the results for this mesh size are reported here, these two fish were excluded from the calculations of mesh net selectivity for butterfish. Hence, the total number of butterfish caught and used in estimating setnet selectivities was 204. Sub-legal fish (i.e., with length under 350 mm) accounted for 13% of all butterfish caught, but none were caught in nets with mesh sizes above 89.6 mm (*see* Table A1 in Appendix A). Selectivity parameters (and 95% bootstrap confidence intervals) were estimated for each of the three models (Kirkwood Walker, linear Kirkwood Walker, and normal Kirkwood Walker) for butterfish using the previously described methodology. These parameter estimates are given in Table 5.

Estimated selectivities by length class for each of the Kirkwood Walker, linear Kirkwood Walker, and normal Kirkwood Walker models are given in Tables A2, A3, and A4 in Appendix A. The estimated relative selectivities for the Kirkwood Walker method for each of the seven mesh sizes are plotted in Figure 5.

Little difference in fit between each of the three models was observed (diagnostics not shown). Model fits suggested that the extension of the standard Kirkwood Walker model to a linear Kirkwood Walker did not improve the fit significantly (and shown in that the range of the estimated confidence interval of associated parameter θ_3 bounds zero). Similarly, no improvement of fit (and possibly a reduction) was observed by constraining the selectivity function to a normal distribution, rather than a gamma distribution.

The adequacy of the standard Kirkwood Walker method in determining selectivity is perhaps explained by the characteristics of the butterfish and gill setnets. As butterfish are a smooth, slippery fish, with no spiny or other protrusions, they are almost always gilled or wedged into the mesh of each net. Hickford & Schiel (1996) found in a study of gillnetting in southern New Zealand that, for butterfish, less than 10% were found to have been caught by "tangling" in the net. The remainder were either "wedged" (20%) or "gilled" (71%). Our net-handling procedures did not allow this us to make this distinction.

The relationship between length, mesh size, and relative selectivity is shown in Figure 5, and the estimated expected proportion of the catch from a net of given mesh size that is less than 350 mm is shown in Table 6. These estimates assume that each net has equal fishing power, and that the fish of all length classes are equally available and vulnerable. While this is unlikely to be true in practice, the estimates allow some comparison of the relative proportions of sub-legal fish likely to be caught by each of the mesh sizes. The difference in estimates between methods was slight, with the standard Kirkwood Walker method giving slightly more conservative point estimates, but tighter confidence intervals. With the current legal minimum mesh size (108 mm), the estimated proportion of sub-legal fish likely to be caught is less than 0.5%. This estimate rises to almost 10% for the 93.7 mm mesh size, and 20% for the 89.6 mm mesh size. With larger mesh sizes (108 mm and above) sub-legal fish are likely to be less than 0.1% of the total catch.

Table 4: Numbers of fish caught by species, percentage of the catch that was bycatch, and total fishing time (hours) for each net mesh size

Species	Mesh size (mm)							Total
	50.0	64.7	89.6	93.7	107.6	113.9	125.0	
Banded wrasse	3	24	1	1	3	4	1	37
Bastard red cod	0	0	1	1	1	1	1	5
Blue cod	0	13	11	6	3	1	1	35
Blue moki	1	18	22	16	22	27	10	116
Blue warehou	1	1	1	5	8	5	0	21
Butterfish	2	34	47	71	35	17	6	212
Jack mackerel	4	8	0	0	1	0	0	13
Kahawai	0	1	6	4	3	2	0	16
Marblefish	0	7	7	5	10	13	7	49
Red gurnard	0	0	0	1	1	0	1	3
Red moki	0	0	0	2	0	0	0	2
Redbanded perch	0	2	0	0	0	0	0	2
Rig	0	0	0	0	2	3	3	8
Rock cod	1	0	0	0	0	0	0	1
Scarlet wrasse	0	8	1	0	0	0	0	9
School shark	0	0	0	0	0	1	0	1
Spiny dogfish	0	0	0	0	1	0	0	1
Spotted stargazer	0	0	0	0	1	0	1	2
Spotty	3	4	0	1	1	0	0	9
Tarakihi	0	1	6	5	4	1	3	20
Telescopefish	0	2	0	0	0	0	0	2
Total	15	123	103	118	96	75	34	564
Bycatch (%)	87	72	54	40	64	77	82	62
Fishing time (hours)	25.2	106.5	122.3	163.2	150.5	203.9	161.6	933.3

3.3 Estimates of setnet bycatch selectivity

The sample sizes for most of the bycatch species were too small to allow calculation of setnet selectivities for bycatch species (for all except blue moki; less than 50 of any species were caught). Some fish, for example banded wrasse, appeared more likely to be caught in smaller meshed nets, while others (e.g., marblefish) appeared more commonly in the larger nets. There are insufficient data to draw any general conclusions from the observed catch on the relative bycatch by mesh size. In addition, it is likely that the number and type of bycatch is indicative of the individual patch fished, for example, the close proximity of other habitats in that location.

Blue moki setnet selectivities may be calculated. However, blue moki tend not to be gilled or wedged into mesh nets; in Hickford & Schiel's (1996) gillnetting study, 55% of blue moki were found to have been caught by "tangling" in the net; only 11% were "wedged" and 33% "gilled". The physical characteristics (for example, the numerous protrusions and spines) of the blue moki make it unlikely that an accurate model fit would be achieved. In addition, the number of samples available in this analysis would make any inference drawn from such fits unreliable.

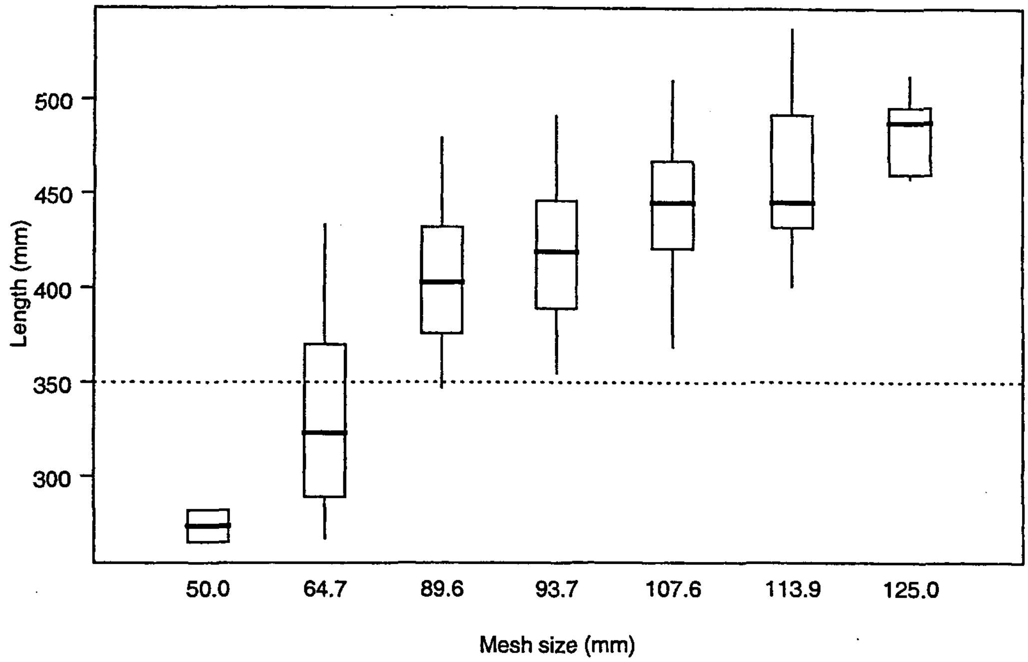

Figure 3: Distribution of the length of butterfish against the net mesh size. Medians are shown as a heavy horizontal line, with approximate inter-quartile range contained by the boxed region. Vertical lines indicate the range. The dotted horizontal line marks the current legal minimum size for butterfish.

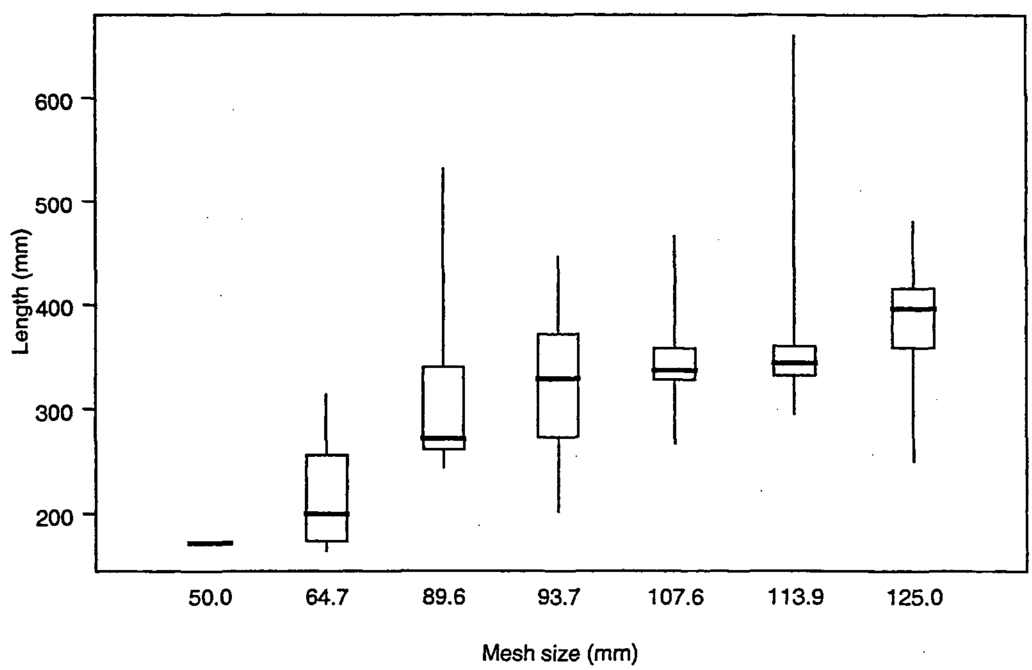

Figure 4: Distribution of the length of blue moki against the net mesh size. Medians are shown as a heavy horizontal line, with approximate inter-quartile range contained by the boxed region. Vertical lines indicate the range.

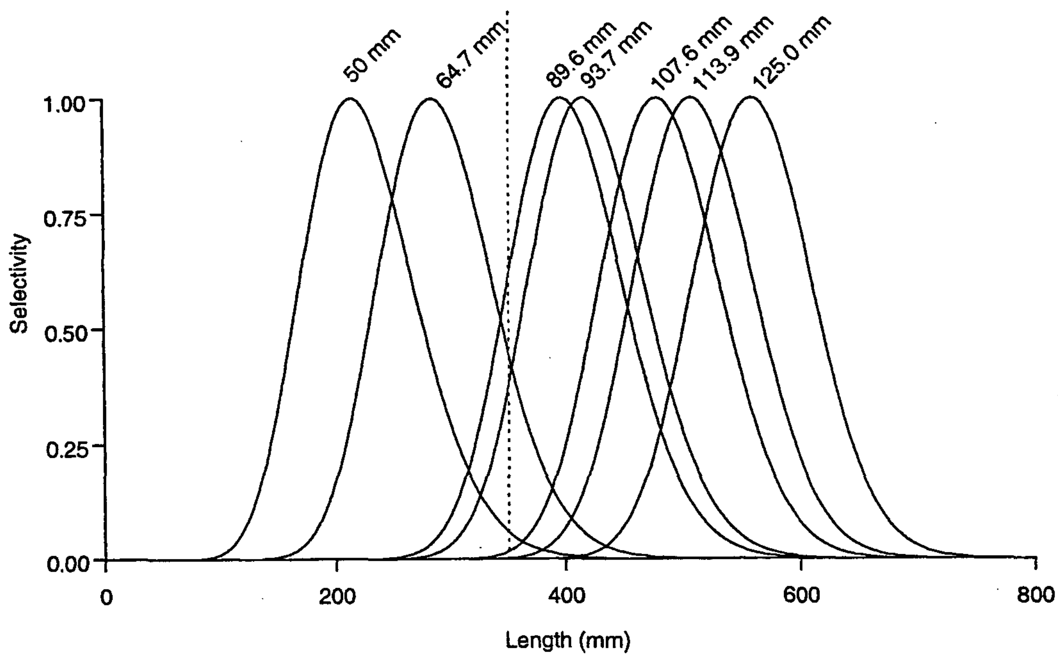

Figure 5: The estimated relative (Kirkwood Walker) butterfish selectivities by length for each mesh size, with the current minimum legal size of butterfish shown as a dotted line.

Table 5: Estimated selectivity parameter values (and 95% confidence intervals) for butterfish by method

Method	θ_1		θ_2		θ_3	
Kirkwood Walker	4.5	(4.4–4.6)	2544	(2014–3098)		
Linear Kirkwood Walker	4.1	(3.6–4.8)	2222	(1690–2896)	33.8	(-26.1–87.3)
Normal Kirkwood Walker	4.1	(3.6–4.7)	46.1	(40.7–51.8)	42.7	(-10.1–92.2)

Table 6: Estimated proportion of butterfish with length < 350 mm selected by mesh size (mm) and method (and 95% confidence intervals), assuming equal numbers of fish in each length class and equal fishing power. Mesh sizes marked * are predicted proportions based on the estimated parameters

Mesh size	Kirkwood Walker		Linear Kirkwood Walker		Normal Kirkwood Walker	
50.0 *	0.99	(0.98–0.99)	0.98	(0.96–0.99)	0.99	(0.96–1.00)
64.7	0.88	(0.84–0.91)	0.85	(0.76–0.91)	0.82	(0.72–0.90)
65.0 *	0.87	(0.84–0.91)	0.84	(0.75–0.91)	0.81	(0.72–0.89)
89.6	0.14	(0.11–0.18)	0.12	(0.08–0.17)	0.10	(0.07–0.14)
90.0 *	0.13	(0.10–0.17)	0.11	(0.07–0.16)	0.09	(0.06–0.13)
93.7	0.07	(0.05–0.10)	0.06	(0.03–0.08)	0.05	(0.03–0.07)
100.0 *	0.02	(0.01–0.03)	0.01	(0.01–0.02)	0.01	(0.01–0.02)
107.6	0.002	(0.001–0.004)	0.001	(0.000–0.003)	0.002	(0.001–0.004)
108.0 *	0.001	(0.001–0.004)	0.001	(0.000–0.003)	0.002	(0.001–0.004)
113.9	< 0.001	(0.000–0.001)	< 0.001	(0.000–0.001)	< 0.001	(0.000–0.001)
115.0 *	< 0.001	(0.000–0.001)	< 0.001	(0.000–0.001)	< 0.001	(0.000–0.001)
125.0	< 0.001	(0.000–0.001)	< 0.001	(0.000–0.001)	< 0.001	(0.000–0.001)

4. CONCLUSIONS

Female butterfish mature between 350 and 400 mm. The present legal size of 350 mm does reasonably define adults, but some fish over 350 mm will be immature females. All males in this study were larger than 350 mm. The sex ratio of fish caught (about 1 male to 2 females) is not necessarily the sex ratio in the population as only the shallower part of the known depth range of the species was sampled. However, it is similar to sex ratios previously reported. Graham (1956) found that in Otago Harbour, "... the female predominated and as many as three females to one male would be caught in setnets." Ritchie (1969) described a sex ratio of 1 male to 2.2 females in a sample of 314 Wellington area fish, but did not state the depth range for this sample.

Model fits of relative selectivity from the standard Kirkwood Walker method appear to be adequate, and a strong relationship between mesh size and selectivity was found. Extensions to the model of the linear and normal methods do not result in substantial improvements in fit. Estimates of selectivity and escapement from all models are similar, with the Kirkwood Walker being slightly more conservative. The number of samples of sub-legal butterfish are low, particularly in larger mesh sized nets and hence, the projections of estimated selectivity outside the range provided by the data should be interpreted with some caution. However, we can still conclude that these estimates of selectivity for butterfish suggest that the current legal minimum sized mesh (108 mm) will catch, proportionally, very few sub-legal fish. The strong relationship between length and mesh selectivity suggests that larger mesh sizes are likely to catch far fewer sub-legal butterfish.

Bycatch from this study appears high, accounting for almost two-thirds of total fish caught. Blue moki made up a large proportion of the bycatch, though the legal minimum mesh size for this fish is currently set at 115 mm. However, the bycatch in the commercial and recreational butterfish fisheries is likely to be very different from that found in this study. Fishing in different regions and at different periods throughout the year will probably also result in a very different bycatch.

The unavoidable fishing mortality of all caught butterfish requires that a mesh size be chosen that minimises (or avoids) the capture of immature fish, if that is the intended purpose of the mesh size regulation. In this study we estimated very low rates (less than 0.5%) of capture of butterfish of sub-legal length (i.e., with length under 350 mm, and assumed to be the size at maturity) in nets with the current legal mesh size of 108 mm. However, this rises to 10% for a 94 mm mesh, and almost 20% for a 90 mm mesh.

The effect of increased mesh size (i.e., greater than 108 mm) on the resulting catch is difficult to determine as the size structure of the population available to the fishery is unknown. With increased mesh size, a greater proportion of smaller legal fish (300–400 mm) would escape meshing, and a greater proportion of larger fish (400–500 mm) — previously too large to mesh — would be caught. However, without knowledge of the underlying population size structure, the relative change in catch is difficult to determine.

The data and experimental method for this study are not appropriate to assess the non-capture of larger, adult fish. Paul *et. al.* (2000) considered the effect of the choice of mesh size in a discussion of the optimal length of butterfish derived from maturity and growth parameters, and yield per recruit analyses.

5. ACKNOWLEDGMENTS

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APPENDIX A: SUMMARY TABLES AND FIGURES

Table A1: Observed numbers of butterfish by length and net mesh size

Length class (mm)	Mesh size (mm)							Total
	50.0	64.7	89.6	93.7	107.6	113.9	125.0	
260–279	1	3	0	0	0	0	0	4
280–299	1	9	0	0	0	0	0	10
300–319	0	4	0	0	0	0	0	4
320–339	0	6	0	0	0	0	0	6
340–359	0	1	6	2	0	0	0	9
360–379	0	6	7	9	1	0	0	23
380–399	0	4	8	12	1	0	0	25
400–419	0	0	8	13	5	2	0	28
420–439	0	1	7	13	8	4	0	33
440–459	0	0	7	12	6	4	1	30
460–479	0	0	3	8	6	1	1	19
480–499	0	0	0	1	4	1	3	9
500–519	0	0	0	0	2	2	1	5
520–539	0	0	0	0	0	1	0	1
Total	2	34	46	70	33	14	6	206
Total < 350 mm	2	22	2	0	0	0	0	26

Table A2: Estimated relative (Kirkwood Walker) selectivities by length and mesh size

Length class (mm)	Mesh size (mm)						
	50.0	64.7	89.6	93.7	107.6	113.9	125.0
260–279	0.69	0.91	0.01	0.00	0.00	0.00	0.00
280–299	0.48	1.00	0.04	0.01	0.00	0.00	0.00
300–319	0.30	0.93	0.13	0.05	0.00	0.00	0.00
320–339	0.17	0.75	0.30	0.14	0.00	0.00	0.00
340–359	0.09	0.54	0.54	0.32	0.01	0.00	0.00
360–379	0.05	0.34	0.79	0.56	0.05	0.01	0.00
380–399	0.02	0.20	0.96	0.81	0.13	0.03	0.00
400–419	0.01	0.10	0.99	0.97	0.30	0.09	0.00
420–439	0.00	0.05	0.87	0.99	0.54	0.22	0.02
440–459	0.00	0.02	0.66	0.86	0.79	0.43	0.06
460–479	0.00	0.01	0.45	0.65	0.96	0.69	0.15
480–499	0.00	0.00	0.27	0.43	0.99	0.90	0.32
500–519	0.00	0.00	0.14	0.25	0.88	1.00	0.56
520–539	0.00	0.00	0.07	0.13	0.67	0.94	0.81
540–559	0.00	0.00	0.03	0.06	0.45	0.76	0.97

Table A3: Estimated relative (Linear Kirkwood Walker) selectivities by length and mesh size

Length class (mm)	Mesh size (mm)						
	50.0	64.7	89.6	93.7	107.6	113.9	125.0
260–279	0.83	0.78	0.00	0.00	0.00	0.00	0.00
280–299	0.61	0.97	0.02	0.01	0.00	0.00	0.00
300–319	0.39	0.98	0.09	0.03	0.00	0.00	0.00
320–339	0.22	0.84	0.23	0.11	0.00	0.00	0.00
340–359	0.12	0.61	0.47	0.27	0.01	0.00	0.00
360–379	0.06	0.39	0.75	0.52	0.04	0.01	0.00
380–399	0.02	0.22	0.95	0.79	0.13	0.03	0.00
400–419	0.01	0.11	0.99	0.97	0.30	0.09	0.00
420–439	0.00	0.05	0.87	0.98	0.56	0.24	0.02
440–459	0.00	0.02	0.65	0.84	0.82	0.47	0.07
460–479	0.00	0.01	0.42	0.61	0.98	0.75	0.19
480–499	0.00	0.00	0.23	0.38	0.97	0.95	0.40
500–519	0.00	0.00	0.12	0.21	0.81	0.99	0.67
520–539	0.00	0.00	0.05	0.10	0.58	0.87	0.90
540–559	0.00	0.00	0.02	0.04	0.35	0.65	1.00

Table A4: Estimated relative (Normal Kirkwood Walker) selectivities by length and mesh size

Length class (mm)	Mesh size (mm)						
	50.0	64.7	89.6	93.7	107.6	113.9	125.0
260–279	0.89	0.72	0.01	0.00	0.00	0.00	0.00
280–299	0.65	0.93	0.03	0.01	0.00	0.00	0.00
300–319	0.40	1.00	0.10	0.04	0.00	0.00	0.00
320–339	0.20	0.89	0.23	0.11	0.00	0.00	0.00
340–359	0.08	0.65	0.44	0.26	0.02	0.00	0.00
360–379	0.03	0.40	0.69	0.48	0.05	0.01	0.00
380–399	0.01	0.20	0.92	0.74	0.13	0.04	0.00
400–419	0.00	0.08	1.00	0.94	0.29	0.10	0.01
420–439	0.00	0.03	0.91	1.00	0.52	0.23	0.03
440–459	0.00	0.01	0.68	0.87	0.78	0.44	0.08
460–479	0.00	0.00	0.42	0.64	0.96	0.70	0.19
480–499	0.00	0.00	0.22	0.38	0.99	0.92	0.38
500–519	0.00	0.00	0.09	0.19	0.84	1.00	0.63
520–539	0.00	0.00	0.03	0.08	0.59	0.90	0.87
540–559	0.00	0.00	0.01	0.03	0.35	0.67	1.00

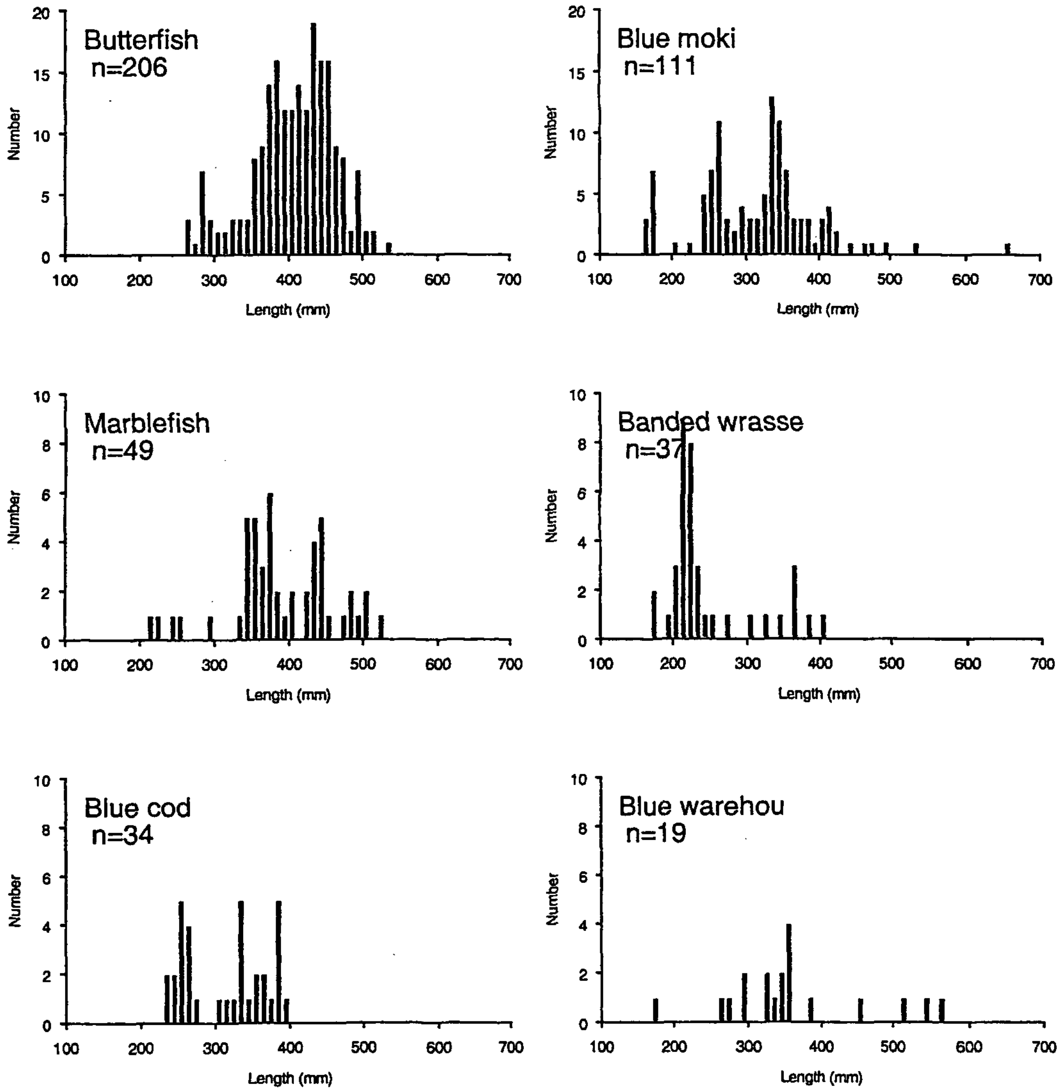

Figure A1: Size frequencies of measured fish for the six most commonly caught species.

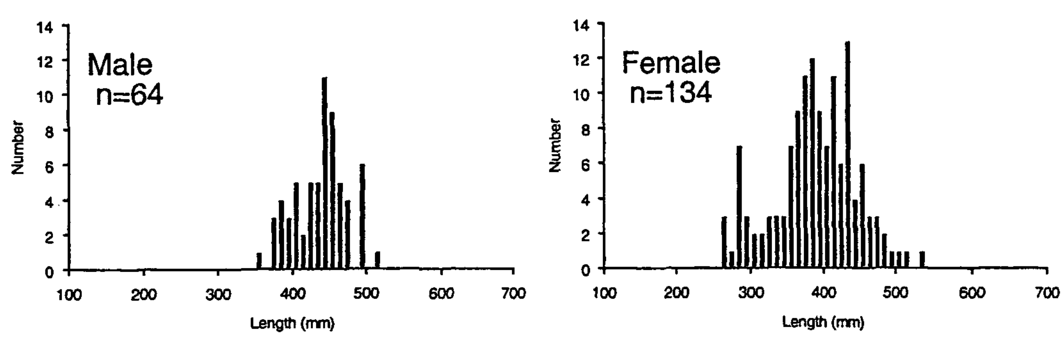

Figure A2: Size frequencies of male and female butterfish.