EFFECTS OF GILL-NETTING ON REEF FISH POPULATIONS IN CENTRAL NEW ZEALAND

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The water that surrounds us has shaped us.
The sea that isolates us, defines us.
We are Islanders, at home in an ocean.

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ABSTRACT

This study examines the effects of gill-netting on reef fish populations. These populations are still relatively undescribed in New Zealand, particularly in the South Island. Without knowledge of the structure of these populations little can be concluded about the likely effects of gill-netting.

The rocky reef environment in the Kaikoura region was found to be neither topographically nor biologically homogeneous. Five basic habitat types were defined using biological and physical features. The unique marine environment in the Kaikoura region required that a sampling design specific to the area be developed to assess reef fish populations within these habitats. Labrid fishes and butterfish (*Odax pullus*) were found almost exclusively in algal-dominated habitats, while latrids and cheioldactylids were more common in areas where large algae was sparse. The fish assemblages present in each of the five habitats were therefore highly correlated with habitat type.

Reef fish populations were surveyed using standard underwater visual censuses before gill-nets were set. Three mesh sizes were used: 2.5", 3.5" and 4.5". There was little correlation between the species composition of the gill-net catch and the reef fish assemblage observed at that site. Transient pelagic species (kahawai and jack mackerel) and cryptic resident reef fish (marblefish and butterfish) made up the largest proportion of the gill-net catch. Labrid species were observed in high numbers during the visual survey, but made up only a small proportion of the gill-net catch. Labrid species were susceptible to being caught in the 2.5" mesh, but not by larger mesh sizes.

Morphological differences and species-specific behaviour significantly affect the number of a species caught in a gill-net. The primary factor that determines how a fish is caught in a gill-net is the shape of the fish's body. Fusiform fish (e.g., labrids) are usually gilled or wedged in the nets, whereas laterally compressed fish (e.g.,latrids and cheilodactylids) are more commonly tangled. Tangling in gill-nets is not as size-selective as gilling or wedging. The catch of gill-nets does not increase linearly with time. The nets appear to become saturated after c.10 hours. The degree of damage to fish caught in gill-nets increases with the duration of the set.

The behaviour of reef fish near gill-nets can significantly alter their susceptibility to being caught. Some species, such as spotties (*Notolabrus celidotus*), make contact with the mesh of gill-nets less frequently than others. Consequently these species are less susceptible to becoming caught. Vulnerability to becoming caught in a gill-net appears to be dependent on swimming motion, behavioural differences and visual acuity.

The conclusions of this study are that there is little relationship between the composition of the fish population observed on reefs and the composition of the catch of gill-nets subsequently set among these populations. Some species of fish are more susceptible to gill-nets because of their behaviour or morphology.

CHAPTER ONE

General Introduction

1.1 INTRODUCTION

> **Gill-net**: a net (usually rectangular) with the size of mesh such, that when fish strike the net they become caught (Garner, 1962).

Gill-nets are one of the simplest fishing methods commonly used by commercial and amateur fishers, yet the way they catch fish is poorly understood. The interactions involved in the capture of fish, avoidance behaviour, increased vulnerability of some species and the effects on fish populations have received little attention. Although mesh selectivity has undergone considerable investigation from a fisheries stance, little progress has been made from an ecological point of view. The long term effects of intense fishing pressure with gill-nets have received little attention in the literature, especially in relatively young fisheries such as New Zealand's.

In New Zealand, gill-nets are disliked by conservationists, treasured by recreational fishers and largely ignored by marine biologists. Only recently have the effects of gill-netting been examined, but these investigations have focused primarily on the interaction between gill-nets and marine mammals. The effects of gill-netting on reef fish populations have not been investigated in New Zealand, and have received little attention in the international literature. Although the concept of gill-netting is a simple one, much is unknown about this commonly used and highly effective form of fishing.

1.2 DESCRIPTION OF A GILL-NET

1.2.1 Gill-net construction

A gill-net is a vertical wall of netting that traps fish within its meshes. Gill-nets can either be anchored to the substrate (set-nets) or free-floating (drift-nets). Throughout this study I will be dealing only with the anchored form of gill-net. The general characteristics of a bottom set gill-net (hereafter referred to as a gill-net) are shown in Figure 1.1. The weighted bottom rope ensures the gill-net sits firmly on the substrate, and the float line keeps the net upright and rigid in most conditions (Stewart & Ferro, 1985; Stewart, 1988). Two anchor blocks keep the net stationary and, if placed correctly, maintain the horizontal tautness of the lead-line and float-line. The buoy ropes enable the net to be lifted from the surface, and the attached buoys aid in identification.

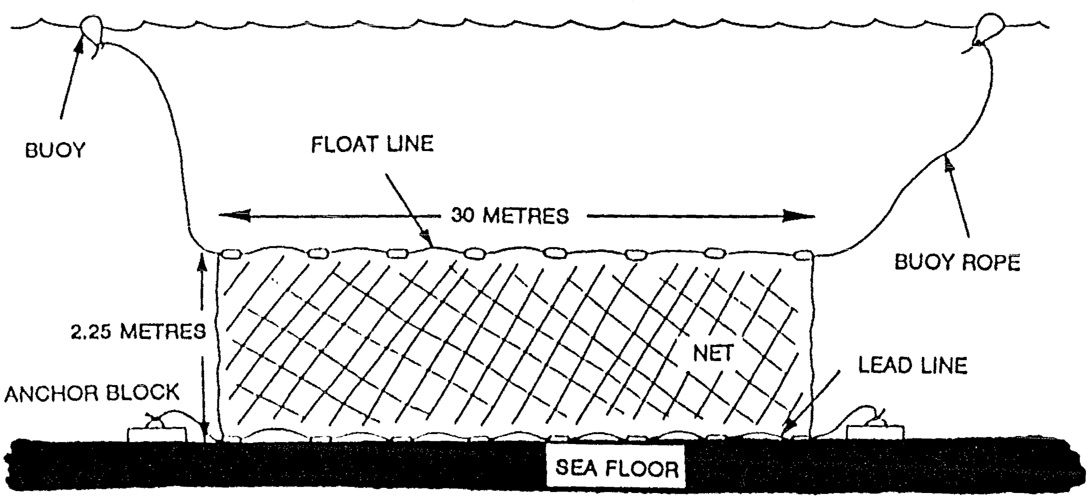


Figure 1.1 The component parts of a fixed bottom gill-net. The dimensions of the nets used during this study are shown.

Gill-nets are slung by percentage. That is, the bale of unslung mesh is reduced by a certain percentage to give the slung net a desired amount of looseness (e.g., if a net is slung by 50%, a bale of netting 100 metres long would make a net 50 metres long). This in-built looseness is useful for snaring fish fins and spines and in allowing the fish to wrap itself up in the mesh as it struggles (Rosman, 1980). The nets used during this study were slung by 50%, which is the most commonly used percentage.

1.2.2 Mesh size

The principal factor relevant to any net is the size of the mesh from which it is constructed (Garner, 1962). Besides determining the way in which the netting can be rigged to the lead line and float line, it also governs, to some extent, the size of fish that can be caught by the net. The mesh size of a gill-net is defined by the Fisheries Regulations 1986 as "the length between the inner edges of the knots of opposite corners of the mesh when closed or, where the mesh has no knots, the length between the inner edges of opposite corners of the mesh with the mesh closed" (Figure 1.2). The mesh size used in a net is dependent on the species of fish being targeted.

The two forms of nylon filament currently used in both commercial and non-commercial gill-nets are multifilament (several woven strands) and monofilament. Multifilament netting is generally recognised as being less selective in terms of the size of fish caught because of the greater number of fish tangled in it by fins and appendages.

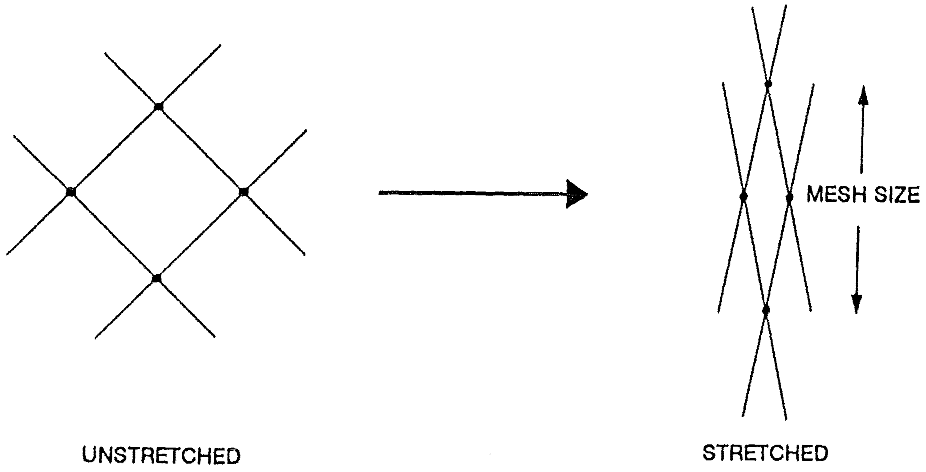


Figure 1.2 Mesh size measurement: stretching the mesh until the mesh cell closes, the distance between the two furthermost knots is then the mesh size. The mesh perimeter is the total length of the four sides of a cell.

1.3 LEGISLATION GOVERNING THE USE OF GILL-NETS

1.3.1 Commercial fishing

The principal legislation governing the use of gill-nets by commercial fishers is the Fisheries (Commercial Fishing) Regulations 1986. This defines a net as "any net or part of a net used or capable of being used to take fish" and a set-net as "a gill-net, drift net, trammel net or any other sort of net which acts by enmeshing, entrapping, or entangling any fish". The minimum net mesh size that may be used or possessed by any commercial fisher and the minimum finfish species fork length that may be taken or possessed are outlined in these regulations (Table 1.1). The length of a commercial set-net is restricted to 1000 metres when used inside the seaward entrance to any harbour, or in any river, stream, lake, lagoon or estuary.

Table 1.1 The restrictions on non-commercial fishers for taking, possession and conveying of various finfish species, as outlined in the Fisheries (Commercial Fishing) Regulations 1986.

SPECIES OF FISH	MINIMUM NET MESH SIZE mm	MINIMUM FISH FORK LENGTH mm	MAXIMUM AMATEUR DAILY LIMIT PER PERSON
Blue cod, *Parapercis colias*	-	300	30*
Blue moki, *Latridopsis ciliaris*	115	400	30
Butterfish, *Odax pullus*	108	350	30
Eels, *Anguilla australis, A. dieffenbachii*	12	-	no limit
Elephant fish, *Callorhynchus milii*	150	-	30
Flatfish (except sand flounder)	100	250	30
Garfish (piper), *Hyporhamphus ihi*	25	-	no limit
Herrings, *Aldrichetta forsteri*	25	-	no limit
Kahawai, *Arripis trutta*	85	-	30
Mullet, *Mugil cephalus*, *Upeneichthys lineatus*	85	-	no limit
Pilchard, *Sardinops neopilchardus*	25	-	no limit
Red cod, *Pseudophycis bachus*	100	250	no limit
Red moki, *Cheilodactylus spectabilis*	115	400	30
Rig, *Mustelus lenticulatus*	150	-	30
Sand flounder, *Rhombosolea plebeia*	100	230	30
Snapper, *Chrysophrys auratus*	100	250	30
Tarakihi, *Nemadactylus macropterus*	100	250	30
Trevally, *Pseudocaranx dentex*	100	250	30
All others	100	-	no limit

* except in the Marlborough Sounds, Golden Bay and Tasman Bay where 12 is the daily limit

Commercial set-nets must not be set in an area where fish are likely to be stranded by the falling tide, or within 60 metres of any other net.

A set-net is defined in New Zealand legislation as any sort of gill or trammel net, except those that are defined as drift-nets, which acts by enmeshing, entrapping or entangling fish. This definition differs from that used in the international literature, where the term gill-net is used for any net that acts by enmeshing, entrapping or entangling, and includes all drift-nets. The term gill-net will be used exclusively throughout this thesis to describe nets that are set on the seabed, and act by entangling fish.

1.3.2 Amateur fishing

The principal legislation governing the use of gill-nets by amateur fishers is the Fisheries (Amateur Fishing) Regulations 1986. The definition of a set-net in this statute is identical with that in the regulations relating to commercial fishing. The minimum net mesh size that may be used by amateur fishers and the minimum fork lengths of each species that may be taken are identical with those applied to commercial fishers. However, the maximum number of finfish that may be taken or possessed by any one person on any day is limited (Table 1.1).

Amateur gill-nets cannot exceed 60 metres in length, and must not be set within 60 metres of any other net. Amateur gill-nets must not be set or used in a way that causes fish to be stranded by the falling tide, and all amateur nets must be hauled by hand. The regulations also require that any person engaged in amateur fishing shall, taking all reasonable care to ensure their survival, immediately return any finfish that is unlawfully taken or is of an unlawful state or size back into the waters from which it was taken.

1.4 CURRENT USAGE OF GILL-NETS

1.4.1 Commercial gill-netting in New Zealand

Gill-nets are used in New Zealand by both commercial and non-commercial fishers. During the early 1980s, the number of people engaged in the commercial gill-net fishery and the geographic range of this fishery expanded greatly. In 1984 the fishery was restricted to full-time fishers only, and in 1986 the Quota Management System (QMS) was introduced. These two events caused a large reduction in the number of commercial gill-net fishers, and consequently the gill-net catch decreased by 60% between 1984-85 and 1987-88 (Taylor, 1992). In addition, there was a 43% decrease in the number of gill-net permit holders between the 1987-88 and 1990-91 fishing years.

Although most permit holders (56%) are based in the North Island, most of the domestic catch from gill-netting is caught around the coast of the South Island (Table 1.2). The fisheries around Kaikoura (Statistical area 018), Banks (020, 022) and Otago Peninsulas (024), and between Greymouth and Westport (034) accounted for over 30% of the domestic gill-net catch in 1991 (Table 1.2). The major gill-net fisheries in the North Island are located in the Firth of Thames (007), off Whakatane (009, 010), in Great Exhibition Bay (002) and south of Napier (014). The catch from gill-nets accounted for approximately 2.2% of the total domestic catch in 1991 (Table 1.3).

Table 1.2 Total gill-net and domestic catches (t) of all species for 1990 and 1991 by statistical area (Figure 1.3). Source: MAF Fisheries catch, effort and landing returns (estimated catches). Reproduced from Taylor (1992).

STATISTICAL AREA	1991		1991	
	DOMESTIC	GILL-NET %	DOMESTIC	GILL-NET %
001	901.7	6.6	647.3	15.9
002	5639.1	5.1	2181.6	10.1
003	2740.2	6.4	7212.1	2.6
004	1429.8	0.6	1297.3	0.2
005	1368.3	6.7	1403.6	0.6
006	1422.4	7.7	1477.6	8.6
007	1773.0	48.4	1870.3	53.6
008	2606.9	2.9	3779.9	3.6
009	9876.5	1.3	7941.9	2.6
010	1356.7	6.3	2041.6	7.0
011	432.3	0.2	447.2	0.7
012	711.5	0.5	779.8	0.3
013	8246.0	1.2	6260.6	1.2
014	4761.7	4.9	4499.0	6.1
015	3081.2	2.0	2508.0	3.0
016	10067.8	0.5	18433.5	0.4
017	9128.7	0.4	12052.8	0.9
018	10737.5	9.7	11040.6	10.2
019	4042.0	0.1	3697.1	0.1
020	8197.9	4.3	1165.5	31.5
021	2635.3	0.1	3245.3	1.4
022	20990.3	1.0	12981.0	1.9
023	11498.8	0.0	12054.8	0.0
024	1761.1	16.5	5616.7	7.0
025	1039.5	11.5	266.5	62.5
026	5029.5	0.9	5036.3	0.9
027	7043.9	1.7	8794.4	2.1
028	17164.7	0.0	29264.2	0.0
029	2057.8	1.2	721.5	1.6
030	10557.1	1.1	11823.9	2.2
031	332.3	12.6	226.3	17.4
032	245.0	27.8	216.9	11.9
033	2115.0	8.4	2749.9	1.6
034	163613.1	0.3	95209.3	0.4
035	13137.3	0.3	47118.2	0.1
036	738.9	3.4	3129.8	1.2
037	6229.8	1.1	6150.5	0.9
038	4119.0	4.4	4025.3	5.4
039	3043.5	7.4	2280.1	8.5
040	2780.7	8.3	3695.3	4.9
041	1314.7	8.6	7769.2	2.8
042	952.4	10.4	679.3	19.9
043	400.7	84.9	389.9	86.2
044	675.9	88.4	524.4	94.1
045	1025.4	5.9	928.5	4.9
046	214.3	9.2	306.4	5.5
047	971.3	9.3	683.1	7.6
048	20.8	1.0	12.3	0.8
049	985.1	0.1	840.0	0.1
050	1164.5	0.3	927.3	0.1
051	10439.4	0.0	4565.0	0.0
052	2268.3	0.0	1507.0	0.0
TOTAL	385086.6	2.0	364475.9	2.2

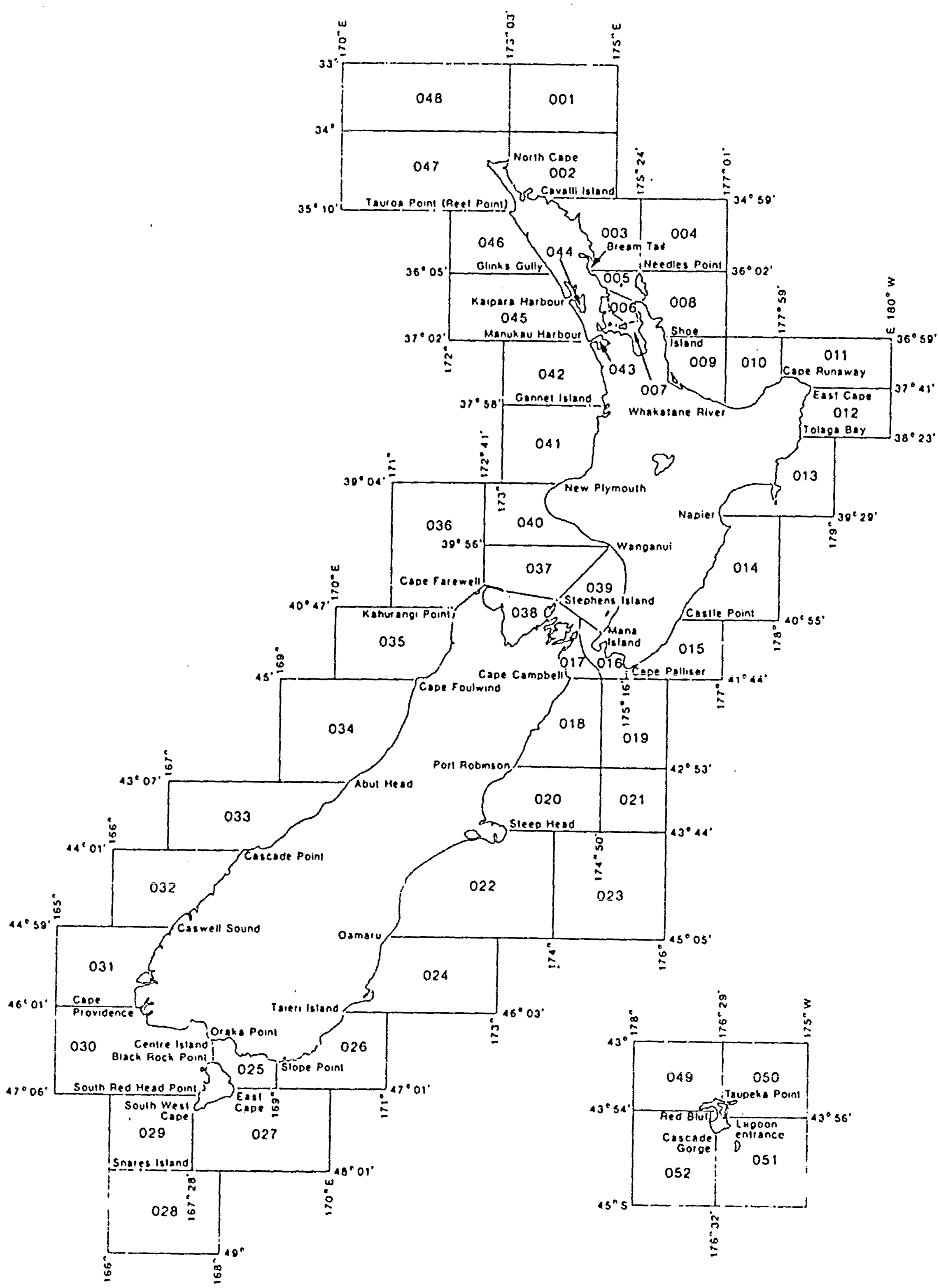


Figure 1.3 General statistical areas for MAF Fisheries catch, effort and landing returns (estimated catches).

Table 1.3 Gill-net and total domestic catch (t) of major gill-net species for 1990 and 1991. Includes species with catch greater than 10 t in either year. Source: MAF Fisheries catch, effort and landings returns (estimated catches). Reproduced from Taylor (1992).

SPECIES CODE	1990		1991	
	DOMESTIC (t)	GILL-NET %	DOMESTIC (t)	GILL-NET %
BUT	113.0	95.8	101.9	97.0
RMO	38.3	82.5	43.6	90.6
YBF	56.0	91.6	217.4	86.9
POR	83.3	78.2	82.7	82.5
BSK	100.5	4.0	12.8	80.5
SPO	1064.9	80.8	1099.1	78.9
BFL	55.1	26.1	106.7	77.4
PAR	101.5	68.4	97.4	75.2
GMU	925.2	79.1	825.8	72.8
YEM	41.6	76.0	56.7	63.1
SCH	1715.0	60.8	1714.9	61.8
BSH	166.4	43.4	140.5	56.6
MOK	258.9	64.1	346.4	51.2
GFL	11.8	50.0	87.1	47.0
KIN	255.8	43.3	370.9	46.4
SFL	55.8	54.7	296.7	43.4
TRU	20.3	45.3	38.1	43.0
FLA	2548.7	26.9	1507.0	42.2
RSN	68.1	29.1	83.4	21.6
OSD	228.7	5.9	273.1	21.5
HPB	789.4	18.5	757.3	20.5
ELE	271.4	14.3	354.2	18.1
SPD	4073.5	18.5	5341.2	16.1
RIB	172.9	6.0	337.2	14.7
KAH	8354.1	5.6	5070.2	9.5
HAP	29.1	1.0	176.6	8.8
BNS	1180.6	6.8	1730.0	7.5
TAR	3808.2	5.5	4614.1	7.2
WAR	1355.6	10.4	3882.0	6.1
TRE	2436.1	8.0	2940.0	6.1
LIN	10103.3	7.8	11313.4	5.8
ESO	44.8	2.5	257.2	5.6
SNA	6744.0	3.5	6602.6	4.2
SFE	423.4	3.4	569.1	3.0
GUR	2364.9	2.3	2645.0	2.5
STA	2363.0	1.4	2158.7	1.6
WWA	1163.5	1.1	1804.8	0.9
SKI	3402.4	0.4	2340.5	0.5
RCO	5305.9	0.1	4272.5	0.2
EMA	7086.2	0.1	12693.7	0.1
HAK	9037.3	0.1	8811.9	0.1
JMA	21394.0	0.1	31869.4	0.1
HOK	208066.1	0.01	215074.6	0.01
TOTAL	307879	2.4	333118.4	2.4

1.4.2 Commercial gill-netting along the East Coast of the South Island

The largest commercial gill-net fishery along the East Coast of the South Island is based at Kaikoura (Table 1.2, statistical area 018) and targets blue moki, *Latridopsis ciliaris*, and rig, *Mustelus lenticulatus*. This fishery developed in the early 1970s. Before the summer of 1968, gill-nets were used at Kaikoura primarily for catching butterfish in the shallow rocky reef environment around the Peninsula. The exploitable rig stock was discovered in the summer of 1968-69, and the following summer butterfish nets were used to catch rig. The nets used initially were 7.5" cotton nets, but with the development of monofilament nylon, the fishery now uses 7" monofilament nylon nets exclusively (Francis, 1979).

The exploitable blue moki population was not detected until 1972, when several fishers continued to fish after the summer rig season had finished and discovered the autumn run of blue moki. The blue moki fishery has used 7" monofilament nylon gill-nets from its inception. During the course of development of these fisheries, both species have become difficult to catch in shallow water, probably due to declining abundance on the continental slope (Francis, 1979). The decline in the inshore fish stock has meant that commercial gill-nets have been set in progressively deeper water. Now most vessels fish the steep slope at the edge of the continental slope in depths of 50 - 100 metres. The gill-nets are usually left in the water for 24 hours before being cleared and reset. The by-catch in this fishery includes groper, *Polyprion oxygeneios*, and spiny dogfish, *Squalus acanthias*.

1.4.3 Commercially targeted species

In 1990, 17% of commercial gill-netters held no quota and targeted either non-QMS species or leased quota to cover catches (MAF Policy records). The remaining 83% held some quota, but are also likely to have caught considerable quantities of non-QMS species (Taylor, 1992).

The total domestic catch of butterfish, *Odax pullus*, red moki, *Cheilodactylus spectabilis*, and yellow-belly flounder, *Rhombosolea leporina*, was caught primarily by gill-nets in 1990 and 1991 (Table 1.3). A high tonnage of school shark, *Galeorhinus galeus*, rig, *Mustelus lenticulatus*, spiny dogfish, *Squalus acanthias*, and ling, *Genypterus blacodes*, were caught by gill-nets in 1990 and 1991 (Table 1.3).

1.4.4 Non-commercial gill-netting in New Zealand

Little quantitative data is available on the non-commercial use of gill-nets in New Zealand. A national marine recreational fishing survey was carried out by the Department of Statistics for MAF Fisheries in 1987. This survey suggested that 66,000 recreational fishers used gill-nets during 1987. If the data are correct, then gill-nets accounted for approximately 7% of the total catch by recreational fishers in 1987. For some species, this percentage will be considerably higher. Information on recreational fishing effort at specific locations around the coast of New Zealand is primarily limited to areas of proposed or existing marine reserves, such as the Banks Peninsula Marine Mammal Sanctuary.

1.4.5 Non-commercial fishing along the East Coast of the South Island

A marine recreational fishing survey was conducted throughout the MAF Fisheries south region in 1990. However, the respondents were not a randomly selected sample of marine recreational fishers so the results should not be taken to represent the views of the general fishing public (Teirney *et al.*, 1992).

The marine recreational fishing survey showed that the finfish species being targeted by recreational fishers differed significantly between locations (Figure 1.4), but some general trends did exist. Blue cod, butterfish and blue moki were the most frequently targeted species by boat fishers along the east coast of the South Island. Bell & Associates (1992), in a survey to obtain baseline data on netting practices around Banks Peninsula, found a different pattern of species targeting by gill-netters. They observed that flatfish were the most frequently targeted species. However, this survey was exclusively of gill-netters, while the recreational fishing survey did not differentiate between line fishing off boats and the use of gill-nets.

Teirney *et al.* (1992) observed that along the rocky Kaikoura coastline recreational fishers targeted blue cod, groper, butterfish and blue moki. This pattern also was observed on the rocky coast of Otago, Southland and Fiordland (Figure 1.4). However, around Banks Peninsula and along the shingle beaches of the Canterbury Bight, red cod and kahawai were targeted, with sea run salmon being caught at the mouths of large braided rivers. Teirney *et al.* found that most butterfish, moki, flatfish, rig and school sharks taken by recreational fishers

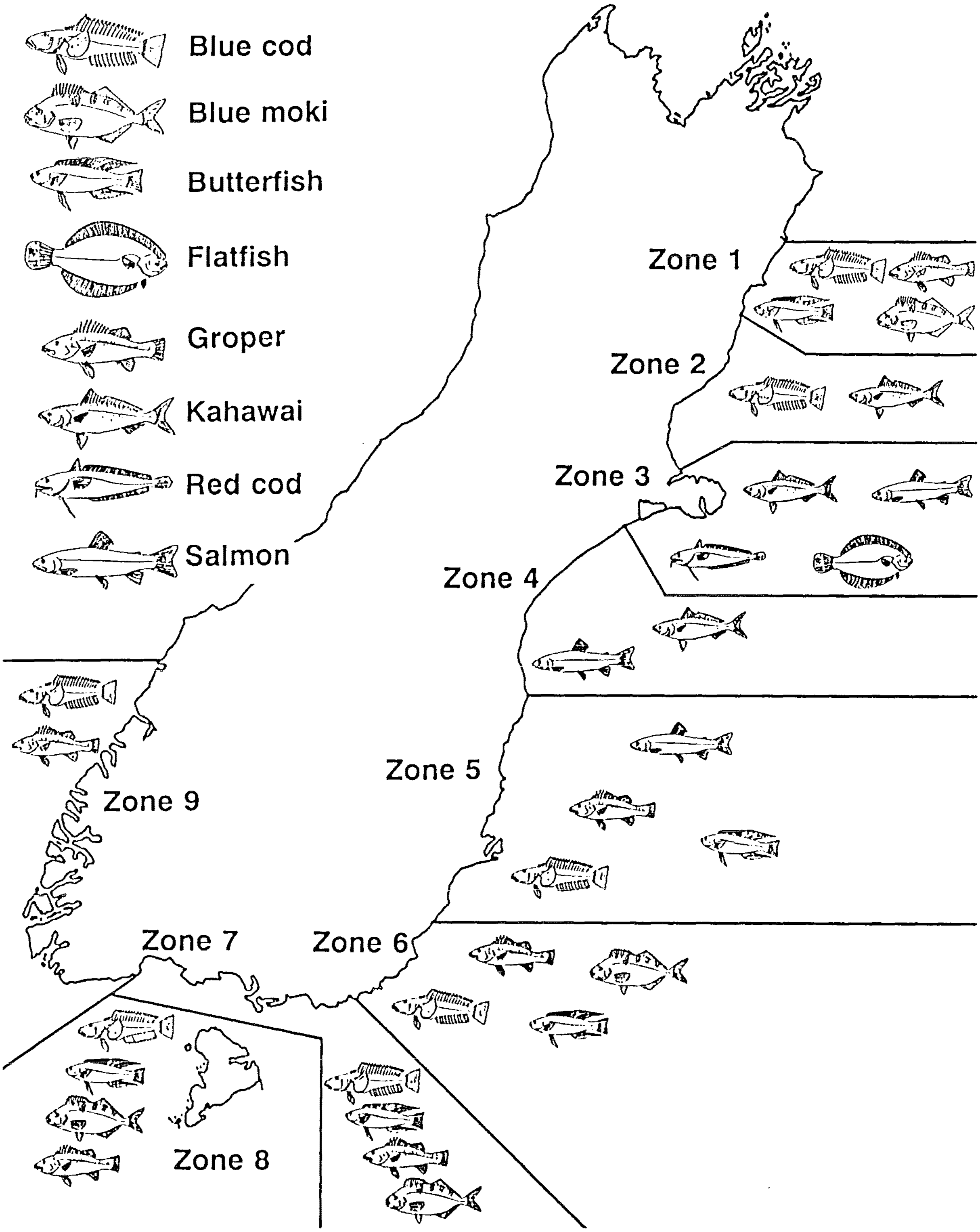


Figure 1.4 Targeting of finfish species by recreational fishers. The MAF Fisheries South Region was split into nine zones, and the relative popularity of finfish species within each zone was determined from the number of fishers who recorded actively harvesting each species. The fish species are shown in order of popularity, with the most popular closest to shore. Adapted from Teirney *et al.* (1992).

were caught by gill-nets. The daily catch of recreational fishers on boats was generally well below current bag limits.

1.5 GILL-NETS USED BY NON-COMMERCIAL FISHERS

There are several distinct amateur gill-net fisheries, each of which is characterised by a different net type and fishing practice (Table 1.4). These practices and net types are intended to maximise the catch of target species and minimise by-catch.

Table 1.4 The characteristics of gill-nets used in traditional fisheries and associated practices. Primary target species and net types are specified along with areas commonly fished, bottom types and depths. Reproduced from Anon, 1993.

Target species	Flatfish	Blue moki	Red Cod	Butterfish	Rig	Herring	Multi-purpose
Net length (m)	20 - 60	20 - 30	20 - 30	20 - 30	30 - 60	10 - 20	20 - 30
Meshes deep	9 - 12	25	25	25	15	50	25
Filament diameter (mm)	0.35	0.5	0.5	0.5	0.9	0.35	0.5
Mesh size (mm)	132 - 150	114 - 125	114	108	162 - 175	50	114
Area fished (Banks Peninsula particularly)	0 - 800 m from shore on mud flats	Outside of kelp beds to 50 m offshore	100 - 500 m offshore	Within kelp beds	Edge of kelp beds	0 - 100 m from shore on mudflats	
Depth of water (m)	1 - 8	3 - 10	5 - 15	1 - 5	10 - 20	1 - 5	2 - 15
Bottom types	mud	sand	mud\sand	reef	sand gravel	mud	rock sand\mud

1.6 ENVIRONMENTAL CONCERNS

1.6.1 Capture of non-fish species

The issue of non-fish species capture in gill-nets is highly emotive and the subject of ongoing debate between conservationists and both recreational and commercial fishers. Data collected in a recreational gill-netting questionnaire by the MAF Set-net Task Force show that of 647 respondents, 30% reported finding birds, turtles or marine mammals trapped in gill-nets at some time. However, this survey and other data available do not permit quantitative estimates of the problem, so the magnitude of the incidental catch of sea-birds and marine mammals in gill-nets is unknown. Sea-birds which dive for food are vulnerable to drowning in gill-nets, particularly when the nets are set at the surface or in shallow water (Taylor, 1992). It is generally assumed that birds become entangled and drown when they unexpectedly come across a net during a dive (Taylor, 1992). However, DeGange & Newby (1980) described the apparent attraction of sea birds to organisms entangled in a lost pelagic gill-net. Whether birds are similarly attracted to actively fishing gill-nets is unknown.

Marine mammals also may be attracted to gill-nets by the organisms entangled in them. Dawson (1990) stated that "in some cases marine mammals appear to feed directly on fish caught in gill-nets, or on the scavengers of gill-netted fish". Incidental catch of cetaceans in gill-nets appears to be a generic problem inherent in all forms of gill-netting (Dawson, in press).

1.6.2 Ghost fishing

Ghost fishing can be defined as "the ability of fishing gear to continue fishing after all control of that gear is lost by the fisherman" (Smolowitz, 1978) i.e., when gear is lost, a common occurrence in many fishing operations, especially in New Zealand's unpredictable climatic conditions. Fishing gear that requires active control (e.g., trawls and purse seines) becomes virtually inert after loss, and consequently is likely to catch few animals. By contrast, gear that normally fishes passively, such as traps and gill-nets, may continue to catch fish at significant rates after loss.

Gill-nets work by trapping animals in the mesh of the net; ghost fishing is a simple continuation of the gill-netting process after the net is lost, often through the loss of marker buoys (Breen, 1990). In inshore waters, algal growth on sunken nets may stop fishing by making the net highly visible to fishes and birds (High, 1985), but Walshe (1980) reports that fish are caught even in overgrown nets.

Short of preventing net loss or prohibiting gill-netting, it is not clear how to stop ghost fishing in gill-nets. Studies of preventable measures such as degradable mesh are still in their early stages, and such measures may simply change the focus of the problem.

1.7 CENTRAL AIMS OF THIS THESIS

Many studies have been done on the fishes inhabiting reefs around the coast of the North Island of New Zealand, particularly the north-eastern coast. However, little is known about the distribution and abundance of reef fish south of Wellington. My investigation into the effects of gill-netting on reef fish populations was to be based around the Kaikoura peninsula. Before the investigation could begin, however, a quantitative study was needed to provide baseline data on fish assemblages in this region.

The marine environment of the Kaikoura coast is unique in several respects. Approximately five kilometres offshore the continental shelf drops sharply from 100 to 500 metres to the continental slope, which then slopes more gently to the bottom of the southern extremity of the Kermadec Trench (Rasmussen, 1965). The Kaikoura coastline is frequently exposed to high energy oceanic swells and storm waves, resulting from winds that are predominantly from the south in winter and from the north in summer (Rasmussen, 1965; Williams, 1990).

The converging sub-antarctic Southland Current, moving north, and the warmer subtropical East Cape Current, moving south, strongly influence the marine environment of Kaikoura (Heath, 1985). The Kaikoura region marks the northernmost position of this Sub-tropical convergence, also known as the Southland Front. The resultant upwellings of deep oceanic water produce inshore water temperatures that range from 9.5°C to 18°C (Pirker, 1992).

The Kaikoura plains support a large agricultural industry, and this, coupled with the limestone composition of the Peninsula, often results in heavy sediment loads in inshore waters. During the summer, north-easterly onshore winds develop in mid-afternoon, and gain in intensity as the day progresses. This stirs up inshore water, often resulting in a distinct murky inshore band. During the autumn and winter months, southerly storms become more frequent, resulting in rough and murky conditions that may persist for several weeks.

These unique marine conditions place several constraints on visual survey methods for censusing reef fish populations. Underwater visibility rarely extends beyond five metres, and cold water temperatures limit the amount of time divers can spend in the water. Consequently, the 'standard' survey methods and transect sizes commonly used in studies in northern New Zealand are inappropriate for the

Kaikoura region. In the present study, it was necessary to derive a sample unit that optimised the precision of estimates of reef fish numbers, while keeping within these logistical constraints (Chapter 2). This sampling technique could then be used to survey the reef fish population in the Kaikoura region.

The rocky subtidal region around Kaikoura is neither topographically or biologically homogeneous. To describe this region effectively, therefore, it is necessary to stratify sampling by habitat (Chapter 3). The demarcation of habitats is somewhat subjective, but can be established with the aid of physical environmental features and biological features. A combination of physical and biological features was used to define several basic habitat types. The habitat types described were subsequently useful in partitioning the variation in reef fish species' distribution and abundance in the Kaikoura region.

Gill-nets are often used to quantify fish populations (Ricker, 1975; Hamley, 1975). However, little is known about how gill-nets sample a fish population. Studies on the selectivity of nets have been restricted to individual fish species, and have concentrated on size selectivity of gill-nets. Most studies have relied on 'indirectly' estimating gill-net selectivity by fishing with several different mesh sizes and comparing the catch. Several studies have estimated gill-net selectivity 'directly' by fishing known (tagged) populations (Koike, 1961; Cucin & Regier, 1966; Sechin, 1969), but no literature has been found that investigates the catch of gill-nets from a population that has been visually surveyed before fishing commences (Chapter 4). By assessing how a gill-net samples a resident population of reef fish, an insight can be gained into the long term effects of gill-netting on reef fish populations. The species that are less vulnerable to gill-nets can be identified, and the characteristics that appear to make these species less susceptible can be established.

Analysis of the catch of gill-nets may provide an indication of their effects on populations (Chapter 5). A comparison of the position in a net where different species are caught, the form of entanglement in the mesh and the size of fish caught should clarify some of the complex interactions involved in a fish becoming caught in a gill-net.

The number of fish caught in gill-nets does not necessarily increase in direct proportion to the time that nets are in the water (Kennedy, 1951). An analysis of gill-net catch with time would be expected to identify vulnerable reef fish species and indicate an optimal set time to maximise the catch of target species and minimise the catch of non-target species. The analysis of catch data should provide an insight into the effectiveness of gill-nets by examining the result of their action. A more direct approach is to observe gill-nets in the water, recording the effectiveness of nets and the reactions of fish to the nets.

Capture of fish by gill-nets is dependent on the activities of fish that bring them into direct physical contact with the net and allow them to be caught. Several authors have observed the reactions of fish in tanks to stationary netting obstacles, and have isolated various stimuli that may provoke an avoidance reaction. No literature has been found that investigates the behaviour of fish in the vicinity of gill-nets in the sea. Direct observations of reef fish species should allow the efficiency of gill-nets to be determined, and will identify vulnerable species (Chapter 6). The behaviour of invulnerable species near gill-nets may show whether these species can detect the net, and may identify which stimuli are important in this detection.

The size distribution of a species caught by gill-nets is often used to make predictions about the population being sampled (Hamley, 1975). However, the length frequency distribution of catches seldom represents that of the fished population because of the size selectivity of gill-nets. A comparison of the catch from gill-nets and the catch from an 'unselective' gear should provide a direct estimate of selectivity. An analysis of the size distributions of fish from individual species caught in different mesh sizes also may provide an estimate of the selectivity of gill-nets to different size classes of a species (Chapter 7). However, differences in abundance of size classes and morphological features may be confounding factors that effect the size distribution of the catch.

By investigating the catch of gill-nets in relation to the population being fished, the method, position and condition of fish caught in gill-nets, and the reaction of fish to gill-nets, this study aims to provide an insight into the effects of gill-netting on reef fish populations in Central New Zealand.

CHAPTER TWO

Optimisation of Sampling Design

2.1 INTRODUCTION

Ecology is the scientific study of the interactions that determine the distribution and abundance of organisms (Andrewartha, 1961). It is usually advantageous to describe patterns of distribution and abundance of study organisms with the greatest precision and accuracy possible within the parameters imposed by available resources. Particularly in field-based work, there is an unavoidable trade-off between accuracy, precision and cost-effectiveness. An optimisation of sampling design prior to the commencement of a study minimises losses in precision and accuracy imposed by financial cost or logistical constraints (Downing & Anderson, 1985).

Inaccuracy in estimates can be attributed to two main sources: (1) inappropriate design of the sampling programme; and (2) biases inherent in the sampling methods (Andrew & Mapstone, 1987). The first of these sources arises because the design of a sampling programme is inappropriate to the question being investigated. The second is a source of error that is systematically implicated in all sampling programmes. Precision is a function of the variance of the sample estimate; precision increases as the variance of the estimate decreases (Cochran, 1963).

The two fundamental components of sampling design that have the most impact on the precision of sample estimates are the size and shape of the sampling unit and the number of replicates (Andrew & Mapstone, 1987). Sale & Sharp (1983) reported increasing underestimation of fish abundance with increasing width of transect during visual surveys. The degree of this underestimation varied between species.

The shape of the sample unit is particularly important when the organisms in the population being assessed are clumped. In this case, the size of the sampling unit relative to the scale at which members of the population aggregate is of paramount importance. An excessively small sample unit will result in most samples containing no individuals and a few containing many. Conversely, a sample unit that is too large may confound density estimation by incorporating a higher level of variation, such as that between habitats (M^{c}Cormick & Choat, 1987).

The number of replicates of a sample unit has also been shown to affect accuracy and precision. Sale & Douglas (1981) found only 59-77% of species and 56-70% of individuals observed on a reef after nine replicate counts were seen during the first count on a reef. After three counts 76-89% of species and 70-88% of individuals were observed. For any size of sampling unit, precision will increase with sample size because the standard error and confidence intervals decrease with increasing replication.

Brock (1954) proposed the use of visual census techniques to survey reef fish populations and, since then, many studies of reef fish ecology have used visual census techniques to determine the abundance and diversity of fish present in an area. There are many variations on visual surveys, each of which may affect the precision and accuracy of abundance estimates. However, the applicability of the methods to the task required has often not been examined.

Visual census methods used in studies of reef fish fall into two categories:

a. A total count of all individuals present in naturally or artificially determined sites such as quadrats or small patch reefs.

b. Replicate counts of individuals contained within a strip transect laid out across a site.

Sale & Douglas (1981) examined the accuracy and precision of the first method. They concluded that, while visual censuses can display high repeatability of results, they never census the entire fish population present at a site, and their accuracy varies with the technique used.

Line transects were initially used by botanists, but a modified version of them has subsequently been used widely for sampling populations of birds (Yapp, 1956) and mammals (Hirst, 1969). However, line transects were not used in the field of marine ecology until suggested by Brock (1954). Brock's initial proposal of visual census required that two divers swim on either side of a fixed line, anchored to the substratum, and record all fish in the water column above a transect of a particular width. The divers' counts are then pooled to give a total count of fish within the area of the habitat surveyed.

Brock's initial recommendation involved the censusing of a transect 40 feet wide by 1500 feet long (60,000 square feet). However, the dimensions of the strip transect applied by modern researchers have varied greatly among studies. Jones & Chase (1975) used a path 2 metres wide and 2 metres high, along 100 metre transects. Robertson & Lassig (1980) used 25 metre long transects, estimated at 2.5 metres wide. Anderson *et al.*, (1981) used unmeasured transects, determined by swimming at a constant speed in a straight path for a set period. Clarke (1977) censused fish by swimming an irregular path and endeavouring to count all individuals of selected species within a given habitat. Sale & Sharp (1983) investigated bias in visual transect censuses of coral reef fishes, and compared various transect sizes. They found that density estimates were negatively correlated with the width of the transect used. Factors such as the conspicuousness of fish or their behaviour influenced the magnitude of this effect.

Details of how a strip transect was searched (i.e., the diver's swimming speed, whether all hidden places were carefully searched, the height of the diver above the substratum, and how mobile species that moved across the strip in front of the diver were counted) have rarely been mentioned, and even less frequently in great detail. Usually, a diver swimming along a transect observes all individuals of the largest species present in the strip. The way in which the diver swims, searches and records the counts, and the appearance and behaviour of the species being surveyed, however, are all factors that contribute to the diver's ability to achieve this. If a target species is cryptic in behaviour or appearance, many individuals in the transect may be missed unless searching is thorough (Brock, 1982). If the divers swim too slowly, they may overestimate the density of species that move across the strip in front of them or those that tend to swim with the diver. In addition, interrupting the observation of the transect to write data on a slate may lead to some individuals of abundant species being overlooked when the search continues.

Strip transects are the most commonly used visual estimation technique for reef fish in both tropical and temperate studies (Thresher & Gunn, 1986). However, few studies have attempted to examine the reliability of a range of transect sizes to determine the optimum size for a survey.

My study assesses a range of transect sizes and shapes for precision and cost effectiveness in terms of time, and determines their applicability to the surveying of reef fish populations around the Kaikoura Peninsula.

2.2 MATERIALS AND METHODS

The abundance of mobile reef fish and transient pelagic fish was assessed at sites around the Kaikoura Peninsula, on the east coast of the South Island of New Zealand. Small benthic fishes were not counted. The precision and cost (time) of five strip transect sizes (50x5, 40x5, 30x5, 20x5, 10x5 metres) were compared in order to determine which size of transect resulted in the most reliable estimate of the fish population for the least cost.

Studies in northern New Zealand (Leum & Choat, 1980; Choat & Ayling, 1987; Choat *et al.*, 1988) have used transects up to ten metres in width. However, sea conditions in the Kaikoura region, where rough seas and a heavy sediment load are common throughout the year, rarely allow underwater visibility to extend beyond five metres, and frequently prevent diving altogether. A wide transect would therefore usually be unsuitable for visual surveys of mobile reef fish. A five metre wide transect (requiring only 2.5 metres visibility either side of a transect tape) was chosen as a standard because it allowed fish to be counted in most conditions.

Fish were counted by two SCUBA divers swimming along a 50 metre tape laid out randomly on the substratum. The species and standard length of any mobile reef fish observed within 2.5 metres of their side of the tape was recorded on a pre-formatted plastic slate. The divers swam at a constant speed one metre above the substratum, searching in weed and crevasses as they progressed. The two divers kept abreast of each other throughout the transect, and assumed that fish seen to cross from the other diver's side of the tape had already been recorded by the other diver. Divisions were made on the slates at each 10 metre portion of the transect, enabling estimates of fish density within five 10x5 metre blocks to be obtained for each transect. The data were then grouped into cumulative blocks, providing fish densities within 50, 100, 150, 200 and 250 m^2 blocks.

Five basic habitat types were arbitrarily chosen for their commonness around the Kaikoura Peninsula. The five habitats were distinguishable by physical and biological features (Chapter Three). At each of three sites within each habitat, three 50 metre transects were done. In total, forty-five transects were completed at fifteen different sites involving different substrata and weed types, to allow for general application of the transect size optimisation throughout the subsequent study. The precision (p), as reflected by the variability around the mean density estimate of the three replicate transects, was calculated at each site for each of the five transect sizes. Data were then combined to give the mean precision of each transect size across the fifteen different sites. The formula

$$p = \frac{(s/\sqrt{n})}{\bar{x}}$$

was used (s = sample standard deviation; n = number of replicates; $\overline{x}$ = mean density)(Southwood, 1966; M^c^Cormick & Choat, 1987, Kingsford, 1987). Precision was determined for total fish numbers, and individually for the two most common species, *Notolabrus celidotus* and *Notolabrus fucicola*.

2.3 RESULTS

Precision was found to improve with increasing transect size for the total fish fauna and the individual species, *Notolabrus celidotus* and *Notolabrus fucicola* (Figure 2.1). The transect size with the greatest precision in all three cases was the 50x5 metre (250 m^2) transect, but the increase in precision was minimal over the three larger transect sizes. There was also a decline in confidence limits around the mean with increasing length of transect, indicating that variability between replicate transects decreased. The peak at the smallest transect size was due to the high and variable numbers of fish seen in the first ten metres of each transect (Table 2.1).

A one-way Analysis of Variance (Minitab, Release 8.2) of the first 10 metre block of each transect against one other randomly selected 10 metre block from the remainder of the transect (for the forty-five transects in the pilot study) showed a significantly greater number of total fish numbers ($F_{1,88} = 78.17$, $p < 0.001$) in the first 10 metres of transect. This is probably due to fish following divers while transect tapes are laid. Recognising this problem, measures were taken during later transects to minimise it. These included laying out the tape while swimming some height above the substrate, and ascending to a shallower depth for a period of time prior to commencing the transect. These techniques appeared to minimise the

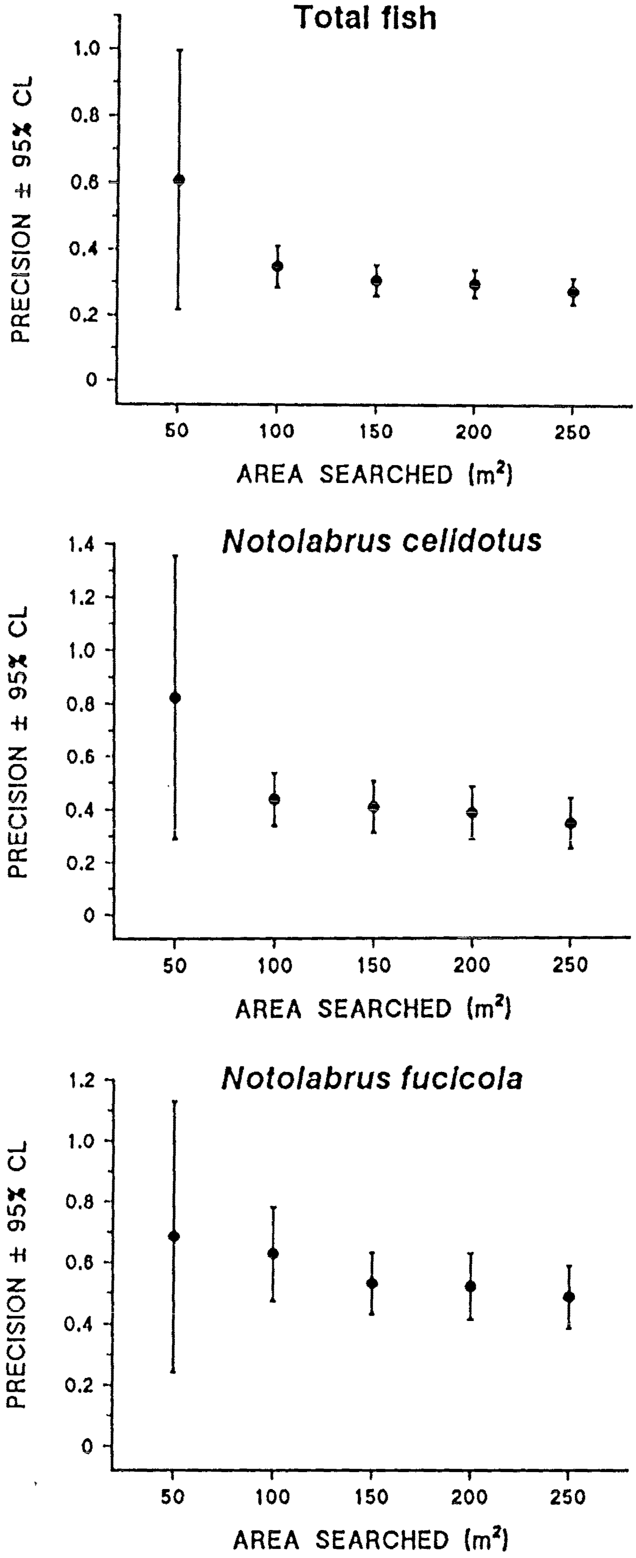


Figure 2.1 Precision (± 95% confidence limits) for total fish, *Notolabrus celidotus* and *Notolabrus fucicola*, in relation to the area searched in each transect size (10x5, 20x5, 30x5, 40x5, and 50x5 metres).

problem. A one-way ANOVA of the first 10 metre block (of forty-five randomly selected transects from the subsequent main study) against one other randomly selected 10 metre block from the remainder of the transect showed no significant difference in numbers of total fish ($F_{1,88} = 0.04$, $p = 0.844$).

Table 2.1 Density per 50 m^2 of total fish numbers and the two most common reef fish in the Kaikoura region, *Notolabrus celidotus* and *Notolabrus fucicola*. For the four largest transect sizes, transects were grouped by 10x5 metre blocks.

Transect size		Total fish No. / 50 m^2		*Notolabrus celidotus* No. / 50 m^2		*Notolabrus fucicola* No. / 50 m^2	
(m)	n	$\bar{x}$	S.E.	$\bar{x}$	S.E.	$\bar{x}$	S.E.
10x5	45	12.96	1.81	9.27	1.45	2.07	0.51
20x5	45	7.89	1.00	5.53	0.80	1.34	0.34
30x5	45	6.36	0.81	4.45	0.65	1.06	0.25
40x5	45	5.36	0.61	3.81	0.55	0.87	0.21
50x5	45	4.79	0.57	3.44	0.48	0.77	0.18

2.4 DISCUSSION

M^{c}Cormick & Choat (1987) established that it was possible to optimise strip transect size, in terms of accuracy and precision, when a single target species (in their case *Cheilodactylus spectabilis*) is involved. However, the optimum transect size that results is likely to be species-specific. Therefore, a compromise in transect size would be required if several species were to be counted within the same transect.

In this study, the same pattern of precision occurred for the total fish numbers and the two most common species. That is, precision increased with increasing length of transect, but only marginal increases in precision occurred after 150 m^2 (30x5 metres).

If precision was the only consideration when assessing the best sampling unit to estimate the abundance of reef fish in the Kaikoura region, then a 50x5 metre transect would be used. However, because of the time taken to swim the longer transects, only three transects of this length can be completed during one SCUBA dive at a depth of 10 metres. If a slight decrease in precision is accepted, as a result of shortening the transect length to 30 metres (150 m^2), then five transects can be done on a single SCUBA tank.

For any size of sampling unit, precision increases with sample size because the standard error and confidence intervals decrease with increasing replication (Andrew & Mapstone, 1987). Therefore, any loss in precision as a result of the smaller sample unit is offset by an increase in precision due to increased replication. It was therefore decided that a transect size of 30x5 metres with five replicates was the most suitable for the subsequent study.

CHAPTER THREE

Reef Fish Assemblages in Shallow Rocky Reef Environments

3.1 INTRODUCTION

Reef fish are often associated with characteristic habitats (Sale, 1977). Many authors have documented, either qualitatively or quantitatively, variations in species composition with depth (Gosline, 1965; Golovanj, 1973) or, more generally, among different habitats (Talbot & Goldman, 1972; Ehrlich, 1975; Goldman & Talbot, 1976; Clarke, 1977). Most of these studies have been concerned with coral reefs and their associated fish fauna. Shallow rocky reef environments in temperate waters support a variety of fish species that are dependent on the reef substratum, kelp and associated crustaceans for food and diurnal shelter.

Most studies of temperate reef fish in New Zealand have been done in the north-east of the North Island (Jones, 1988). These studies have primarily been concerned with associations between fish assemblages and benthic components of reef communities, such as kelp beds and grazing invertebrates. The interaction between fish assemblages and benthic characteristics has been studied in two ways. Firstly, attempts have been made to assess the major features of the benthic habitat influencing the distribution and abundance of fishes inhabiting shallow reef environments (M^{c}Cormick, 1986). A second set of studies has focused on fish feeding activities (Russell, 1983), and their impact on the structure of benthic algal and invertebrate communities (Jones, 1988).

Variations in individual species density have been investigated at a variety of spatial scales, from a local scale within sites (M^{c}Cormick, 1986) to broad geographic scales (Choat & Ayling, 1987). Almost without exception, significant differences in density have been recorded at all the spatial scales examined (Jones, 1988).

Substantial differences in species composition and abundance of reef fish were observed by Choat & Ayling (1987) in a study encompassing a wide geographic scale, including the North Island of New Zealand and adjacent offshore islands. Choat & Ayling noted differences in species composition between offshore islands and the mainland, and differences between different locations along the North Island coastline. When fish were grouped into feeding categories, variations in species abundances appeared to relate to habitat. Reefs dominated by macroalgae support large numbers of small fish, mainly labrids, while echinoid-dominated coralline flats mainly support larger benthic-feeding carnivores.

A few studies have used stratified sampling, and compared densities among habitat types, and among sites within habitats (Ayling, 1978; Kingett & Choat, 1981; M^{c}Cormick, 1986). There are consistent differences in associated fish assemblages among habitats and sites. Ayling (1978) identified six different habitats within the Marine Reserve at Leigh, and found marked differences in the abundance of fish species between these habitats. Ayling concluded that these habitat types represented meaningful biological divisions in terms of fish distribution and abundance.

Species-specific patterns of abundance have been correlated with a variety of physical and biological factors (Jones, 1988)(Table 3.1). Biological characteristics, such as the proportions of macro- or turfing algae, and physical characteristics, such as topographic complexity, appear to have a major impact on fish assemblages and the structure of local communities. Jones (1984b) and Choat & Ayling (1987) showed that the abundance of the common wrasse *Notolabrus celidotus* was positively related to the quantity of macroalgae (Table 3.1).

Table 3.1 Significant correlations between reef fish abundance and habitat covariates from medium-scale studies in north-eastern New Zealand. (ρ, Pearson's correlation coefficient). Reproduced from Jones (1988) Table 2.

Species	Family	Category	Covariate	ρ	Reference
Cheilodactylus spectabilis	Cheilodactylidae	All	Topographic complexity	0.88	Leum & Choat(1980)
Chromis dispilus	Pomacentridae	All	Topographic complexity	0.83	Kingsford (1980)
Chromis dispilus	Pomacentridae	All	Current speed	0.73	Kingsford (1980)
Chromis dispilus	Pomacentridae	Juveniles	Topographic complexity	0.53	Kingsford (1980)
Chrysophrys auratus	Sparidae	Juveniles	Turf-algae cover	0.79	Kingett & Choat (1981)
Forsterygion varium	Tripterygiidae	Adults	Topographic complexity	0.82	Thompson (1979)
Notolabrus celidotus	Labridae	Juveniles	Shallow-Macroalgae cover	0.94	Jones (1984b)
Notolabrus celidotus	Labridae	Juveniles	Deep-Macroalgae cover	0.90	Jones (1984b)
Notolabrus celidotus	Labridae	Adults	Topographic complexity	0.59	Jones (1984c)
Parapercis colias	Parapercidae	Juveniles	Turf-algae cover	0.79	Mutch (1983)
Parapercis colias	Parapercidae	Adults	Macroalgae cover	-0.68	Jones (1981a)
Parika scaber	Monacanthidae	Adults	Sessile-invertebrate cover	0.86	Jones unpublished data
Pempheris adspersus	Pempheridae	All	Topographic complexity	0.89	MacDiarmid (1981)
Scorpis violaceus	Kyphosidae	Juveniles	Topographic complexity	0.81	MacDiarmid (1981)

Kingett & Choat (1981) and Choat & Ayling (1987) showed that large carnivores, such as snapper, *Chrysophrys auratus*, and blue cod, *Parapercis colias*, were more common in turf areas (Table 3.1). Topographic complexity has also been shown to influence the density (Leum & Choat, 1980) and richness of species.

Although a considerable amount of literature can be found relating habitats to fish assemblages in northern New Zealand, relatively little work on this topic has been undertaken south of Wellington. The aim of my study was to investigate and describe shallow rocky reef habitats along the north-eastern coast of the South Island, including a smaller study on the south coast of the North Island, and to quantify and describe their associated fish assemblages. It was hoped that several distinct habitats, such as those described by Ayling (1978), could be identified.

Ideally, these habitats and their associated environmental indicators could be used to predict associated fish populations.

3.2 MATERIALS AND METHODS

The abundance of common reef fish and transient pelagic species was assessed at thirty-six sites along the north-east coast of the South Island, and the south coast of the North Island. At each site, five 30x5 metre transects were done, as described in section 2.2. The general habitat at each site was initially determined, and then an effort was made to stay within this habitat, and at a constant depth within this habitat, throughout each of five replicate transects. Species identity and standard length of each fish were recorded.

The thirty-six sites were initially divided into five basic habitat types that were arbitrarily chosen for their commonness around the Kaikoura Peninsula. The five habitats were distinguishable by certain physical and biological features:

1. Rocky reef, mixed algae.

This habitat is characterised by areas of highly broken and convoluted reef, with crevasses containing small sand patches or areas of cobbled rock. The predominant algae are the large browns (i.e., *Marginariella boryana*, *Carpophyllum maschalocarpum*, *Landsburgia quercifolia* and *Ecklonia radiata* (the latter being found more predominantly in the Wellington region)). However, on exposed rock there are also crustose coralline algae and patches of other red algae. The sea urchin *Evechinus chloroticus* is common, and paua, *Haliotis iris*, and *Scutus breviculus* are often present. This habitat is found in depths between 0-20 metres.

2. Rocky reef, *Marginariella boryana* forest.

This habitat is similar to the rocky reef, mixed algae habitat in that it contains areas of highly broken reef, crevasses, and sand or cobbled rock patches. However, the dominant alga is *Marginariella boryana*, which forms dense forests with plants reaching up to 1.5 metres in blade length. Crustose coralline algae is less abundant, with the thick mat of blades of *Marginariella boryana* covering most bare rock. The sea urchin *Evechinus chloroticus* is common in this habitat and is usually found aggregated in depressions and cracks or between boulders, where it feeds on drift algae torn off by wave action. This habitat is more commonly found in areas up to 10 metres in depth.

3. Flat reef, algal carpet.

This habitat is characterised by the presence of a thick layer of low-lying algae, containing both reds and browns, which consolidate to form an algal carpet. *Marginariella boryana* and *Landsburgia quercifolia* occur sporadically in small isolated clumps. There is little bare rock, and crustose coralline algae are rare. The sea urchin *Evechinus chloroticus* is less abundant in this habitat, while sea tulips, *Pyura pachydermatina*, occur frequently. This habitat is generally found at depths of up to 10 metres.

4. Rocky reef, crustose coralline algae.

This habitat is dominated by crustose coralline algae. All rock surfaces are thickly encrusted with coralline algae, and the occurrence of large brown algae (predominantly *Marginariella boryana* and *Carpophyllum maschalocarpum*) is restricted to small clumps of usually less than 10 plants. The rocky substrate also has a sparse covering of sponges (especially *Halichondria* and *Tethya aurantium*). This habitat is most commonly found at depths greater than 15 metres.

5. Sandy bottom, patch reefs with coralline turf.

Although not truly a rocky reef, this habitat, with its scattering of small patch reefs, does support high numbers of 'reef' fish. The small patch reefs are encrusted with coralline turf, and often provide a solid substrate for the holdfasts of several large brown algae, predominantly *Marginariella boryana*. Invertebrates are uncommon on the smaller reefs, which is possibly an indication of the unstable and changeable nature of this habitat, with patch reefs being covered and uncovered as sand shifts during storms. This habitat occurs at a range of depths, but is more common below 15 metres.

The frequency of occurrence of common reef fish in these five habitats was described and graphed. The abundance of each individual species, and the total fish numbers within each habitat, was analysed with Analysis of Variance (SAS, Release 6.04). Before comparisons were made, Cochran's tests for homogeneity of variances were done. Where appropriate, transformations of data were done prior to ANOVA. The total number of species in each habitat was also analysed with ANOVA. Treatment means were compared with Duncan's multiple range test. Species associations were assessed with correlation coefficients.

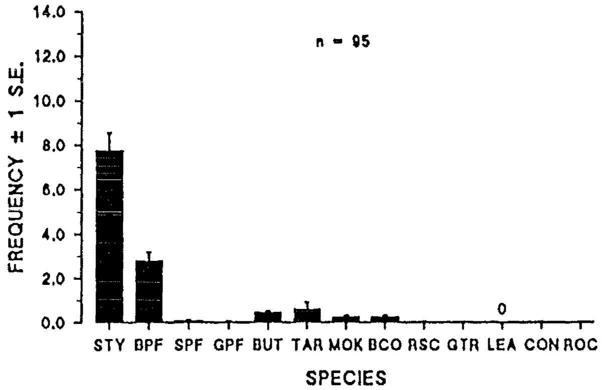
An ANOVA was done to assess the variability in individual species numbers between sites within a habitat. Five transects were completed at each of five sites which were described as Flat reef, algal carpet (habitat 3). A oneway ANOVA was done on each species observed at each site of habitat 3, and on total fish numbers at each site.

3.3 RESULTS

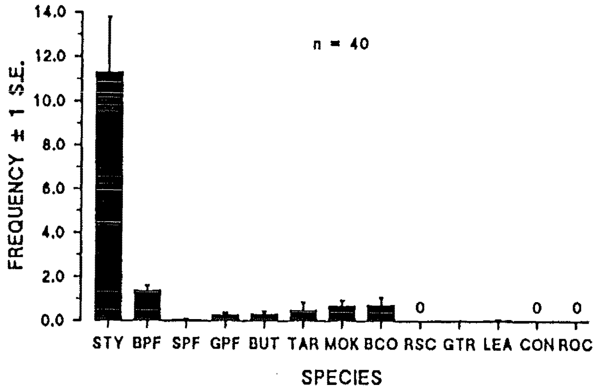
When counts from individual site were pooled by habitat, individual species showed considerable variation in abundance across the five habitats (Figure 3.1). Duncan's multiple range test showed that spotties, *Notolabrus celidotus*, were observed in significantly higher densities ($F_{4,175} = 8.38$, $p < 0.001$) in habitat 5, than in the other four habitats. Duncan's multiple range test showed that the two deep water wrasses, *Pseudolabrus miles* ($F_{4,175} = 73.63$, $p < 0.001$) and *Notolabrus cinctus* ($F_{4,175} = 50.91$, $p < 0.001$), were each observed in significantly higher densities in the deeper habitat 4 than in the remainder of the habitats. The three large carnivores, tarakihi, *Nemadactylus macropterus*, ($F_{4,175} = 4.84$, $p < 0.001$), blue moki, *Latridopsis ciliaris*, ($F_{4,175} = 11.52$, $p < 0.001$) and blue cod, *Parapercis colias*, ($F_{4,175} = 30.05$, $p < 0.001$), were all observed in significantly higher numbers over the sand and patch reefs of habitat 5 than in any other habitat. Duncan's multiple range test showed that the total fish numbers per transect were also significantly greater in habitat 5 than those in the other four habitats ($F_{4,175} = 6.48$, $p < 0.001$). Banded wrasse, *Notolabrus fucicola*, showed no significant difference in abundance across the five habitat types ($F_{4,175} = 2.17$, $p = 0.0740$).

The number of species found within each habitat (Figure 3.2) was significantly different between habitat types ($F_{4,175} = 6.84$, $p < 0.001$). Duncan's multiple range test showed that habitat 5 contained more species than the other four habitats. It

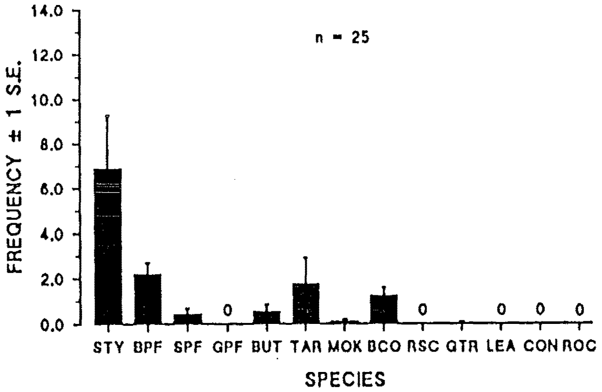
Rocky reef, mixed algae



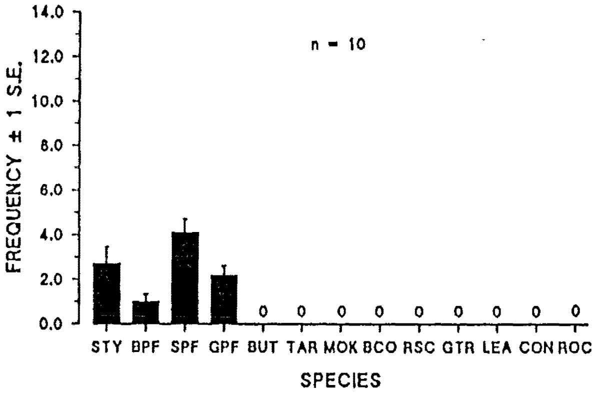
Rocky reef, *Marginariella boryana* forest



Flat reef, algal carpet



Flat reef, crustose coralline algae



Sandy bottom, patch reefs with coralline turf

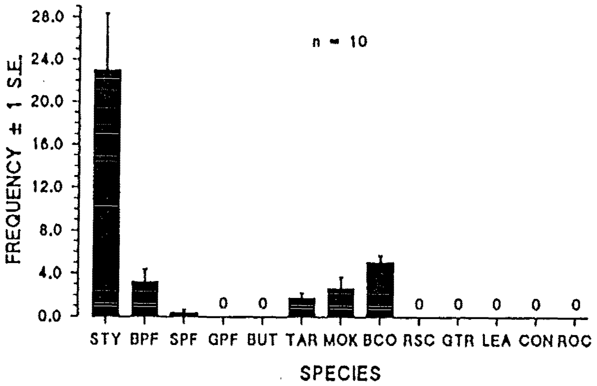


Figure 3.1 Mean frequency (number) ± 1 S.E. per 30 x 5 metre transect of thirteen species of common reef fish in each of five different habitats (n = total number of transects). See Appendix 1 for species codes.

is noteworthy that the greatest average number of species seen on transects was c. four.

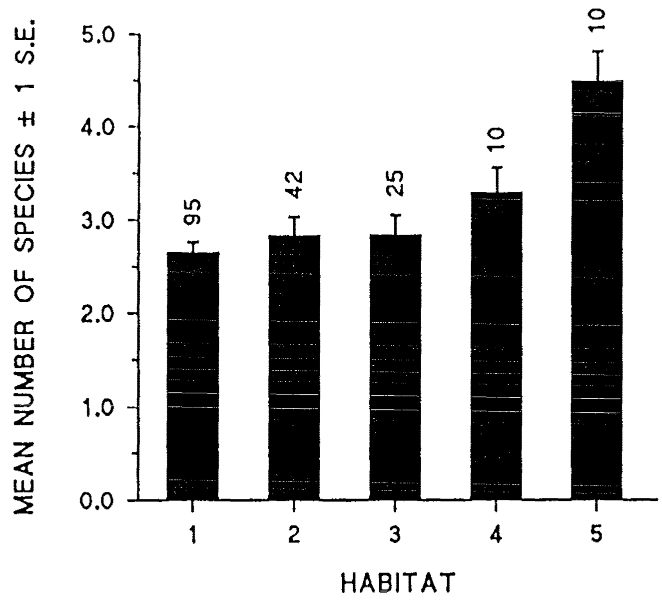


Figure 3.2 Mean number of species observed in each of the five habitats (n = number of transects).

Scarlet wrasse, *Pseudolabrus miles*, and girdled wrasse, *Notolabrus cinctus,* were deep water species usually found together in the deeper water of habitat 4 (r_{178} = 0.590, $p < 0.001$). The large carnivores blue moki and blue cod were usually found together in habitats that contained open areas of sand or gravel (r_{178} = 0.305, $p < 0.001$). Butterfish and blue cod showed a significant negative correlation (r_{178} = -0.146, $p < 0.05$), with the former being present in algae-dominated habitats (1-3) and the latter being more common in open areas of sand or gravel (habitat 5).

There was no significant difference in the total number of fish observed at each of the five sites within habitat 3 ($F_{4,20}$ = 0.45, p = 0.771). However, there were several significant differences in species abundances between sites (Figure 3.3). Tukey's

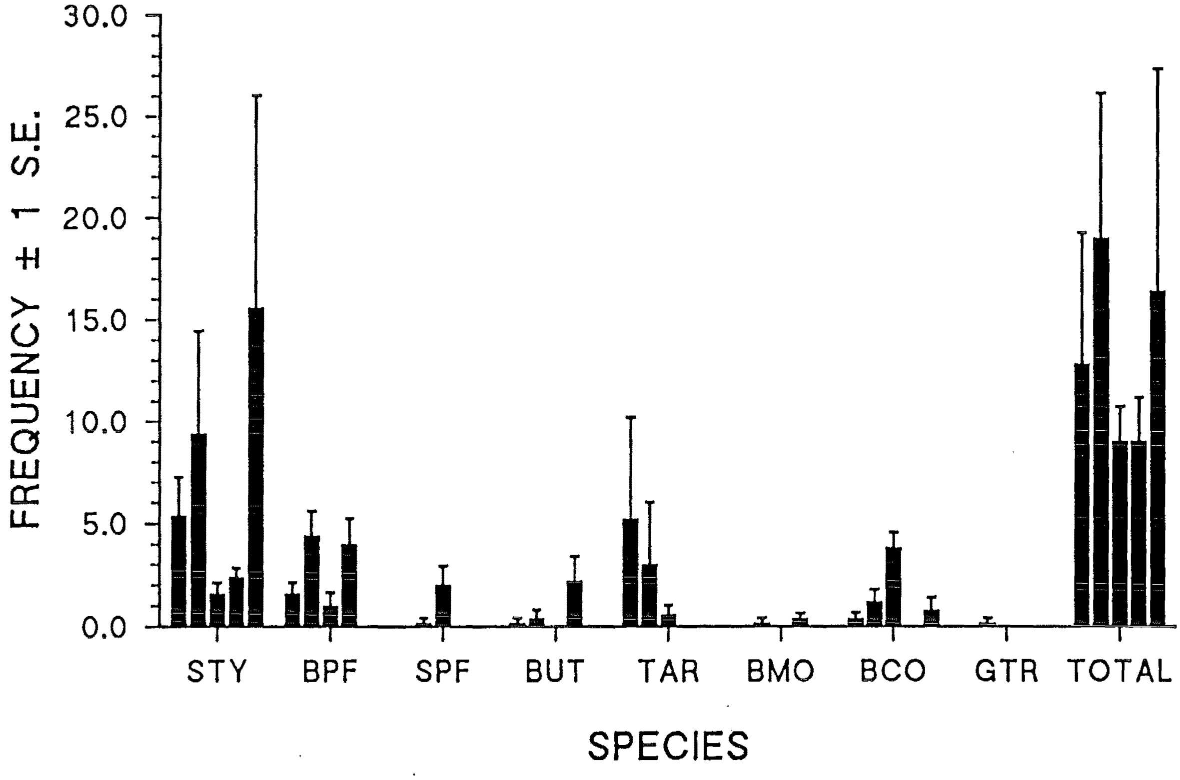


Figure 3.3 The mean abundance of eight species of reef fish observed at each of five sites within habitat 3, Flat reef, algal carpet. The sites are each represented by a bar and are in the same relative position for each of the species. See Appendix 1 for species codes.

pairwise comparisons showed that the mean number of scarlet wrasse ($F_{4,20}$ = 4.57, $p < 0.01$) and blue cod ($F_{4,20}$ = 8.78, $p < 0.001$) observed at site 3 was significantly larger than at all other sites. There was a significant difference in the number of banded wrasse ($F_{4,20}$ = 5.23, $p < 0.01$) observed at each site. There was no significant difference in the number of spotties ($F_{4,20}$ = 1.20, $p = 0.341$), butterfish ($F_{4,20}$ = 2.82, $p = 0.053$), tarakihi ($F_{4,20}$ = 0.78, $p = 0.554$), blue moki ($F_{4,20}$ = 1.60, $p = 0.213$) or marblefish ($F_{4,20}$ = 1.00, $p = 0.431$) observed at each of the five sites.

3.4 DISCUSSION

The rocky subtidal region is not topographically or biologically homogeneous. In order to describe this region effectively, therefore, it is necessary to stratify sampling by habitat type (Ayling, 1978). The demarcation of habitats, however, is somewhat subjective. It can be established with the aid of either physical environmental features, such as topography and depth, or biological features, such as the presence/absence of certain flora and fauna. Although the definitions are somewhat circular (i.e., defining the habitat by what is in them and vice versa), these general habitats are easy to recognise, are common, and are large enough to provide an obvious category for stratified sampling. In this investigation, a combination of physical and biological features has been used to define five basic habitat types.

The description of the fish assemblages associated with the five habitats produced several significant results. As expected, the herbivorous fish *Odax pullus* was observed only in areas with dense algal cover. This herbivore eats mostly mature fucoid and laminarian algae (Russell, 1983; Choat & Clements, 1992) and is dependent on algal cover for both food and refuge. Blue cod were found in much greater numbers on the sandy bottom of habitat 5 (Figure 3.1), where they can easily forage for the crabs and shellfish that make up their diet (Russell, 1983). This result agrees with the negative correlation between adult blue cod abundance and macroalgal cover (Table 3.1) observed by Jones (1981a).

Two other large carnivores, tarakihi and blue moki, were also found in significantly greater numbers over the sand and patch reefs of habitat 5. This relationship was observed by Choat & Ayling (1987) in northern New Zealand. Choat & Ayling noted that larger carnivorous fishes appeared to forage predominantly in open reef areas, which support large densities of their invertebrate prey. Both fish are 'bottom gleaners' that push their fleshy lips firmly against a silty patch of substratum and suck up sand along with invertebrates. The sand is washed out through the gill openings, and the small invertebrates are crushed in the gill rakers and swallowed. These benthic-feeding reef fishes do not appear to forage within or occupy kelp forest habitats (Choat & Ayling, 1987).

The two deep-water wrasses, *Pseudolabrus miles* and *Notolabrus cinctus,* were rarely seen in the shallow habitat 1, but replaced the more common spotty and banded wrasse on the deeper reefs of habitat 4. The great numbers of spotties seen over the sparsely vegetated sandy bottom of habitat 5 is contrary to the positive correlations observed by Jones (1984b, 1984c) between *Notolabrus celidotus* abundance and macroalgal cover (Table 3.1).

Habitat 5 supported the greatest number of total fish and was the most diverse, supporting a significantly greater number of species than the other habitats (Figure 3.2). The species diversity across all five habitats was low, with the greatest mean number of fish species being c. four in habitat 5. Habitat 5 has several characteristics that are often associated with greater species diversity, particularly environmental fluctuations (Krebs, 1985), but only has increased abundance of individual species, rather than significantly greater species richness.

The correlation coefficients calculated for individual species abundances agree with several relationships described above. The significant negative correlation between butterfish and blue cod supports the assumption that the different food requirements of these two species will cause them to occupy different habitats. The positive correlation between blue moki and blue cod agrees with the assumption that these species will be found in similar abundances in each habitat because of their similar food requirements. The positive correlation between scarlet wrasse and girdled wrasse supports the assumption that these species both occupy similar deep habitats.

Ayling (1978) concluded that the six habitats he described for north-eastern New Zealand represent meaningful biological divisions, as far as fish distribution and abundance are concerned. Although the habitats described in my study produced similar divisions, the variation between different sites in the same habitat suggests further refinement of the habitats may be needed.

The abundance of several species of fish varied significantly between the sites of habitat 3, suggesting a further factor may be influencing individual species abundances. This factor is likely to be depth, as reef fish numbers have been observed to vary significantly with depth in both temperate (Leum & Choat, 1980) and subtropical waters (Schiel *et al.*, 1986). Although standardised at each site, by keeping at a constant depth during the five transects, depth was not standardised between sites. Further investigations into reef fish distributions with depth are required in the Kaikoura region, to reduce between site variations and to further refine these habitats. However, until then, the habitats described in my study are useful in partitioning the variation in reef fish species' distribution and abundance observed along the north-eastern coast of the South Island.

CHAPTER FOUR

Gill-net Catches from Surveyed Populations

4.1 INTRODUCTION

Gill-nets are generally perceived as an indiscriminate fishing gear that catch all fish in their immediate vicinity. High levels of by-catch and wastage are often cited as reasons to ban gill-netting in inshore waters. However, no literature has been found that describes what fraction of a reef fish population is removed by gill-nets or which species or size classes of fish appear most susceptible. The most direct method of determining the effects of gill-netting on reef fish populations is to survey a population, and then to analyse the catch of gill-net that subsequently samples this population. This was the primary aim of this study. A secondary aim was to compare the population that was perceived to exist from the catch of the gill-nets with that visually surveyed by divers.

The techniques used for investigating reef fish assemblages can be divided into two categories: destructive and non-destructive methods. Although destructive methods have been used mainly for collections of fish, poison (Russell *et al.*, 1978), explosives (Talbot & Goldman, 1973; Williams & Hatcher, 1983) and fish traps (Sheaves, 1992) have been applied in quantitative assessments. The use of gill-nets is a standard technique for sampling fish populations in reservoirs, lakes and on reefs (Sale, 1980; Helser *et al.*, 1991).

The advantages of gill-nets include their ease of use and the low cost. However, it is well known that they do not sample a population randomly but, depending on the mesh size used, select certain size classes and species of fish in preference to others (Hamley, 1975). As a result, the relative abundance of different size/age classes of fish in a population cannot be estimated with confidence unless correction can be made for this selectivity. Investigators have tried to overcome this problem experimentally by using nets which have several mesh sizes increasing in geometric progression. Such methods may reduce the bias, but as Hamley (1980) has emphasised, knowledge of mesh selectivity is still meagre.

Catch data obtained with gill-nets are commonly used to compare the relative abundance of fish among populations, and to show change within populations (Ricker, 1975; Hamley 1980). Catch data have included both yield (weight of fish captured per unit area (Rounsefell, 1946; Ryder *et al.*, 1974)) and, more commonly, catch per unit of effort (weight of fish captured per unit of fishing effort (Beggs & Gunn, 1986; Kelso *et al.*, 1986)). Catches by passive fishing gear such as gill-nets can be influenced by behavioural differences among and within species, the season of capture, and various gear characteristics (Ryan & Kerekes, 1989).

Gill-net selectivity is usually described by curves, one for each mesh size, that show how the probability of catching a fish changes according to the size of that fish (Figure 4.1). If the size frequency distribution of the fish population was known, selectivity could be determined from catches by:

$$s_{ij} = \frac{C_{ij}}{X_i N_j}$$

where s_{ij} is the selectivity of mesh i toward fish of size j, C_{ij} is the catch of fish j by mesh i, X_i is the fishing effort by mesh i, and N_j is the number of fish j in the exploited population (Hamley & Regier, 1973). However, unless the selectivity is already known, the N_j can be determined only by techniques such as mark-recapture or counts in a circumscribed area. Therefore, techniques have been developed to estimate gill-net selectivity "indirectly" without first estimating the N_j

(Regier & Robson, 1966). These techniques compare the catches by two or more mesh sizes, and assume that the selectivity curves for all meshes have the same shape and amplitude (Figure 4.1) (Baranov, 1914). This assumption has been questioned (Ricker, 1947; Ishida, 1964; Regier & Robson, 1966; Hamley, 1972) but has never been fully tested.

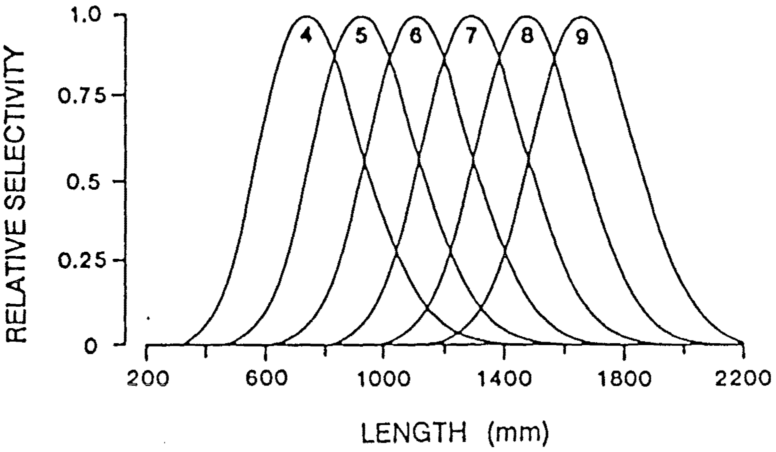


Figure 4.1 Estimated relative selectivities as a function of length of gummy shark, *Mustelus antarcticus* Günther, for 4-9 inch mesh gill-nets (labelled 4-9). Reproduced from Kirkwood & Walker, 1986, Figure 1.

Only Koike (1961), Cucin & Regier (1966), and Sechin (1969) have estimated gill-net selectivity "directly", by fishing known populations without making prior assumptions about the shapes or amplitudes of the curves. However, each author used only one mesh size, and so could not compare the curves for different meshes. All studied smooth-bodied fish (trout, whitefish, and bream respectively), which are usually wedged in the meshes, and all obtained unimodal normal (Gaussian) or skew-normal selectivity curves. However, the selectivity curves can be very skewed or even multimodal for species of fish that are commonly tangled in nets (Gulland & Harding, 1961; Holt, 1963; Riedel, 1963; M^{c}Combie & Berst, 1969; Coulter, 1970), but no direct estimates exist for such fish.

I found no literature that investigates the catch of gill-nets from a population which has been visually surveyed previously. The comparison of the gill-net catch from a 'known' population will allow gill-net selectivity to be derived directly, and establish how a gill-net samples a resident population of reef fish.

The aim of this study was to investigate the relationships between reef fish assemblages and the associated catch from gill-nets that were set among these assemblages. These relationships could then be used to estimate gill-net selectivity "directly" for species observed in the assemblages and then subsequently caught. Behavioural and morphological differences between species could be related directly to gill-net catches, providing further information about the selection characteristics of gill-nets for individual species. By determining the selection characteristics of gill-nets to mobile reef fish it should be possible to predict the effect of intensive gill-netting on reef fish populations.

4.2 MATERIALS AND METHODS

Seven sites were selected around the Kaikoura Peninsula (Figure 4.2), which differed in depth, substrate and algal types (Table 4.1). At each site, five 30x5 metre visual transects were done. The number, size (standard length) and sex (where visually identifiable) of all mobile reef fish seen in transects were recorded. The average depth of each site was estimated using a diver's depth gauge. The transects were completed between 8.00 am and 10.00 am, and the site was marked with a buoy.

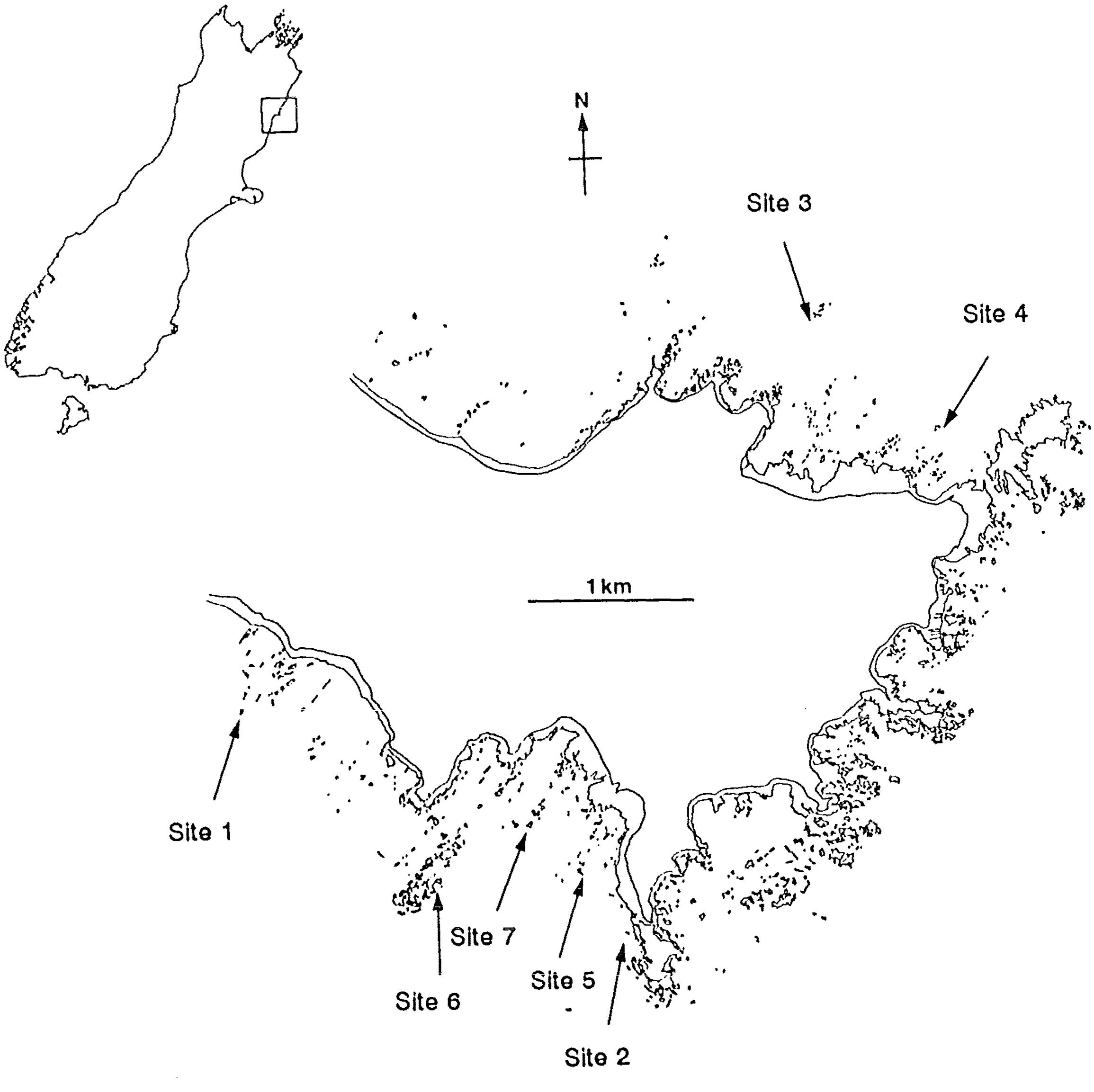


Figure 4.2 The Kaikoura Peninsula on the east coast of the South Island with the seven study sites shown.

On the same day, nine gill-nets were set randomly at the marked site. Three replicate nets of each of three mesh sizes (2.5", 3.5" and 4.5") were set for six hours from late morning to late afternoon. The nets were transported back to the

Table 4.1 Habitat description and average depth of the seven sites chosen for visual survey and subsequent experimental gill-netting.

SITE	HABITAT DESCRIPTION	DEPTH
1	Rocky reef, mixed algae with cobbled patches	7 m
2	Rocky reef, mixed algae, mainly *Marginariella boryana*	12 m
3	Cobbled bottom, red algal carpet with clumps of *M. boryana*	13 m
4	Rocky reef, mixed algae, mainly *Carpophyllum maschalocarpum*	5 m
5	Rocky reef, mixed algae	11 m
6	Sandy bottom, patch reefs with clumps of *M. boryana*	12 m
7	Rocky reef, *Marginariella boryana* forest	8 m

laboratory with the fish still entangled in them. The fish were then removed from the nets, their standard length was measured to the nearest millimetre, and where possible the fish were visually sexed. The combined catch at each site was derived by randomly pooling the catch from one net of each mesh size. Because there were three repicates of each mesh size, this yielded three replicates of combined mesh sizes at each site.

The number of each species observed in each of the five transects at each site was compared with ANOVA, and the Tukey-Kramer method was used to determine differences between means. The number of fish from each species caught in each mesh size and in total was analysed with ANOVA between sites. Correlation analyses were done on the total number of each species counted and caught, and similarly on the proportion of the total count and catch that each species comprised. The total number of fish and total number of species caught in each mesh size at each site was compared with ANOVA. The standard length of individual species seen in the visual survey and caught in the gill-nets was compared with ANOVA. Cochran's tests for homogeneity of variances were done prior to all ANOVA, and where appropriate, transformations of data were made.

4.3 RESULTS

The numbers of individual species observed during the visual survey varied considerably between sites (Figures 4.3-4.9). The data in these graphs have been grouped, with the species that were seen in the visual survey but not caught in the gill-nets on the left, and those that were caught but not seen on the right of the graph. The central region of each graph contains species that were both observed

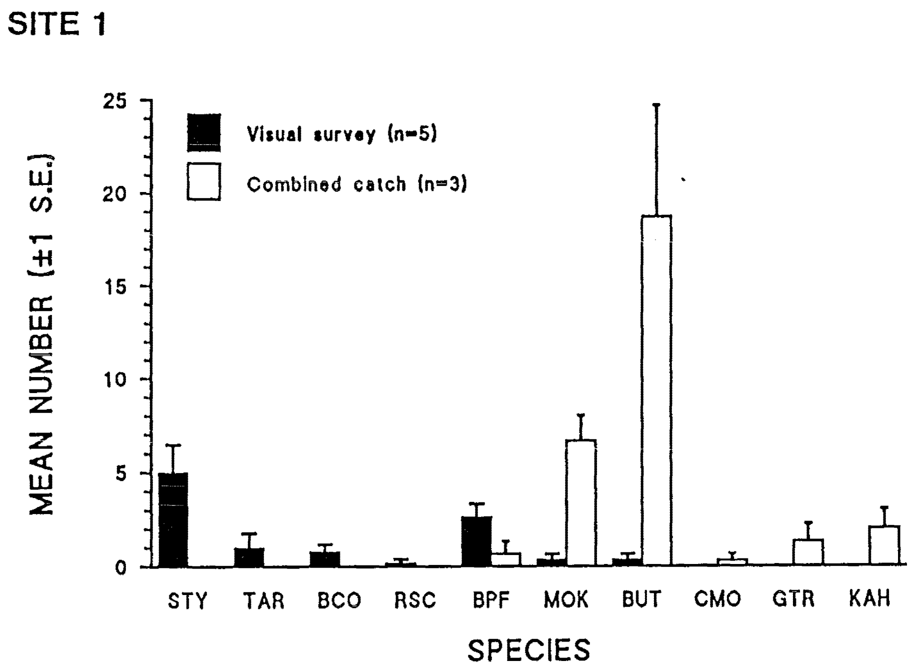


Figure 4.3 The mean number (± 1 S.E.) of each species observed in five transects of a visual survey, and of those caught in three replicate sets of three mesh sizes of gill-net at Site 1.

SITE 2

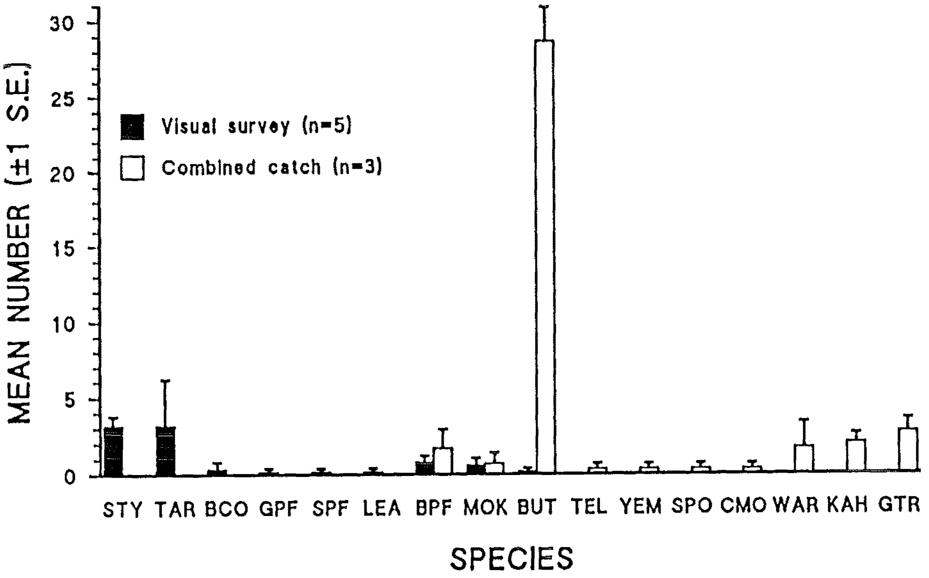


Figure 4.4 The mean number (± 1 S.E.) of each species observed in five transects of a visual survey, and of those caught in three replicate sets of three mesh sizes of gill-net at Site 2.

SITE 3

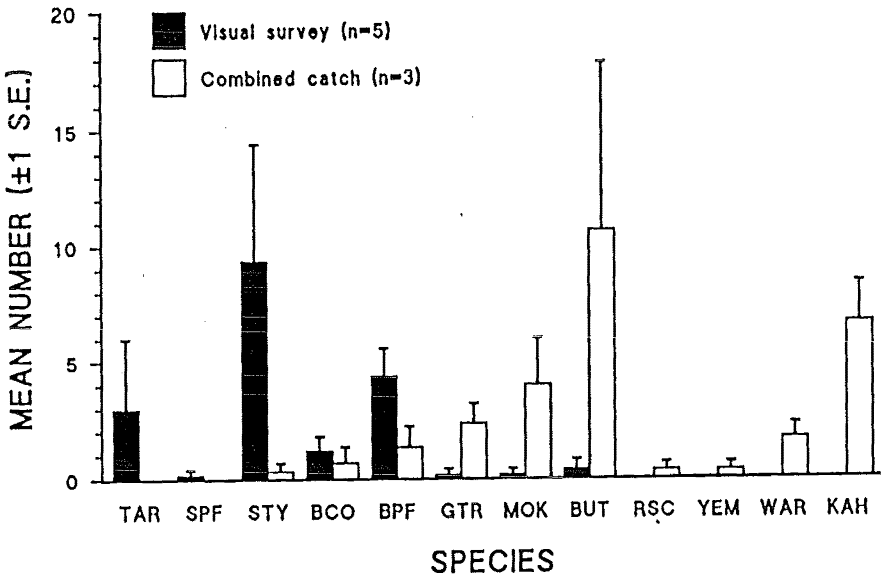


Figure 4.5 The mean number (± 1 S.E.) of each species observed in five transects of a visual survey, and of those caught in three replicate sets of three mesh sizes of gill-net at Site 3.

SITE 4

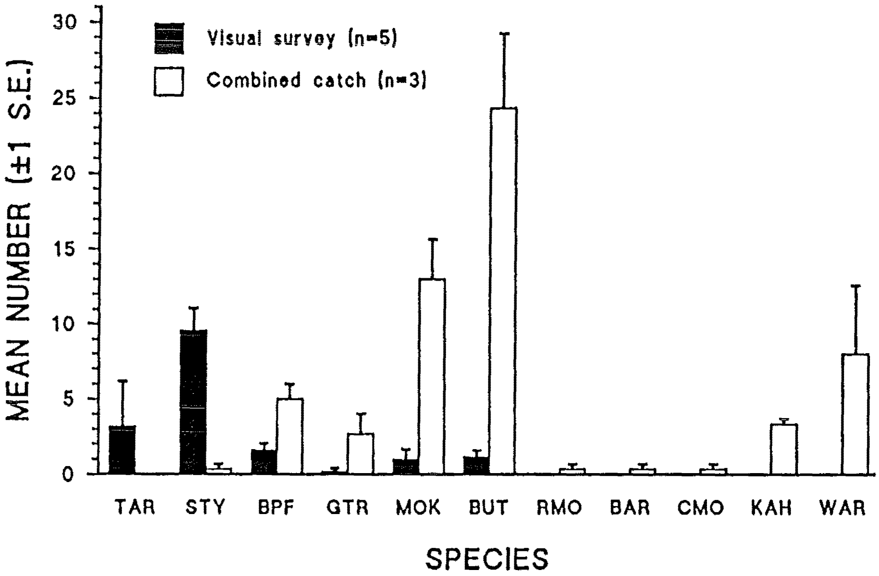


Figure 4.6 The mean number (± 1 S.E.) of each species observed in five transects of a visual survey, and of those caught in three replicate sets of three mesh sizes of gill-net at Site 4.

SITE 5

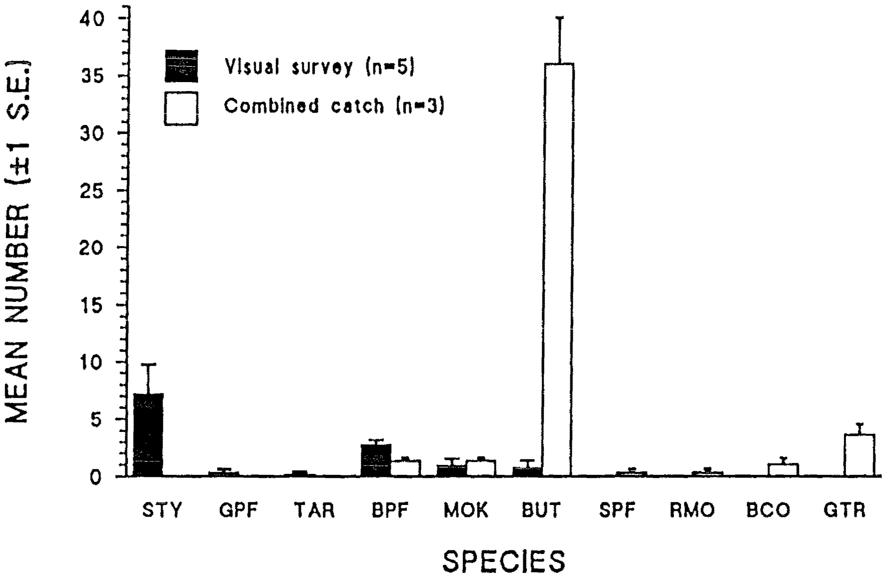


Figure 4.7 The mean number (± 1 S.E.) of each species observed in five transects of a visual survey, and of those caught in three replicate sets of three mesh sizes of gill-net at Site 5.

SITE 6

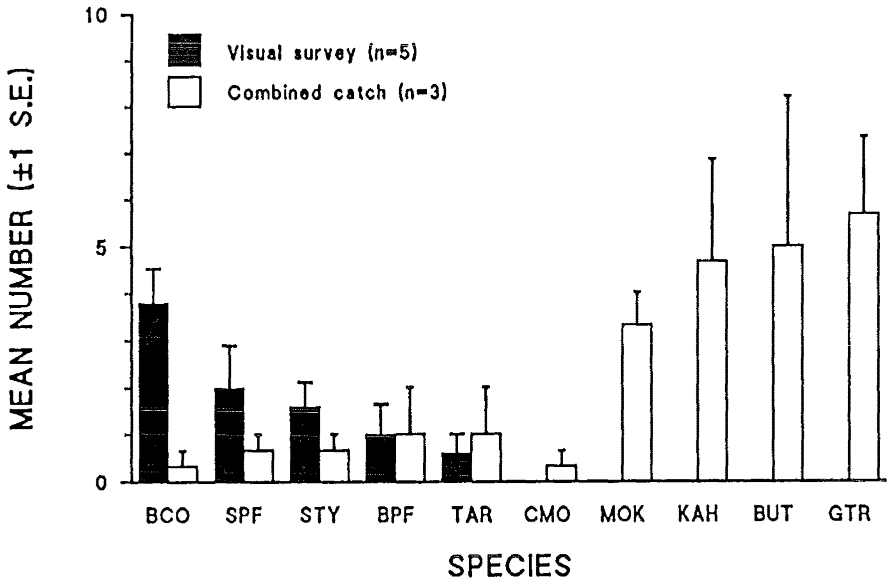


Figure 4.8 The mean number (± 1 S.E.) of each species observed in five transects of a visual survey, and of those caught in three replicate sets of three mesh sizes of gill-net at Site 6.

SITE 7

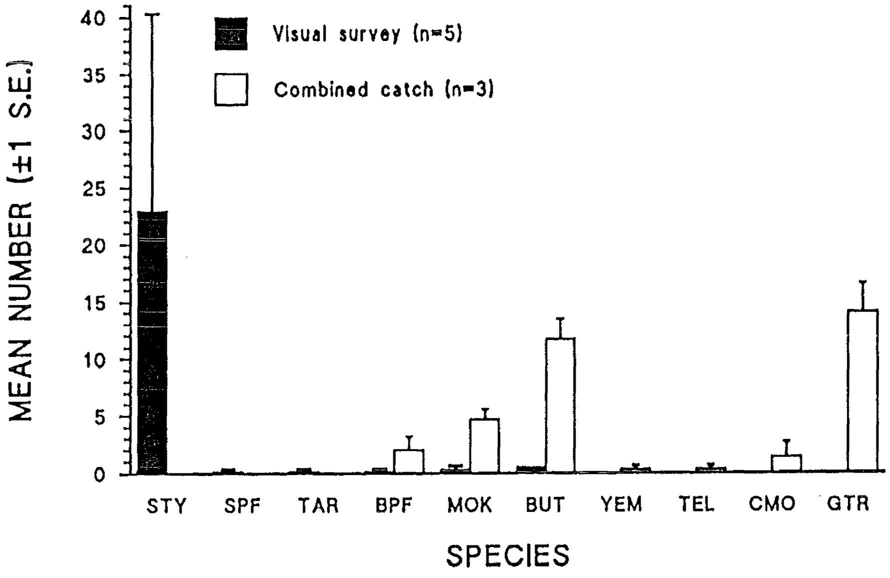


Figure 4.9 The mean number (± 1 S.E.) of each species observed in five transects of a visual survey, and of those caught in three replicate sets of three mesh sizes of gill-net at Site 7.

and caught at each site. There were no significant differences in the total number of fish observed at each site ($F_{6,28} = 0.60$, $p = 0.730$), but there were significant differences in the numbers of banded wrasse, *Notolabrus fucicola*, ($F_{6,28} = 5.40$, $p = 0.001$), scarlet wrasse, *Pseudolabrus miles*, ($F_{6,28} = 2.79$, $p = 0.029$), girdled wrasse, *Notolabrus cinctus*, ($F_{6,28} = 3.95$, $p = 0.006$) and blue cod, *Parapercis colias*, ($F_{6,28} = 11.06$, $p < 0.001$) between sites.

The greatest number of fish was observed at site 7, primarily because of the high but variable number of spotties, *Notolabrus celidotus,* observed at this site (Figure 4.9). Banded wrasse numbers were significantly greater in site 3 (Figure 4.5) than in all sites except site 1 and site 5. Scarlet wrasse numbers were significantly greater in site 6 than in all other sites (Figure 4.8). Butterfish, *Odax pullus*, were observed in similar numbers at all sites, but were slightly more common at site 4 (Figure 4.6). Blue cod were observed in significantly higher numbers in site 6 (Figure 4.8) than in all other sites. Blue moki, *Latridopsis ciliaris*, numbers were consistent across all seven sites.

There was a significant difference in the total number of fish caught (all mesh sizes combined) at each site ($F_{6,14} = 5.79$, $p = 0.003$)(Table 4.2). Tukey's pairwise comparisons showed that significantly more fish were caught at site 4 than at all other sites except site 2 and site 5. However, there was no significant difference between the number of species caught at each of the seven sites ($F_{6,14} = 2.14$. $p = 0.113$)(Table 4.2).

Table 4.2 Mean number of fish and mean number of species caught in gill-nets at seven sites around the Kaikoura Peninsula by gill-nets. At each site, the three catches from each of the three mesh sizes were randomly pooled to produce three replicates which each containing the catch from a 2.5", 3.5" and 4.5" net.

		NUMBER OF FISH		NUMBER OF SPECIES	
SITE	n	MEAN	STD DEV.	MEAN	STD DEV.
1	3	29.667	9.292	4.667	0.577
2	3	39.000	4.583	6.000	1.000
3	3	28.333	15.275	6.667	1.528
4	3	57.667	4.509	7.000	1.000
5	3	44.000	6.557	5.333	0.577
6	3	22.667	7.095	6.333	1.155
7	3	34.333	6.429	4.667	1.528

There was a significant difference between the total number of fish caught by each mesh size ($F_{2,60} = 54.86$, $p < 0.001$)(Figure 4.10). Tukey's pairwise comparisons showed that the 2.5" mesh caught significantly more fish than the 3.5", mesh which in turn caught significantly more fish than the 4.5" mesh. There was also a significant difference between the total number of species caught by each mesh size ($F_{2,60} = 29.81$, $p < 0.01$)(Figure 4.10). Tukey's pairwise comparisons showed that the 2.5" mesh caught significantly more species than the 3.5" mesh, which in turn caught significantly more species than the 4.5" mesh.

The correlation analyses between the total number of each species observed during the visual surveys at each site and the total number of each species caught by all three mesh sizes at that site gave only two significant correlations. The number of spotties observed in the visual surveys was positively correlated with the

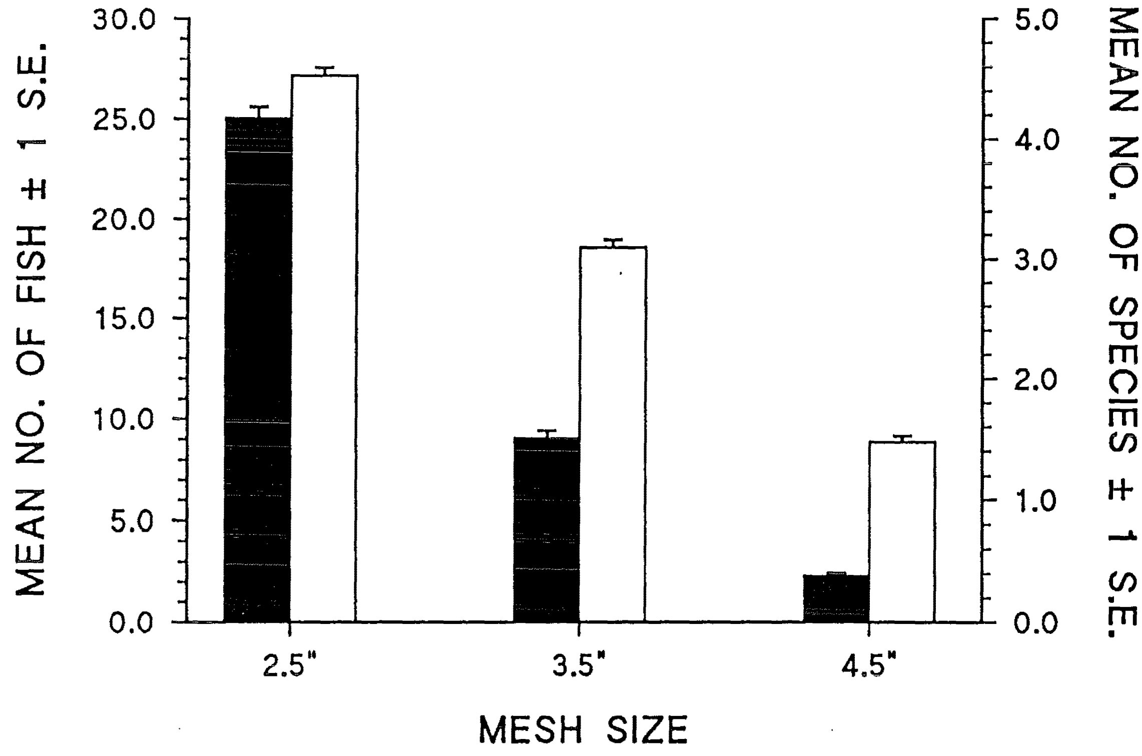


Figure 4.10 The mean number of fish (solid bars) and mean number of species (open bars) caught by gill-nets of three different mesh sizes around the Kaikoura Peninsula. The catch from each mesh size is pooled from seven sites (n = 21).

number of spotties caught in the gill-nets (r_5 = 0.830, $p < 0.05$). However, the relative abundance of spotties in each of the above categories was significantly different (4 spotties were caught in the gill-nets, while 295 were observed during the visual surveys). A similar relationship was observed for scarlet wrasse (r_5 = 0.843, $p < 0.05$). The correlation between the proportion of the total fish observed at each site and the proportion of the total catch for each species gave only one significant correlation. The proportion of scarlet wrasse observed in the visual survey at each site was significantly correlated (r_5 = 0.953, $p < 0.001$) to the proportion of scarlet wrasse caught by gill-nets at that site. However, the relative abundance of this species in each category was significantly different (13 fish were observed, and only 3 were caught).

The mean number of each species observed in the five transects at each site during the visual survey, and the mean number of each species caught in the gill-nets at that site, clearly demonstrates the lack of correlation between species counted and those caught (Figure 4.3-4.9).

The labrids *Notolabrus celidotus* and *Notolabrus fucicola* were the two species seen in the highest numbers at most sites. Tarakihi, *Nemadactylus macropterus,* were also common, but more variable in numbers. Butterfish were caught in the highest numbers at most sites. The pelagic species kahawai, *Arripis trutta*, and warehou, *Seriolella brama*, were also caught frequently, but rarely seen in the visual transects. The herbivorous marblefish, *Aplodactylus arctidens,* made up a large percentage of the total catch at most sites (mean percentage of total catch at each site = 13.7 ± 1.9 %), but was rarely observed during the visual surveys (mean percentage of total fish observed at each site = 0.3 ± 0.1 %). Blue moki, *Latridopsis ciliaris*, were also caught in disproportionately greater numbers than those observed in the visual surveys. There was little correlation between the number of each species observed and those subsequently caught, when the percentage composition of the visual surveys and the combined catch of all three mesh sizes are compared by species (Figure 4.11).

The species that were observed and subsequently caught in great enough numbers to be compared by ANOVA show no significant difference in standard length (Table 4.3). A comparison of the standard lengths of all species observed during the visual survey and all species caught in the gill-nets (Figure 4.12) showed a significant difference in sizes ($F_{1,1276}$ = 1516.24, $p < 0.001$). The mean standard length of all fish observed during the visual surveys was 139.16 ± 2.59 ($\bar{x}$ ± S.E.). The mean standard length of all fish caught in the combined gill-nets was 266.69 ± 2.04.

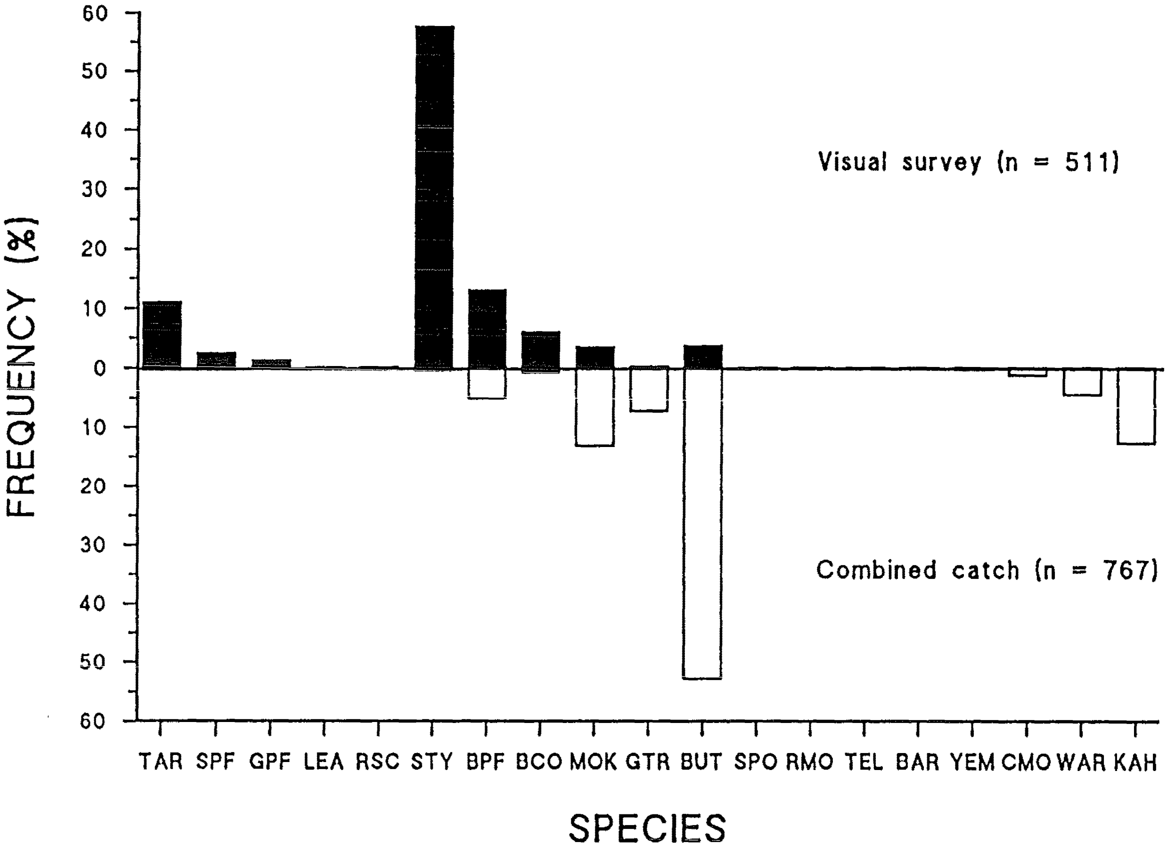


Figure 4.11 The percentage composition by species of the total number of fish observed during the visual surveys, and of those subsequently caught in the gill-nets.

When the combined catch is separated into the catch from each of the three mesh sizes (Figure 4.13), the 2.5" is the best approximation to the length frequency curve derived from the visual survey. However, there is still an obvious difference in the standard length of fish sampled by each method. The size distributions of the catch of the 2.5"and 3.5" mesh sizes appear to be bimodal. This is likely to be a result of differences in the method of capture (section 5.3.2). Fish which are gilled in a gill-net generally have a larger fork length than those that are wedged.

By combining morphological relationships with catch data, it is possible to derive an expected catch at each site. This is best described with a worked example:

Table 4.3 ANOVA table and means of standard length of three species observed during visual surveys and subsequently caught in gill-nets. Eighteen fish were randomly selected from each species for comparison.

SPECIES	SOURCE	df	MS	F	p		n	MEAN	STD DEV.
Notolabrus fucicola	COUNT\CATCH	1	0.3093	4.04	0.052	COUNT	18	183.02	1.42
	ERROR	34	0.0765			CATCH	18	220.30	1.18
	TOTAL	35							
Odax pullus	COUNT\CATCH	1	0.211	1.21	0.278	COUNT	18	235.00	1.79
	ERROR	34	0.174			CATCH	18	273.88	1.11
	TOTAL	35							
Latridopsis ciliaris	COUNT\CATCH	1	0.0097	0.18	0.674	COUNT	18	225.74	1.25
	ERROR	34	0.0540			CATCH	18	233.29	1.27
	TOTAL	35							

For blue moki, *Latridopsis ciliaris*, (see Appendix 3):

Standard length (SL) = -1.46 + 0.940 x Fork length (FL)

Maximum girth (MG) = 9.84 + 0.781 FL

Opercular girth (OG) = 8.30 + 0.689 FL

94.6 % of blue moki caught throughout this project had a ratio of girth at the point of capture to mesh perimeter between 1.0 and 1.4 (see Chapter 5).

2.5" mesh perimeter = 130 mm

3.5" mesh perimeter = 176 mm

4.5" mesh perimeter = 220 mm

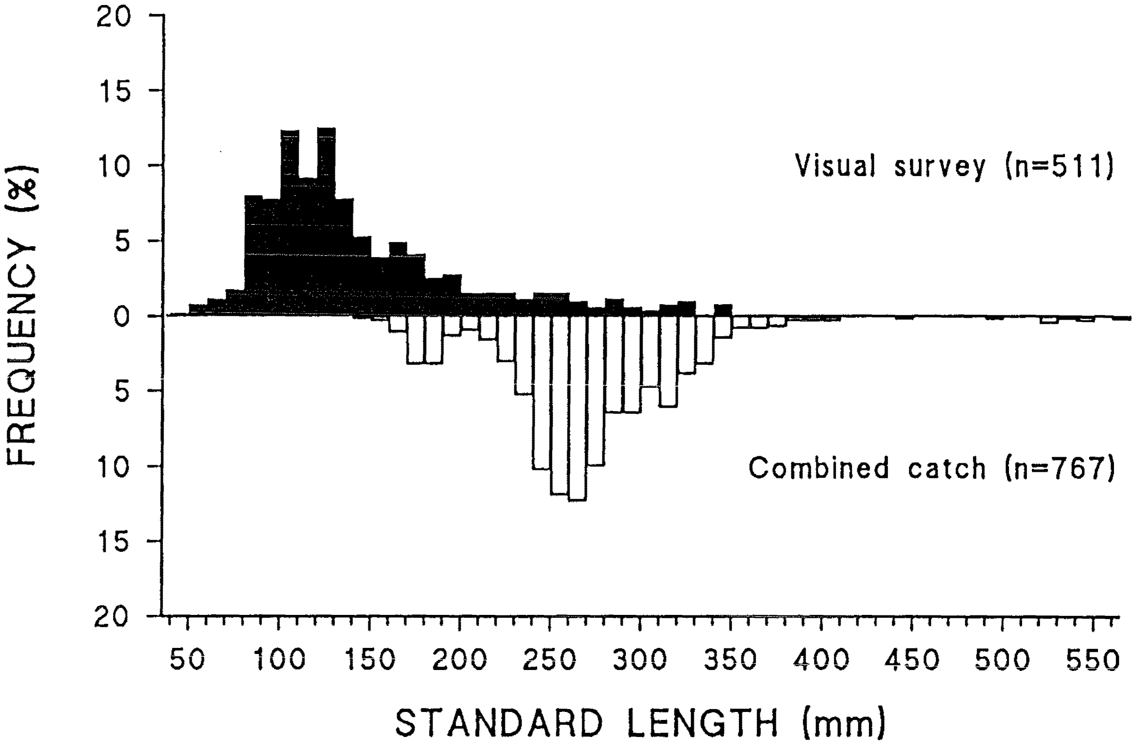


Figure 4.12 The length frequency distribution of the total population of fish observed during the visual surveys, and of the total combined catch of the three mesh sizes.

Therefore, the smallest and largest fish likely to be caught in each mesh size can be determined by deriving the standard length of the smallest fish likely to be wedged and the largest fish likely to be gilled in that mesh (Table 4.4). The maximum girth of the smallest blue moki, *Latridopsis ciliaris*, likely to be caught will be 1.0 times the mesh perimeter. The opercular girth of the largest fish likely to be caught will be 1.4 times the mesh perimeter. The standard length of these fish can then be derived from the morphological relationships described by the regression equations listed above. It should be noted that there is considerable overlap in the size classes of fish caught by each mesh size. By applying these ranges to the observed population of blue moki, it is possible to predict which size classes would be expected to be caught by each mesh size (Figure 4.14). The expected catch can then be contrasted with the observed catch for each species.

The expected catch of blue moki included all but the smallest fish observed in the visual survey (Figure 4.14). However, the observed catch contained some fish from this and smaller size classes, as well as fish expected to be beyond the size limit of the 4.5" net.

The expected catch of banded wrasse, *Notolabrus fucicola*, excluded the upper extreme of the size frequency plot of fish observed in the visual survey (Figure 4.15). However, the observed catch contained several fish considerably larger than

Table 4.4 The standard lengths of the smallest and largest fish of blue moki, *Latridopsis ciliaris*, likely to be caught in three different mesh sizes of gill-nets. Lengths are derived from observed girth\perimeter ratios and morphometric relationships. The size of fish which may become tangled cannot be derived because it is not necessarily related to mesh size.

MESH SIZE	SMALLEST FISH	LARGEST FISH
2.5" mesh	167 mm	258 mm
3.5" mesh	222 mm	346 mm
4.5" mesh	275 mm	430 mm

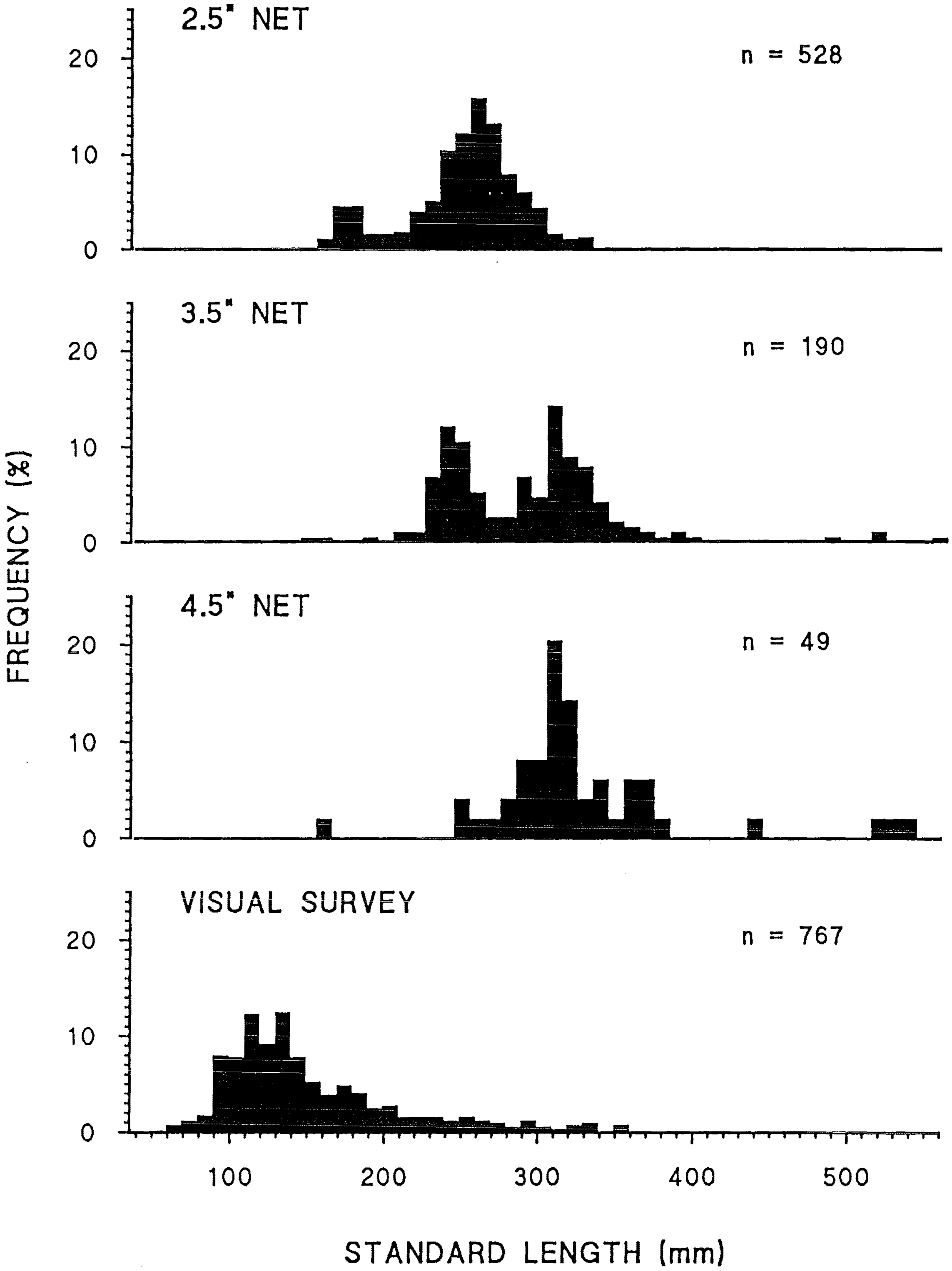


Figure 4.13 The length frequency distributions (%) of the catch from each of the mesh sizes, and the length frequency distribution (%) of the total fish population observed during the visual surveys.

the upper size limit of the 4.5" net, and no fish which could be caught exclusively by the 2.5" mesh.

The expected catch of butterfish, *Odax pullus*, excluded the lower extreme of the size frequency distribution observed during the visual survey (Figure 4.16). The observed catch was within the predicted size limits of the three mesh sizes. However, the proportion of butterfish in the 250 - 300mm size range landed in the

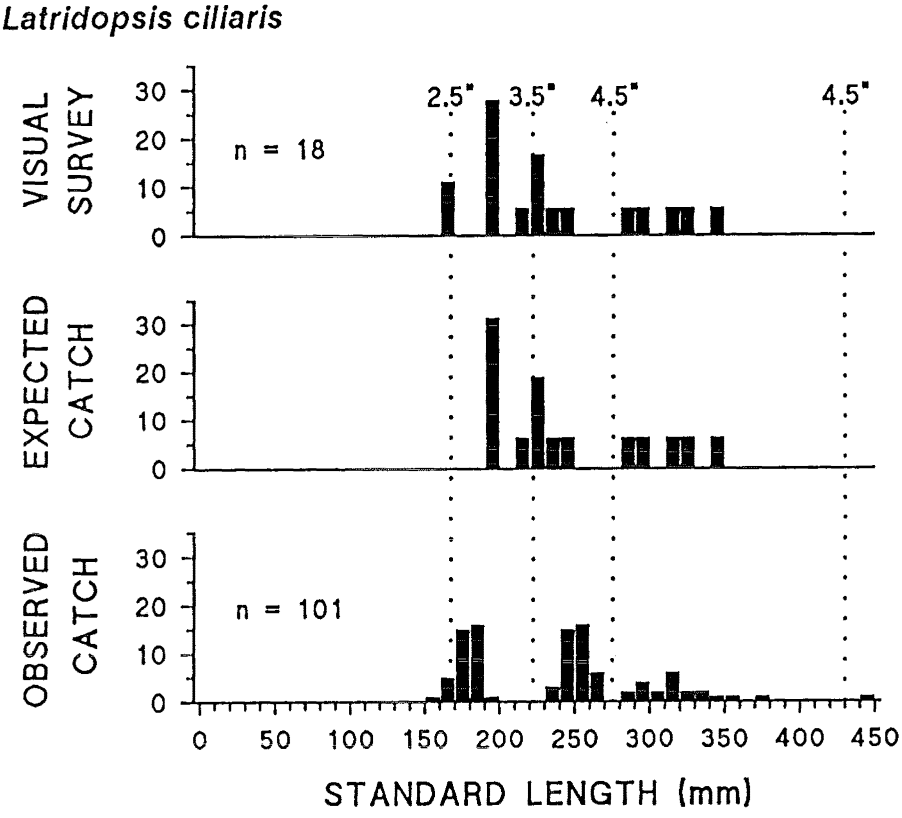


Figure 4.14 The size frequency distribution (%) of blue moki, *Latridopsis ciliaris*, observed during the visual surveys, the expected catch (derived from morphological relationships) and the observed catch from the three mesh sizes combined. Superimposed on this (dotted lines) are the lower size limits of fish likely to be caught in the 2.5", 3.5" and 4.5" mesh and the upper size limit of the 4.5" mesh. There is considerable overlap between mesh sizes.

catch of the gill-nets was considerably greater than that observed during the visual surveys.

The observed catch of spotties, *Notolabrus celidotus*, was at the upper extreme of the estimated size limits of the 4.5" nets (Figure 4.17). The size frequency peak at 120 mm observed during the visual survey was absent from the catch distribution. This size class should be susceptible to capture by both the 2.5" and 3.5" nets.

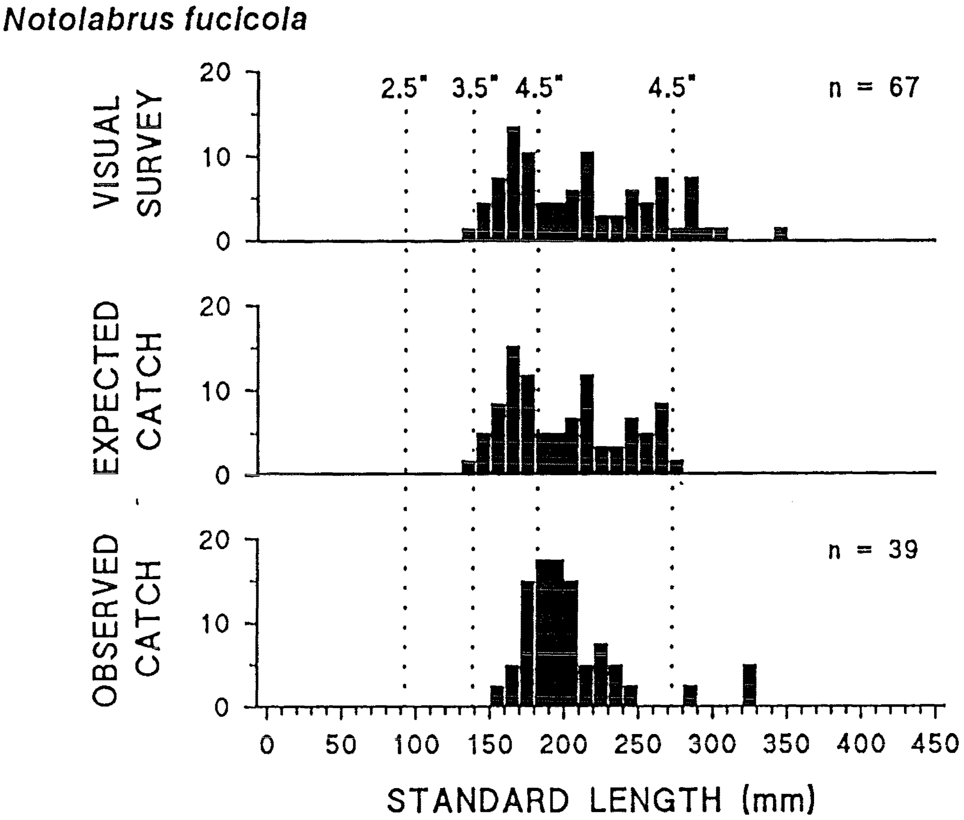


Figure 4.15 The size frequency distribution (%) of banded wrasse, *Notolabrus fucicola*, observed during the visual surveys, the expected catch (derived from morphological relationships) and the observed catch from the three mesh sizes combined. Superimposed on this (dotted lines) are the lower size limits of fish likely to be caught in the 2.5", 3.5" and 4.5" mesh and the upper size limit of the 4.5" mesh. There is considerable overlap between mesh sizes.

Although 295 spotties were observed during the visual survey, only 4 were subsequently caught in gill-nets.

The expected catch of blue cod, *Parapercis colias*, included all but the smallest size class of fish observed (Figure 4.18). However, the fish in the observed catch were at the upper extreme of the frequency distribution seen during the visual survey. The number of blue cod caught was considerably less than the number observed during the transect counts.

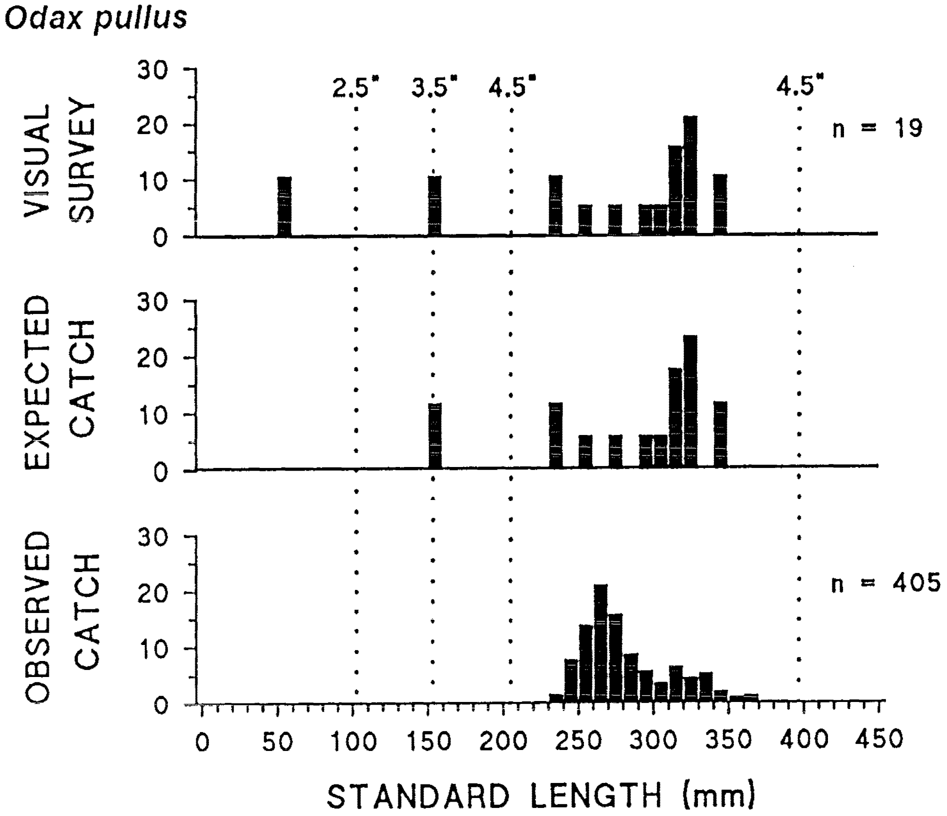


Figure 4.16 The size frequency distribution (%) of butterfish, *Odax pullus*, observed during the visual surveys, the expected catch (derived from morphological relationships) and the observed catch from the three mesh sizes combined. Superimposed on this (dotted lines) are the lower size limits of fish likely to be caught in the 2.5", 3.5" and 4.5" mesh and the upper size limit of the 4.5" mesh. There is considerable overlap between mesh sizes.

4.4 DISCUSSION

In Chapter Three, the relative abundances of several species of mobile reef fish were shown to be related to habitat. Habitats were differentiated by physical and biological characteristics, such as substratum type and the algae present. The initial selection of the seven sites for visual survey and subsequent gill-netting was designed to compare the catch with the observed fish assemblage at each site.

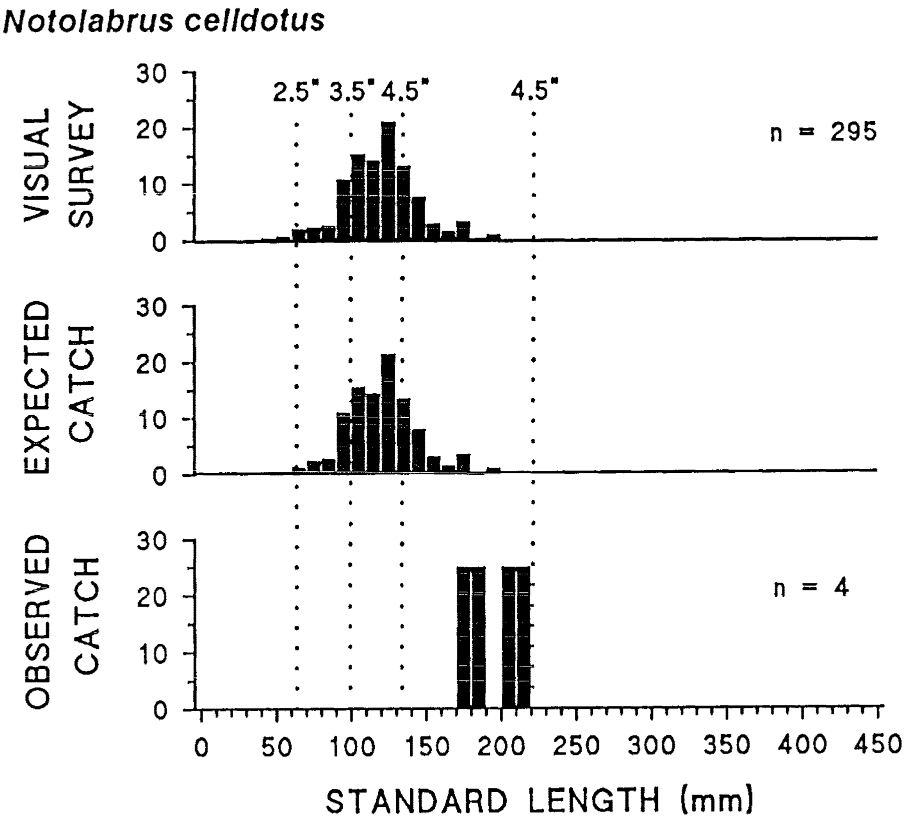


Figure 4.17 The size frequency distribution (%) of spotties, *Notolabrus celidotus*, observed during the visual surveys, the expected catch (derived from morphological relationships) and the observed catch from the three mesh sizes combined. Superimposed on this (dotted lines) are the lower size limits of fish likely to be caught in the 2.5", 3.5" and 4.5" mesh and the upper size limit of the 4.5" mesh. There is considerable overlap between mesh sizes.

Each site was selected because it represented a different form of habitat common around the Kaikoura Peninsula. By visually surveying fish populations within several different habitats and subsequently setting gill-nets within these habitats, the information obtained regarding how a gill-net samples a resident reef fish population should be more widely applicable.

The relative abundance of each species within the various habitats appears to be in good agreement with the patterns observed in Chapter 3. Butterfish, *Odax pullus*,

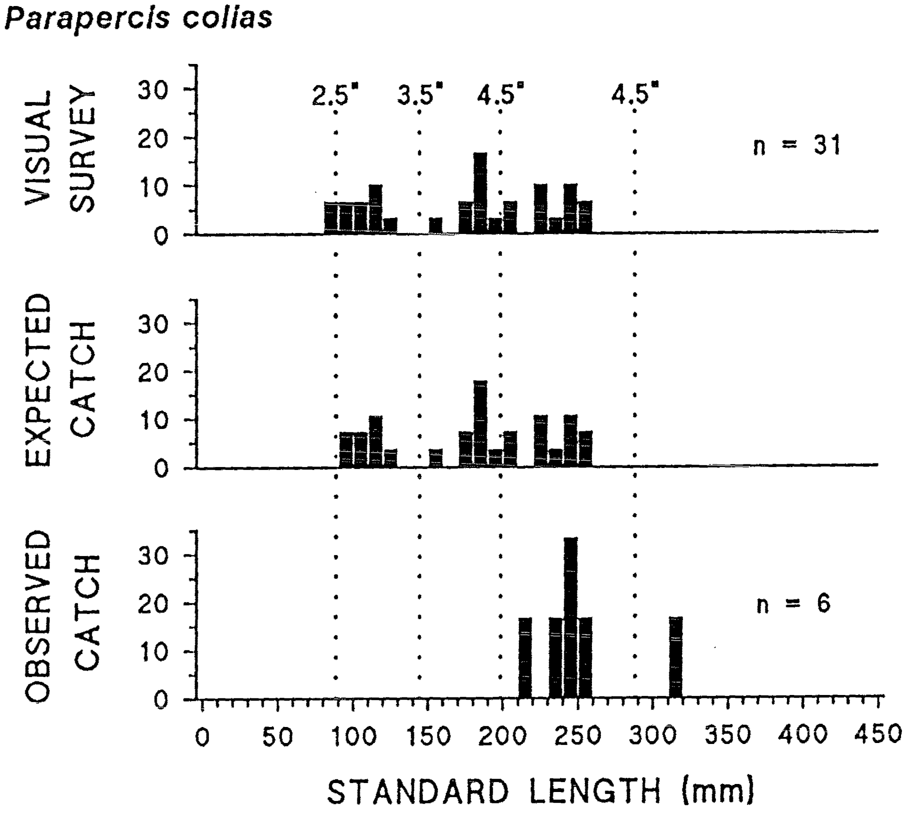


Figure 4.18 The size frequency distribution (%) of blue cod, *Parapercis colias*, observed during the visual surveys, the expected catch (derived from morphological relationships) and the observed catch from the three mesh sizes combined. Superimposed on this (dotted lines) are the lower size limits of fish likely to be caught in the 2.5", 3.5" and 4.5" mesh and the upper size limit of the 4.5" mesh. There is considerable overlap between mesh sizes.

are herbivorous, and were expected to be abundant in areas with dense algal cover. Scarlet wrasse, *Pseudolabrus miles*, are more common in deeper areas such as site 6. Blue cod, *Parapercis colias*, are a bottom dwelling carnivore that feed predominantly in sandy areas such as site 6.

Analysis of data obtained from both the visual survey and from the catch of the gill-nets showed that the habitat of site 2 appeared to support the highest number of fish species. However, there was little overlap in the species observed in the visual survey and those caught in the nets. In Chapter 3, the sandy bottom habitat (site 6 in this study) was observed to contain the highest number of species. Even with the species only seen in the gill-net catch removed, the number of species recorded to be present at site 2 is still greater than that observed in the sandy habitat in Chapter 3.

Site 7, which contained dense *Marginariella boryana* forest, was expected to contain high numbers of butterfish. However, in comparison to the other sites, butterfish numbers were low in both the visual survey and in the gill-net catch at this site.

The smallest mesh size caught significantly more fish and a greater number of species at all sites. This is may be a reflection of the relative abundance of the size class of fish susceptible to becoming trapped in this mesh. However, many fish caught by the 2.5" mesh were 'tangled' (Chapter 5) rather than truly selected by the mesh size. The high number of species caught in this mesh size is also likely to be a result of 'tangling' of larger species. Kahawai, jack mackerel and copper moki, which are usually too large to become gilled in the 2.5" net, often become tangled in the net by maxillae or fins. Because the 2.5" mesh size also catches the smaller labrids and cod that were observed to swim unhindered through the larger mesh sizes (Chapter 6), it subsequently catches more species than the 3.5" or 4.5" nets.

Although there was no significant difference in the number of fish observed at each site during the visual surveys, there was a significant difference in the number of fish caught at each site. This indicates that the number of fish seen at a site is not necessarily related to the number of fish caught at that site. Clearly, some species of fish are less susceptible to becoming caught in a gill-net than others. The disparity between the number of spotties, *Notolabrus celidotus*, and banded wrasse, *Notolabrus fucicola*, (of a size likely to be caught by the nets) observed at each site and those subsequently caught suggests these species are less susceptible to gill-netting, perhaps because of species-specific behaviour. Butterfish, *Odax pullus*, appear to be very vulnerable to gill-netting. Although observed in relatively low numbers, this species made up most of the catch at all sites. Again, this may be a result of behavioural differences between species, or morphological differences.

Further indications of the lack of susceptibility of the labrids to gill-nets is seen in the size frequency distributions observed during the visual surveys and in the subsequent gill-net catch. The banded wrasse that were caught in the gill-nets were within the size range observed during the visual surveys. However, the relative abundance of this species in the visual survey and in the catch are clearly disproportionate. This disparity is even more apparent considering that the visual survey sampled the population at each site for approximately 30 minutes, while the nets sampled the population for 6 hours.

During a sampling period, fish of different sizes should travel a distance proportional to their swimming speed, if they have the same daily activity pattern (Rudstam *et al.*, 1984). Since swimming speed is a power function of fish length (Bainbridge, 1958; Yates, 1983), large fish will travel a greater distance in any set period. Consequently, larger fish have a greater probability of encountering a gill-net than do smaller fish (Lagler, 1968). Butterfish are larger and wider ranging than the more territorial spotties and banded wrasse (Ayling & Cox, 1987). Therefore, any given butterfish will have a significantly greater probability of encountering a gill-net than a spotty or banded wrasse.

Due to the territorial nature of banded wrasse and spotties, the sample of these species taken in the gill-nets may be representative only of the labrid population in the immediate area of the net. The butterfish caught in the gill-nets may have been sampled from a much larger area because of their wide ranging habits.

The spotties caught by the gill-nets were at the upper extreme of the size frequency distribution observed during the visual surveys, but again the disparity in abundances between the visual survey and the net catch suggests that this species is less vulnerable to gill-netting. Most spotties observed were within a size range capable of being caught by the gill-nets, based on their size and the observed relationship between girth and mesh perimeter for the total catch of spotties during this project (Chapter 5). However, only the largest size classes appeared to be susceptible to becoming caught.

The total catch of fish was significantly larger in standard length than the total population observed during the visual surveys. This is primarily a result of the species composition of the two populations, rather than being due to the gill-nets selecting only the larger individuals of a population. Most fish seen during the visual survey were small labrids, blue moki and juvenile tarakihi. However, the majority of fish caught were larger butterfish, kahawai and moki. The large pelagic fish (kahawai and jack mackerel), and even some large cryptic reef fish (marblefish, *Aplodactylus arctidens*), were rarely seen during the visual surveys. This resulted in the visual surveys underestimating the size-frequency distribution of the fish population being sampled by the gill-nets at each site.

Visual surveys and experimental gill-netting produced significantly different estimates of relative abundances of mobile reef fish and transient species on reefs around Kaikoura. The visual surveys underestimated the abundance of cryptic and transient species, while the gill-net catch underestimated the abundance of some species of mobile reef fish, and distorted the size frequency distribution of others. The bias in both these methods is likely to result from behavioural differences between species.

The most common mesh size used by amateur fishers in the Kaikoura region is the 4.5" net. This is the smallest legal mesh size than can be used when targeting butterfish. If the expected catch model developed during this study is valid (the observed catch does fall within the upper and lower size limits calculated for most species) then it appears that for some species immature fish are likely to make up a large percentage of the total catch.

The upper and lower size limits of butterfish likely to be caught in the gill-nets was calculated from the 773 fish caught during this project. These limits imply that butterfish between 204 and 398 mm are the most susceptible to capture in a 4.5" net. Butterfish do not reach sexual maturity until they have a standard length of approximately 305 mm (Ayling & Cox, 1987), which suggests that a high proportion of the butterfish caught in the 4.5" mesh will be immature. If immature fish are being removed from a population, the fishery is unlikely to be sustainable.

The legal size of butterfish that may be taken is 350 mm. If the expected catch model for butterfish is correct, then most of the butterfish caught in the 4.5" net would have to be returned to the sea. However, butterfish were observed to die very quickly when caught in the nets (most fish from this species were dead when removed from the nets after only a six hour set). Amateur fishers targeting butterfish in the Kaikoura region usually leave their nets out overnight.

The effects of gill-netting on the common reef fish species *Notolabrus celidotus* appears to be insignificant. A very small proportion of the spotty population observed at each site were caught in the gill-nets. Other reef fish such as banded wrasse, blue moki and butterfish were caught in high relative numbers compared to those observed during the visual survey. However, the cryptic nature of some of these species may mean the visual survey underestimated their abundance. Gill-netting may be removing immature fish from both the blue moki and butterfish populations. If the amateur gill-net fishery of these species is to be sustainable, the minimum mesh size allowed when targeting these species may need to be revised.

The results of this study suggest that gill-nets are particularly effective at catching the species they are primarily designed to catch (i.e., butterfish, blue moki and kahawai). The gill-nets remove these species from the total fish population on a reef with relatively little by-catch of spotties and banded wrasse, the most common reef fish species in the Kaikoura region. However, several other species which are untargeted and unusable (e.g., marblefish), are caught in high numbers and subsequently wasted. A greater knowledge of mesh selectivity and fish behaviour may prevent the wastage of this untargeted by-catch.

CHAPTER FIVE

Patterns of Abundance of Fish Caught in Gill-nets

5.1 INTRODUCTION

Gill-nets are highly selective in terms of the size and species of fish they catch. The size distribution of a catch may give little indication of that of the sampled population (Hamley, 1975; Boy & Crivelli, 1988). Gill-nets that use a series of different mesh sizes simultaneously catch a broader range of fish size-classes. The scientific study of gill-nets began with Baranov (1914), who proposed that a fish is caught if it enters a mesh beyond the gill covers but cannot pass completely through the mesh. Baranov was the first to suggest that selectivity curves for different mesh sizes are uniform in shape. These generalisations have remained the basis of most subsequent work.

Baranov (1914) recognised three ways in which a fish can be caught in a gill-net, i.e., wedged, gilled or tangled. For smooth fusiform fishes, the following generalisations can be made from the studies of Taguchi (1961), Regier & Robson (1966) and Lander (1969):

a. large fish are wedged more anteriorly than smaller fish in a given mesh size;
b. fish of a given size are wedged more anteriorly in small than in large meshes;
c. fish with head girths larger than the mesh cannot enter, but may be snagged by the teeth, maxilla or preopercle;
d. fish with maximum girths smaller than the mesh typically escape, but may become tangled in the mesh.

Different species of fish are not equally vulnerable to any given method of fishing.

Selectivity can be defined as any process that causes the probability of capture to vary with the characteristics of a fish. According to Lucas *et al.* (1960), selectivity is a quantitative expression of selection, and traditionally means selection by size. There are many other factors that influence the vulnerability of fish to being caught in a gill-net. Hamley (1975) listed these factors as the reaction of fish to nets, different behaviour of fish, type of net construction, hanging ratio of nets, net saturation and gill-net characteristics such as visibility, elasticity of meshes and filament size. Dimensional characteristics of fishes such as length-weight relationships (Kipling, 1957), length-condition relationships (Regier, 1969), and length-girth relationships (Kawamura, 1972) also influence selectivity.

Many studies of gill-net selectivity have been done in tropical and temperate waters. It is generally agreed that the gill-net selectivity of a particular species by a given mesh size is characterised by a lower size limit, below which fish are small enough to pass through the mesh without hindrance, and an upper size limit, above which fish do not enter the mesh and become entangled (Hamley, 1975). Between these limits, the length frequency distribution of the catch is approximately normal, with a mode at the length where the corresponding girth measure is slightly greater than the mesh perimeter (M^{c}Combie & Fry, 1960; Berst, 1961; Garrod, 1961; M^{c}Combie & Berst, 1969).

Selectivity curves based on the girth of fish at the point where the mesh holds them, rather than on maximum fish girth or length, show that the efficiency of capture tends to be maximal when the girth of the fish is 1.0 - 1.2 times as great as the perimeter of the mesh. M^{c}Combie & Berst (1969) found catch efficiency to be negligible at girth/perimeter ratios smaller than 0.8 or 0.9, and that efficiency declined rapidly at ratios greater than 1.2. However, fish can be caught with girth/perimeter ratios of up to 1.6.

The number of fish caught in gill-nets does not necessarily increase in direct proportion to the time that nets are in the water (Kennedy, 1951). Van Oosten (1935) showed that gill-nets left for eight nights caught only 47 per cent more fish than the same nets left for four nights, whereas if the catch increased in direct proportion to the time fished, the increase should have been 100 per cent. The presence of captured, struggling fish and of dead fish may result in the efficiency of gill-nets decreasing with time (Kennedy, 1951).

The analysis of catches of fish taken in gill-nets is complicated by the passive nature of this type of fishing gear (Berst, 1963). Several factors affect gill-net catches, such as the movement of fish, the shape and structure of the fish, and the associative pattern or grouping of the individuals of any species or assemblage of species (Moyle, 1950). When there is a relatively isolated catch of fish in a large area of net, it seems reasonable to assume that the spatial distribution of the fish in the net corresponds to their distribution on approach. However, the correspondence between the spatial distribution of fish in the net and that in the water may be distorted by the escape of fish that are too big or small to be entangled in the mesh.

The aim of the present study was to determine the size range and abundance of the most common fish species caught in gill-nets in central New Zealand. The data used for this analysis resulted from the catch of nets used for comparison of reef fish populations previously assessed by visual survey, and from gill-nets being used for behavioural observations. By recording the morphological features of the subsequent catch, along with the form and position of entanglement, it was intended to identify the most important factors that determine the vulnerability of individual species to particular mesh sizes.

5.2 MATERIALS AND METHODS

This part of the study was done around the Kaikoura Peninsula, within the Marlborough Sounds and along the Wellington coast, using the combined catch of 251 net sets and three mesh sizes. The dimensions of the nets used were:

Mesh Size (")	2.5	3.5	4.5
Net Length (m)	30	30	30
Filament Size (mm)	0.36	0.48	0.58
Net Height (mesh cells)	41	26	20
Mesh Perimeter (mm)	130	176	220

The gill-net catch used for this study was pooled from several smaller studies carried out during the course of my project. Consequently, the resulting sampling design is a combination of that of several studies and is not orthogonal. The nets were set in water depths ranging from 3 - 20 metres and for periods of 0.5 to 20 hours. At some sites, the fish populations had been surveyed prior to the nets being set, with visual transects. During some sets, observations were made of fish behaviour around the nets. At the end of all sets, the nets were brought back to the laboratory with the fish still entangled in the mesh.

5.2.1 Spatial distribution

As each fish was removed from the net its species, fork length and vertical position in the net (upper, mid, lower section) were recorded. The net was divided vertically into thirds, and by measuring the distance from either the lead line or the float line, the vertical position could be determined accurately. The data were collated for individual species in each of the three mesh sizes. The proportion of each species caught in each third of the net was then calculated and plotted for the three mesh sizes and for the total fish caught.

5.2.2 Form of entanglement

The method by which each fish became trapped was recorded as it was removed from the net. If a fish was held by mesh encircling its body between the posterior edge of its operculum and the base of its pectoral fin, then it was determined to be 'gilled' (Plate 5.1). If the mesh encircling the fish's body was posterior to the base of the pectoral fin, it was determined to be 'wedged' (Plate 5.2). If the fish was held because of the mesh snagging an appendage, such as fins, spines, teeth, or maxilla (Plate 5.3), or if the fish's struggling had enveloped it in the mesh (Plate 5.4), then it was described as 'tangled'.

The form of entanglement data were collated for each species in each mesh size, and the proportion of each species captured by each method was calculated. 3 x 3 contingency tables were created, with each of the three forms of entanglement and the three mesh sizes represented. The catch data were placed into these tables, and analysed with Chi-square tests of independence (Minitab, release 8.2).

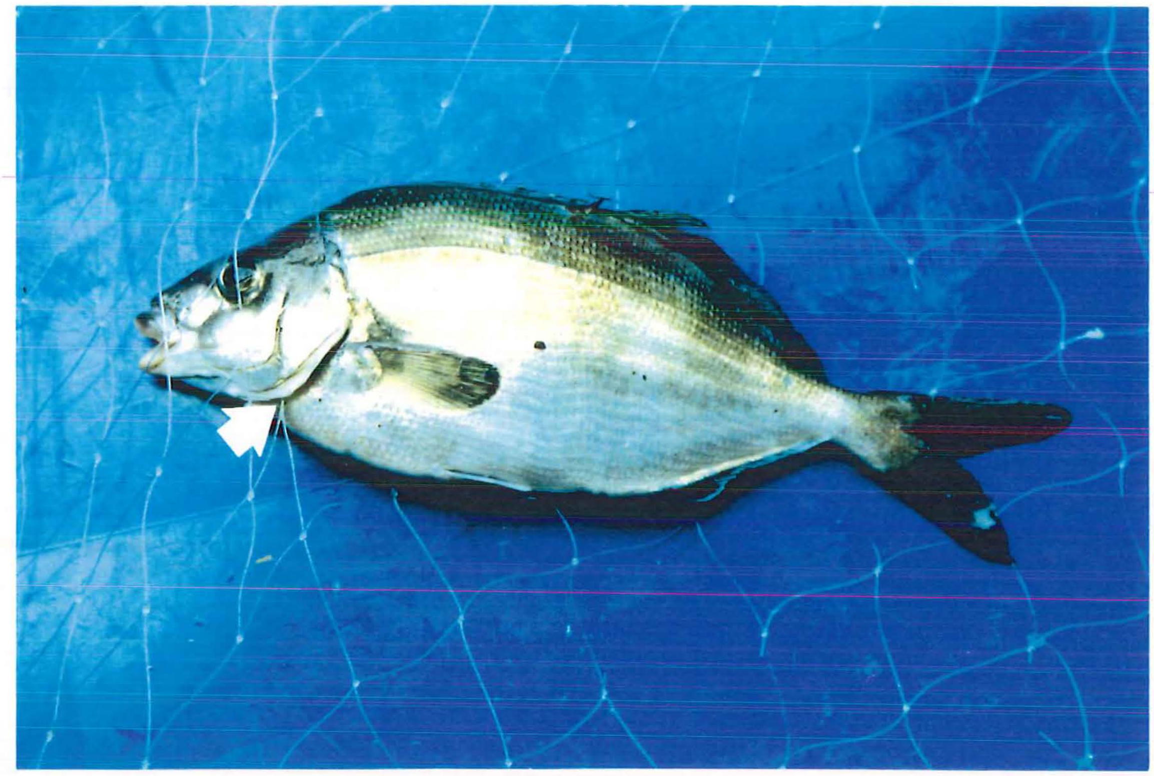


Plate 5.1 A blue moki, *Latridopsis ciliaris*, 'gilled' in a 4.5 inch gill-net. The mesh is trapped behind the operculum (arrow) preventing the fish from escaping backwards, while the mesh size is too small to allow forward progress.

Plate 5.2 A juvenile butterfish, *Odax pullus*, 'wedged' in a 2.5 inch gill-net. The resistance of the mesh encircling the fish's body prevents both forward or backward progress.

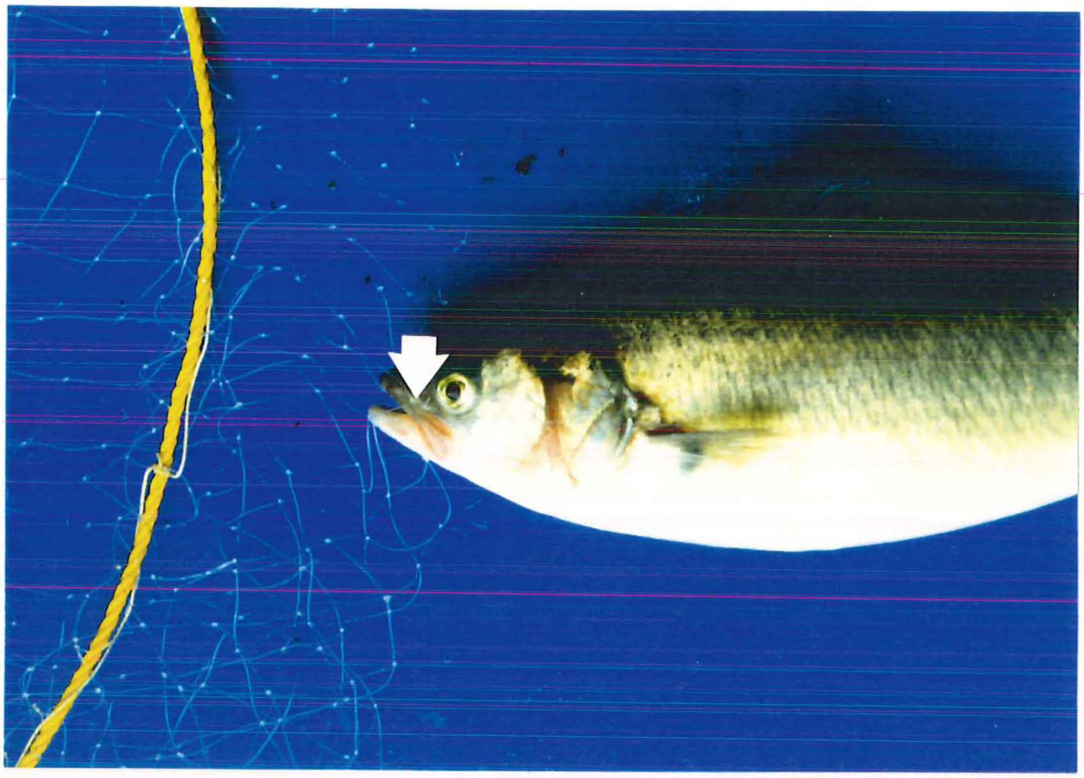


Plate 5.3 A kahawai, *Arripis trutta*, 'tangled' in a 2.5 inch gill-net. The mesh has become trapped behind the fish's maxilla (arrow) preventing the fish escaping backwards, while the small mesh size prevents forward progress.

Plate 5.4 A copper moki, *Latridopsis forsteri*, 'tangled' in a 2.5 inch gill-net. The fish was not initially held by the net, as the mesh has not passed over the operculum (arrow). However, its subsequent struggle has enveloped it in the net.

Partial χ^2 tests were used, where possible, to separate mesh effects. Mesh sizes were combined if cells had expected counts less than 1.0, or if more than 20% of the cells had expected frequencies less than 5.

The mean fork length of each species caught by each method was plotted for each of the three mesh sizes. The fork length of each species caught by each method was analysed with ANOVA (Minitab, release 8.2), and the Tukey-Kramer method was used to determine differences between means (Sokal & Rohlf, 1981). Before comparisons were made, Cochran's tests for homogeneity of variances were done. Where appropriate, transformations of data were done prior to ANOVA.

The relationship between fork length and form of entanglement for individual species was also investigated. The mean fork length of each species caught in each of the three mesh sizes was plotted for each of the three forms of entanglement. The fork length of each species caught in each mesh size was analysed with ANOVA, and the Tukey-Kramer method was used to determine differences between means. Butterfish, *Odax pullus*, was the only species that was caught in large enough numbers to allow detailed analysis. The proportion of fish caught by each method in each size class of butterfish was plotted for the 2.5 and 3.5 inch nets.

5.2.3 Temporal relationships

The duration of each net set was recorded. The total number of fish caught in each set was noted, and the mean number of fish caught was plotted against time. The total number of species caught in each net set was also recorded, and plotted against time. Each fish caught was given a condition index according to the degree of damage it had sustained while in the net. The index was defined as follows:

Severe damage.	This included loss of skeletal material.
Major damage.	This included major lesions with flesh loss, and internal sea lice damage.
Minor damage.	This included minor lesions, fin loss or damage, and eye damage.
No damage.	Only chafing or scale loss as a result of contact with the mesh filament.

The proportion of fish in each condition class was plotted against time for each of the three mesh sizes.

5.2.4 Mesh selectivity

The mean fork length of each species caught by each of the three mesh sizes was plotted. The fork lengths of species caught in each mesh size were analysed with ANOVA, and the Tukey-Kramer method was used to determine differences between means. Before comparisons were made, Cochran's tests for homogeneity of variances were done. Where appropriate, transformations of data were done prior to ANOVA.

The girth of the fish at the point of entanglement (opercular girth for fish that were 'gilled', and maximum girth for fish that were 'wedged' (Figure 5.1)) was determined for all fish caught. Fish that were tangled were excluded from this analysis. The frequency distribution of the ratio of the girth at the point of entanglement to the net mesh perimeter was plotted. ANOVA was used to investigate the species and mesh size interaction, with girth as the variable. The Tukey-Kramer method was used to determine differences between means.

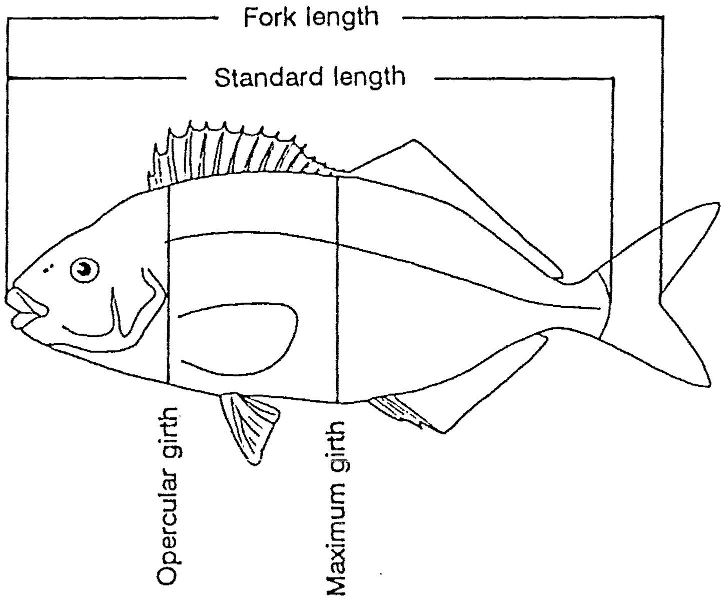
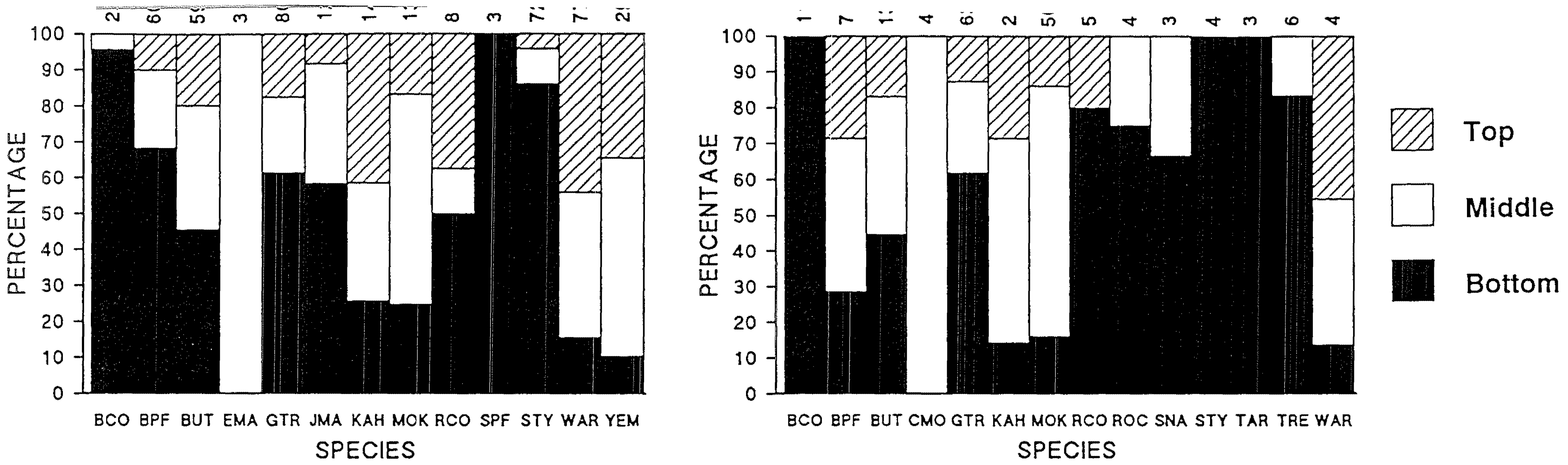


Figure 5.1 The position of the morphometric measurements made on each fish.

5.3 RESULTS

5.3.1 Spatial distribution

Most species showed a similar spatial distribution in the gill-net, with over 50% of the fish from most species being caught in the bottom third of the net (Figure 5.2). There was no apparent effect of mesh size on these distributions (Figure 5.2A-C). However, there was considerable variation among species in their vertical distributions in the nets. Combining data from the three mesh sizes, 97.1% of blue cod, *Parapercis colias*, 86.8% of spotties, *Notolabrus celidotus*, and 65.7% of banded wrasse, *Notolabrus fucicola*, were caught in the bottom third of the nets



C. 4.5" mesh

D. Total fish caught

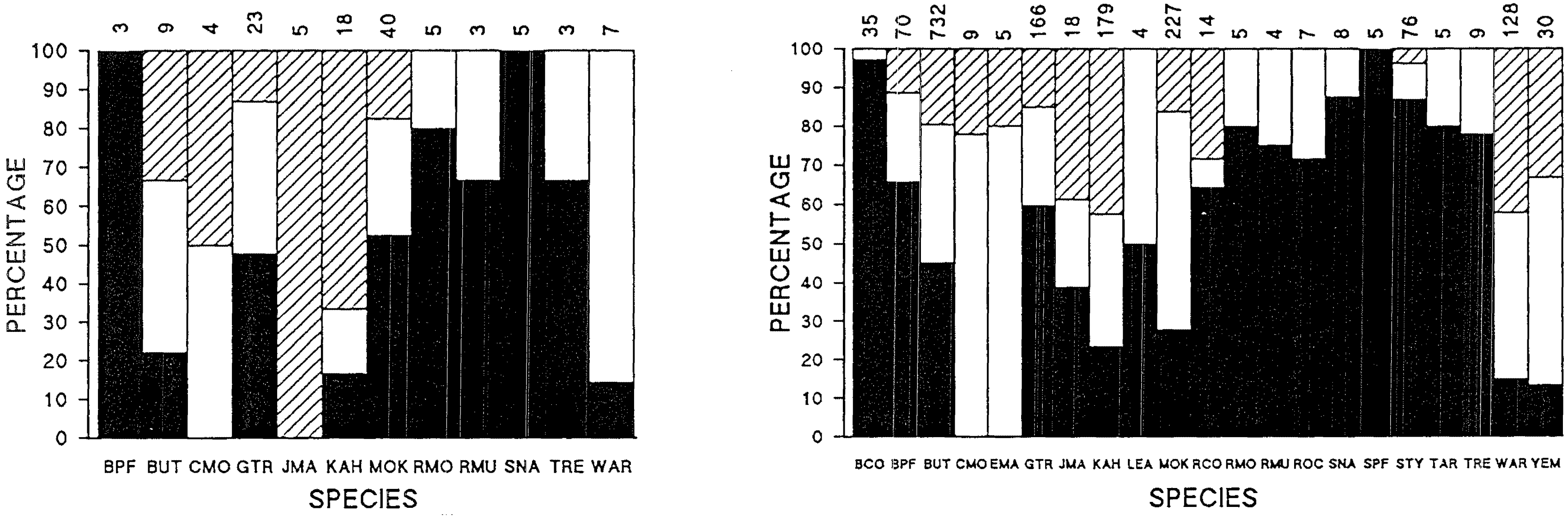


Figure 5.2 The proportion of each species caught in each third of the three mesh sizes. **A.** 2.5" mesh, **B.** 3.5" mesh, **C.** 4.5" mesh and **D.** total fish caught, combining

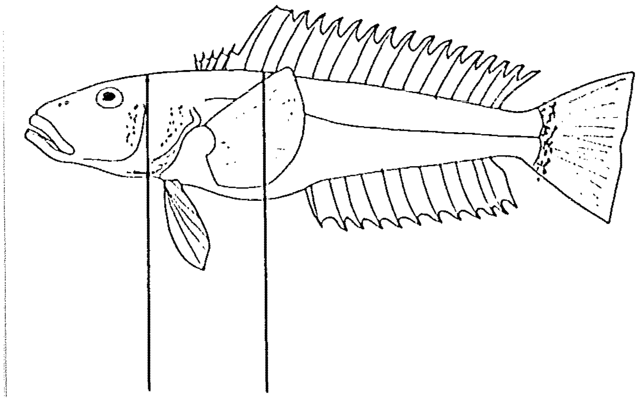
(Figure 5.2D). Other species were caught more frequently in the upper two-thirds of the nets, with only 24.4% of kahawai, *Arripis trutta*, 14.8% of warehou, *Seriolella brama*, and 13.3% of yellow-eyed mullet, *Aldrichetta forsteri*, caught in the bottom third of the net. Blue moki, *Latridopsis ciliaris*, were caught primarily in the bottom two thirds of the nets, with only 16.3% caught in the top third. The two herbivorous fish marblefish, *Aplodactylus arctidens,* and butterfish, *Odax pullus*, were caught predominantly in the bottom third and the bottom two thirds of the nets respectively (Figure 5.2D).

5.3.2 Form of entanglement

There were significant differences among species in the way they were caught in each of the three mesh sizes. Blue cod, *Parapercis colias*, were mostly gilled in the 2.5" and 3.5" meshes (Figure 5.3A). Only one fish was caught in the 4.5" mesh, and this was by tangling. The χ^2 test showed a significant difference between the number of blue cod caught by each method in the total catch, with most being gilled. A partial χ^2 test, by mesh size, could not be done because of the low number of fish caught in the two larger mesh sizes.

Jack mackerel, *Trachurus declivis*, were mostly gilled and tangled in the 2.5" and 4.5" meshes (Figure 5.3B). Only one fish was caught in the 3.5" mesh, and this was by tangling. The χ^2 test showed a significant difference between the number of jack mackerel caught by each method in the total catch, with most being gilled. A partial χ^2 test, by mesh size, could not be done because of the low number of fish caught in the two larger mesh sizes.

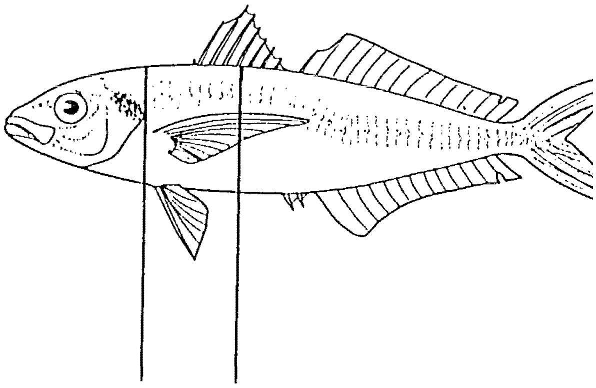
Parapercis colias



Mesh	Gilled	Wedged	Tangled	n
2.5"	82.6	13.0	4.4	23
3.5"	90.9	0.0	9.1	11
4.5"	0.0	0.0	100.0	1
Total	82.8	8.6	8.6	35

$\chi^2 = 36.63, p < 0.001$

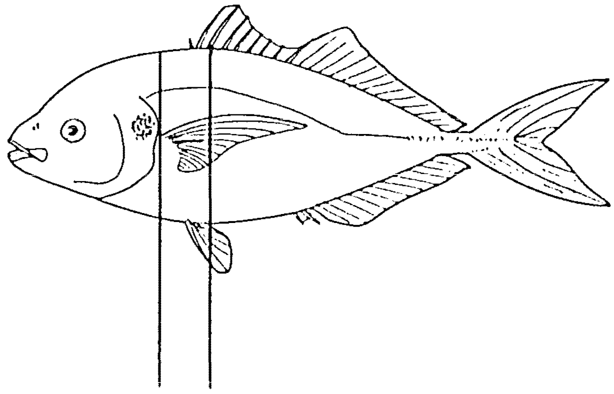
Trachurus declivis



Mesh	Gilled	Wedged	Tangled	n
2.5"	58.4	8.3	33.3	12
3.5"	0.0	0.0	100.0	1
4.5"	80.0	0.0	20.0	5
Total	61.1	5.6	33.3	18

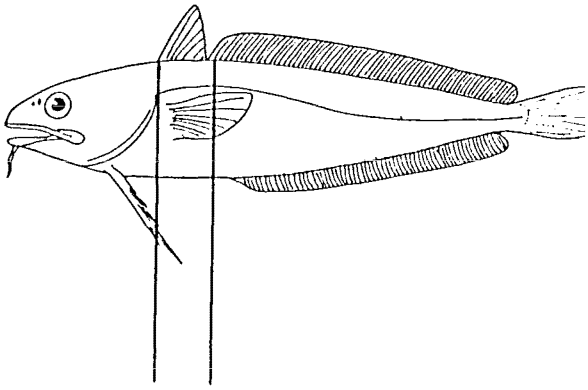
$\chi^2 = 8.33, p < 0.05$

Pseudocaranx dentex



Mesh	Gilled	Wedged	Tangled	n
2.5"	0.0	0.0	0.0	0
.5"	83.3	0.0	16.7	6
.5"	100.0	0.0	0.0	3
otal	88.9	0.0	11.1	9

Lotella rhacinus



Mesh	Gilled	Wedged	Tangled	n
2.5"	100.0	0.0	0.0	2
3.5"	100.0	0.0	0.0	4
4.5"	100.0	0.0	0.0	1
Total	100.0	0.0	0.0	7

Figure 5.3 The percentage of individual species captured by each method in 2.5", 3.5" and 4.5" nets, and in the total catch. χ^2 tests of independence and partial χ^2 are shown where appropriate.

Low numbers of trevally, *Pseudocaranx dentex* (Figure 5.3C), and rock cod, *Lotella rhacinus* (Figure 5.3D), were caught in the three mesh sizes, preventing analysis of their form of entanglement.

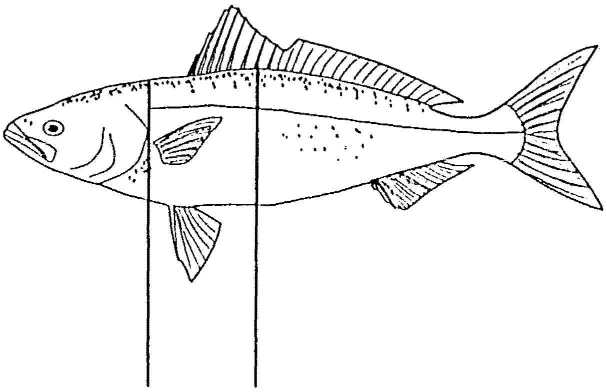
Kahawai, *Arripis trutta*, were mostly gilled in the 2.5" and 3.5" nets (Figure 5.4A). However, the number of fish gilled and tangled was approximately equal in the 4.5" nets. The χ^2 test showed a significant difference between the number of kahawai caught by each method in the total catch, with most being gilled. A partial χ^2 test, by mesh size, could not be done because of the low number of fish wedged in the 4.5" mesh.

Yellow-eyed mullet, *Aldrichetta forsteri*, were mostly gilled in the 2.5" mesh (Figure 5.4B). Only one fish was caught in the 3.5" net, and this was by tangling. The χ^2 test showed a significant difference in the number of yellow-eyed mullet caught by each method in the total catch, with most being gilled. A partial χ^2 test, by mesh size, could not be done because of the low number of fish caught in the 3.5" and 4.5" mesh sizes.

Butterfish, *Odax pullus*, were mostly gilled in the 2.5" mesh, but were gilled and wedged in equal proportions in the 3.5" mesh (Figure 5.4C). Only 9 fish were caught in the 4.5", mesh and most of these were wedged. The χ^2 test showed a significant difference between the number of butterfish caught by each method in the total catch, with most being gilled. A partial χ^2 test, by mesh size, could not be done because of the low number of fish caught in the 4.5" mesh.

Marblefish, *Aplodactylus arctidens*, were mostly gilled and tangled in the 2.5" mesh (Figure 5.4D). Most fish were gilled and wedged in the 3.5" and 4.5" mesh sizes.

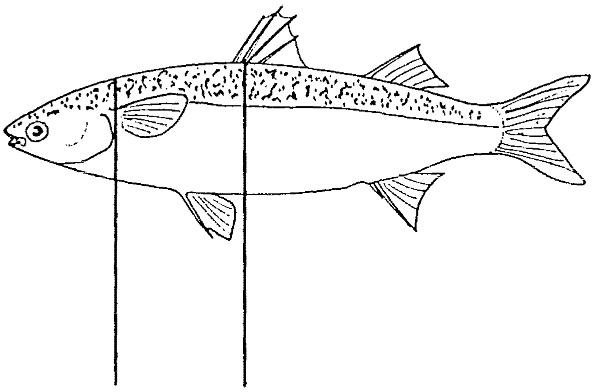
Arripis trutta



Mesh	Gilled	Wedged	Tangled	n
2.5"	69.3	20.0	10.7	140
3.5"	61.9	23.8	14.3	21
4.5"	44.4	0.0	55.6	18
Total	65.9	18.5	15.6	179

$\chi^2 = 85.75$, $p < 0.001$

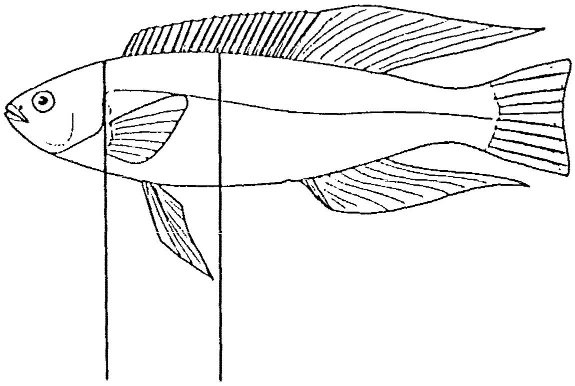
Aldrichetta forsteri



Mesh	Gilled	Wedged	Tangled	n
2.5"	55.2	17.2	27.6	29
3.5"	0.0	0.0	100.0	1
4.5"	0.0	0.0	0.0	0
Total	53.3	16.7	30.0	30

$\chi^2 = 6.20$, $p < 0.05$

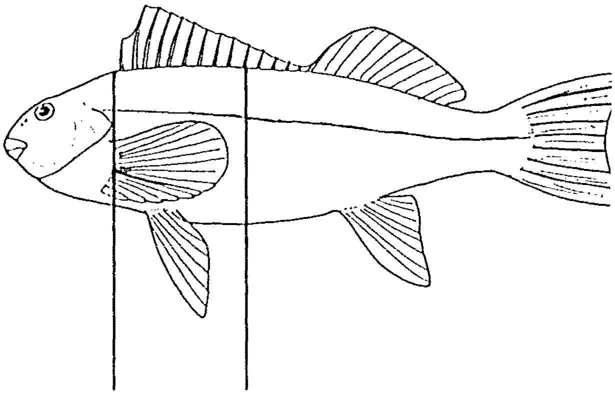
Odax pullus



sh	Gilled	Wedged	Tangled	n
"	73.1	16.4	10.5	593
"	51.5	45.4	3.1	130
"	22.2	66.7	11.1	9
al	68.7	22.1	9.2	732

$= 430.88$, $p < 0.001$

Aplodactylus arctidens



Mesh	Gilled	Wedged	Tangled	n
2.5"	40.0	6.2	53.8	80
3.5"	54.0	39.7	6.3	63
4.5"	30.4	60.9	8.7	23
Total	44.0	26.5	29.5	166

$\chi^2 = 8.69$, $p < 0.05$
partial χ^2 (mesh) $= 60.18$, $p < 0.001$

Figure 5.4 The percentage of individual species captured by each method in 2.5", 3.5" and 4.5" nets, and in the total catch. χ^2 tests of independence and partial χ^2 are shown where appropriate.

The χ^2 test showed a significant difference between the number of marblefish caught by each method in the total catch, with most being gilled. The partial χ^2 test, by mesh size, showed a significant difference in the number of fish caught by each method in the three mesh sizes, primarily because of the high number of fish tangled in the 2.5" mesh.

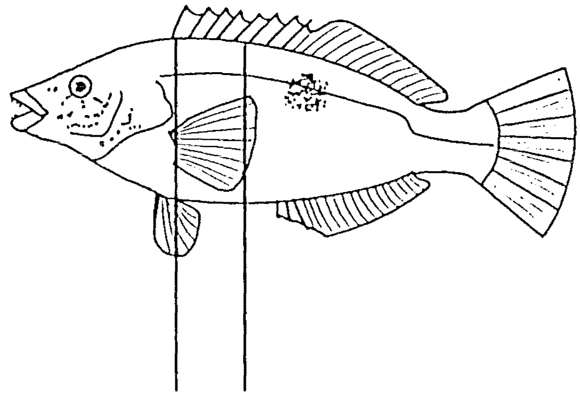
Spotties, *Notolabrus celidotus*, were mostly gilled in the 2.5" and 3.5" meshes (Figure 5.5A). No fish were caught in the 4.5" mesh. The χ^2 test showed a significant difference in the number of spotties caught by each method in the total catch, with most being gilled. A partial χ^2 test, by mesh size, could not be done because of the low number of spotties caught in the two larger mesh sizes.

Banded wrasse, *Notolabrus fucicola*, were mostly gilled in the 2.5" and 3.5" meshes (Figure 5.5B). Only three fish were caught in the 4.5" mesh, and these were all gilled. The χ^2 test showed a significant difference in the number of banded wrasse caught by each method in the total catch, with most being gilled. A partial χ^2 test, by mesh size, could not be done because of the low number of banded wrasse caught in the 4.5" mesh.

Low numbers of scarlet wrasse, *Pseudolabrus miles*, were caught in the three mesh sizes (Figure 5.5C), preventing analysis of their form of entanglement.

Warehou, *Seriolella brama*, were mostly gilled and tangled in the 2.5" mesh, and mostly gilled in the 3.5" mesh. Only seven fish were caught in the 4.5" mesh, and most of these were tangled. The χ^2 test showed significant differences in the number of warehou caught by each method in the total catch, with equal numbers

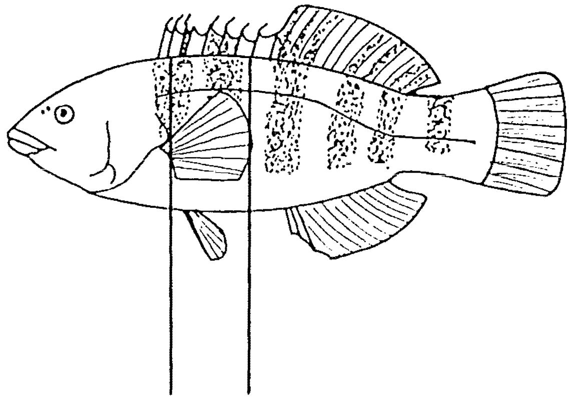
Notolabrus celidotus



Mesh	Gilled	Wedged	Tangled	n
2.5"	76.4	8.3	15.3	72
3.5"	100.0	0.0	0.0	4
4.5"	0.0	0.0	0.0	0
Total	77.6	7.9	14.5	76

$\chi^2 = 67.61, p < 0.001$

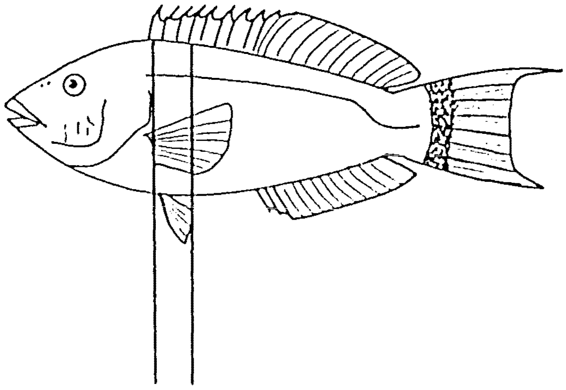
Notolabrus fucicola



Mesh	Gilled	Wedged	Tangled	n
2.5"	86.7	10.0	3.3	60
3.5"	57.1	14.3	28.6	7
4.5"	100.0	0.0	0.0	3
Total	84.3	10.0	5.7	70

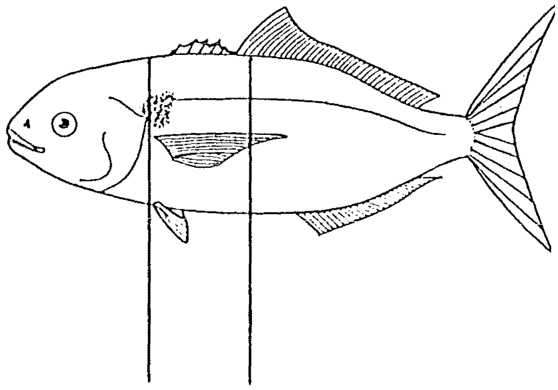
$\chi^2 = 81.97, p < 0.001$

Pseudolabrus miles



esh	Gilled	Wedged	Tangled	n
.5"	66.7	33.3	0.0	3
.5"	100.0	0.0	0.0	2
.5"	0.0	0.0	0.0	0
otal	80.0	20.0	0.0	5

Seriolella brama



Mesh	Gilled	Wedged	Tangled	n
2.5"	42.9	0.0	57.1	77
3.5"	56.8	27.3	15.9	44
4.5"	0.0	14.3	85.7	7
Total	45.3	10.2	44.5	128

$\chi^2 = 30.95, p < 0.001$

Figure 5.5 The percentage of individual species captured by each method in 2.5", 3.5" and 4.5" nets, and in the total catch. χ^2 tests of independence and partial χ^2 are shown where appropriate.

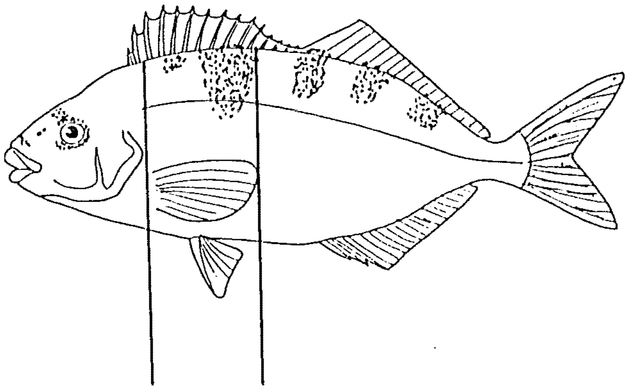
being gilled and tangled. A partial χ^2 test, by mesh size, could not be done because of the low number of fish caught in the 4.5" mesh.

Blue moki, *Latridopsis ciliaris*, were mostly tangled in the 2.5" mesh, and gilled and tangled in approximately equal numbers in the 3.5" mesh (Figure 5.6A). Most fish were gilled in the 4.5" mesh. The χ^2 test showed significant differences in the number of blue moki caught by each method in the total catch, with most being tangled but a high proportion being gilled. The partial χ^2 test, by mesh size, showed a significant difference in the number of fish caught by each method in the three mesh sizes, primarily because of the low number of fish being gilled in the 2.5" mesh.

Low numbers of copper moki, *Latridopsis forsteri* (Figure 5.6B), tarakihi, *Nemadactylus macropterus* (Figure 5.6C), trumpeter, *Latris lineata* (Figure 5.6D), leatherjackets, *Parika scaber* (Figure 5.7A), red cod, *Pseudophycis bachus* (Figure 5.7B), snapper, *Chrysophrys auratus* (Figure 5.7C), and scorpion fish, *Scorpaena cardinalis* (Figure 5.7D), were caught in the three mesh sizes, preventing analysis of their form of entanglement.

Overall, the average lengths of fish increased with mesh size for gilled and wedged fish, but not for tangled ones (Figure 5.8). However, again there was considerable variation among species. The fork length of gilled fish was significantly greater for each successive mesh size for blue cod ($F_{1,27} = 71.47$, $p < 0.001$), banded wrasse ($F_{2,56} = 67.41$, $p < 0.001$), butterfish ($F_{2,500} = 347.78$, $p < 0.001$), marblefish ($F_{2,70} = 14.64$, $p < 0.001$), kahawai ($F_{2,115} = 602.18$, $p < 0.001$), blue moki ($F_{2,80} = 149.55$, $p < 0.001$) and warehou ($F_{1,56} = 176.13$, $p < 0.001$).

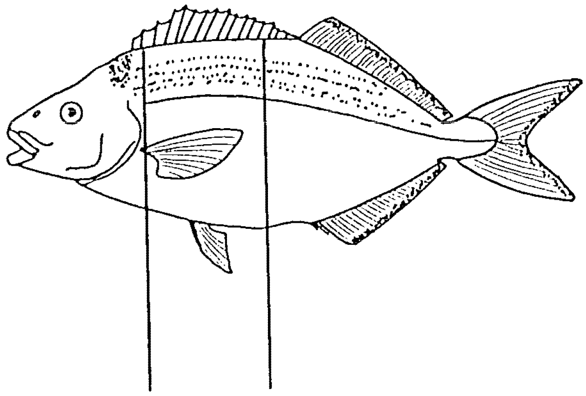
Latridopsis ciliaris



Mesh	Gilled	Wedged	Tangled	n
2.5"	24.1	11.7	64.2	137
3.5"	52.0	4.0	44.0	50
4.5"	62.5	25.0	12.5	40
Total	37.0	12.3	50.7	227

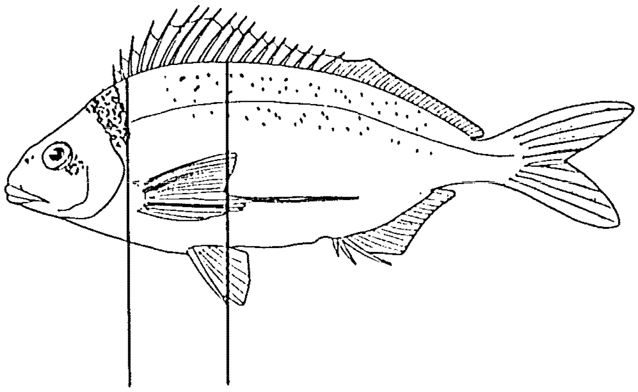
$\chi^2 = 51.39, p < 0.001$
ɔartial χ^2 (mesh) = 41.23, $p < 0.001$

Latridopsis forsteri



Mesh	Gilled	Wedged	Tangled	n
2.5"	0.0	0.0	100.0	1
3.5"	0.0	0.0	100.0	4
4.5"	75.0	0.0	25.0	4
Total	33.3	0.0	66.7	9

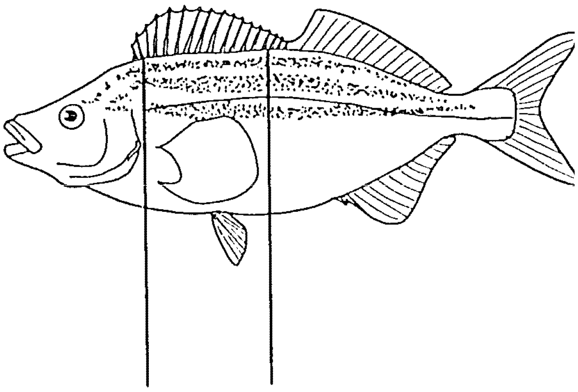
Nemadactylus macropterus



lesh	Gilled	Wedged	Tangled	n
.5"	100.0	0.0	0.0	2
.5"	33.3	33.3	33.3	3
.5"	0.0	0.0	0.0	0
otal	60.0	20.0	20.0	5

$^2 = 1.60$, n.s.

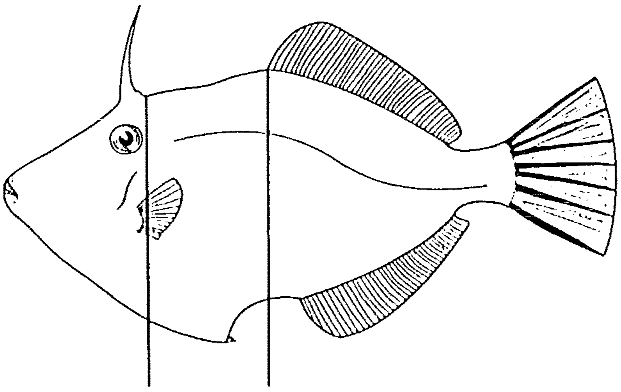
Latris lineata



Mesh	Gilled	Wedged	Tangled	n
2.5"	50.0	0.0	50.0	2
3.5"	0.0	0.0	0.0	0
4.5"	0.0	0.0	0.0	0
Total	50.0	0.0	50.0	2

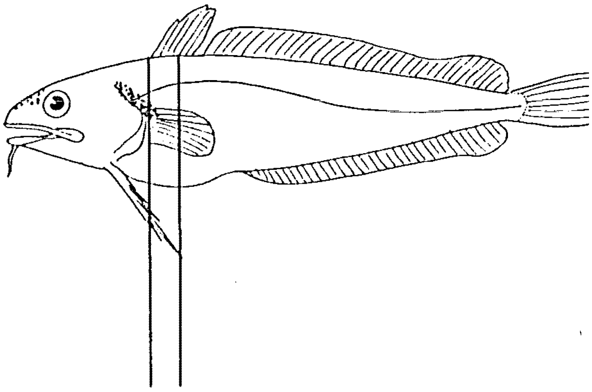
Figure 5.6 The percentage of individual species captured by each method in 2.5", 3.5" and 4.5" nets, and in the total catch. χ^2 tests of independence and partial χ^2 are shown where appropriate.

Parika scaber



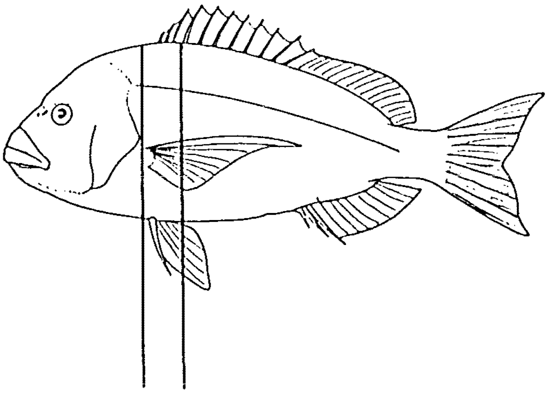
Mesh	Gilled	Wedged	Tangled	n
2.5"	0.0	0.0	100.0	1
3.5"	0.0	100.0	0.0	1
4.5"	0.0	0.0	100.0	2
Total	0.0	25.0	75.0	4

Pseudophycis bachus



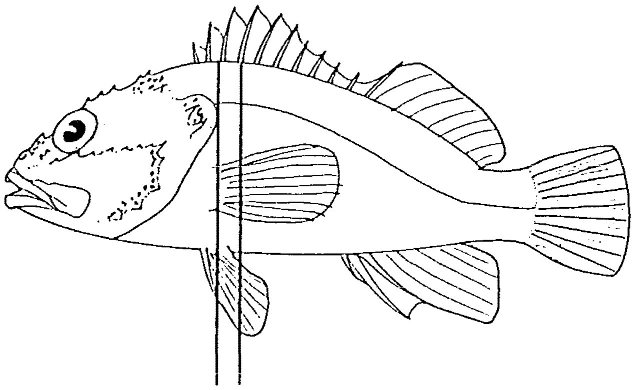
Mesh	Gilled	Wedged	Tangled	n
2.5"	37.5	12.5	50.0	8
3.5"	60.0	40.0	0.0	5
4.5"	0.0	0.0	100.0	1
Total	42.9	21.4	35.7	14

Chrysophrys auratus



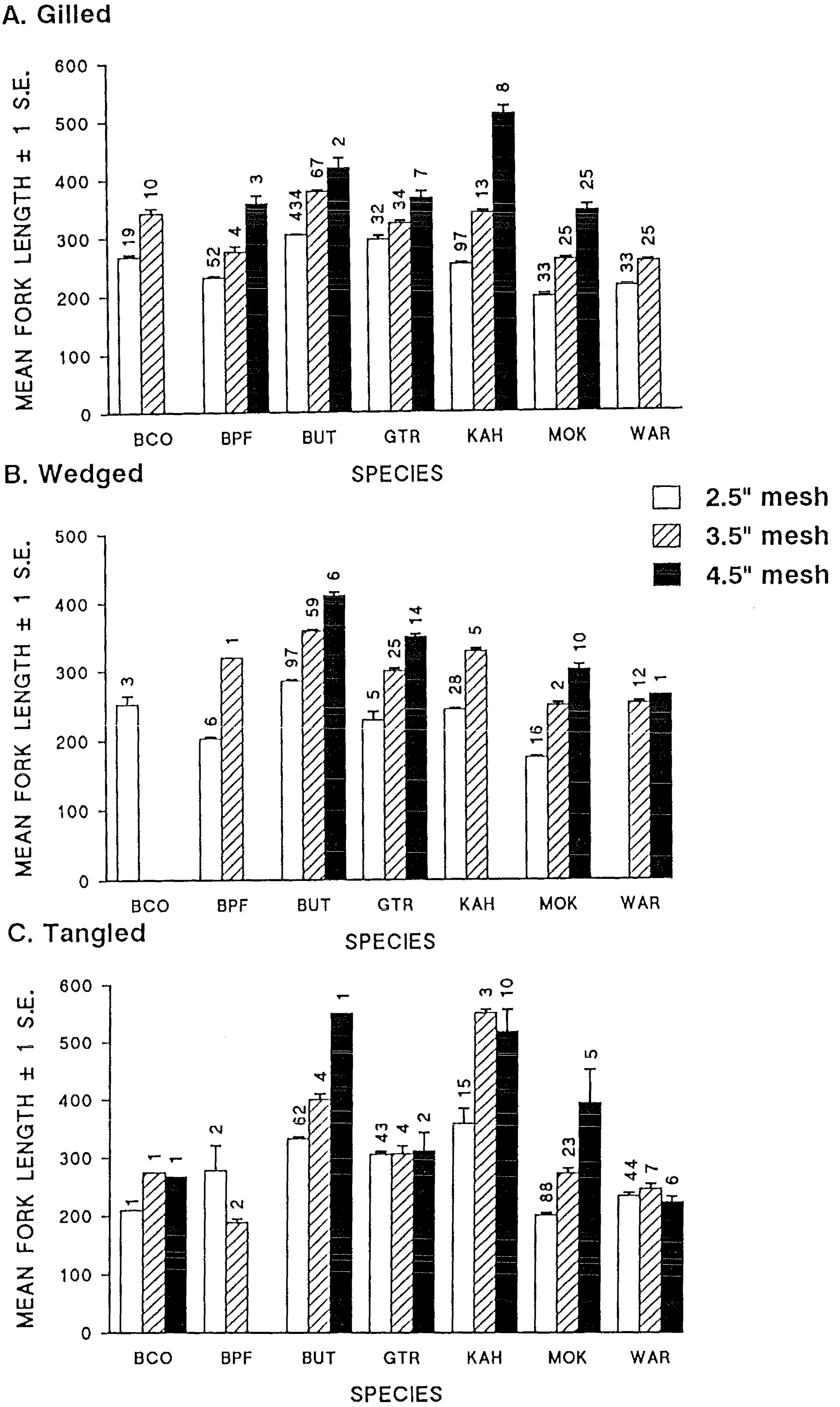
esh	Gilled	Wedged	Tangled	n
5"	0.0	0.0	0.0	0
5"	33.3	0.0	66.7	3
5"	60.0	0.0	40.0	5
otal	50.0	0.0	50.0	8

Scorpaena cardinalis



Mesh	Gilled	Wedged	Tangled	n
2.5"	100.0	0.0	0.0	2
3.5"	0.0	0.0	0.0	0
4.5"	0.0	0.0	0.0	0
Total	100.0	0.0	0.0	2

Figure 5.7 The percentage of individual species captured by each method in 2.5", 3.5" and 4.5" nets, and in the total catch. χ^2 tests of independence and partial χ^2 are shown where appropriate.



A. Gilled

B. Wedged

C. Tangled

Figure 5.8 The mean fork length (± 1 S.E.) of fish **A.** gilled **B.** wedged and **C.** tangled by each of the three mesh sizes. n = the number of fish from each species caught in each mesh size. See Appendix 1 for species codes.

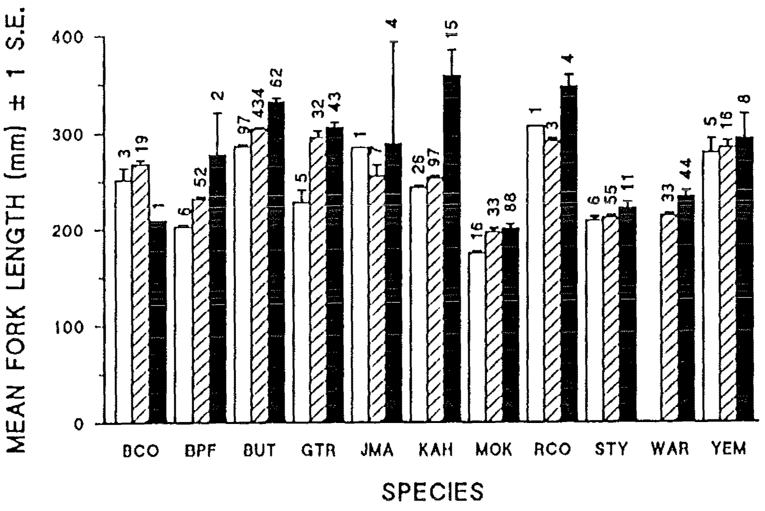
The fork length of wedged fish was significantly greater for each successive mesh size for butterfish ($F_{2,159} = 489.81$, $p < 0.001$), marblefish ($F_{2,41} = 77.23$, $p < 0.001$), kahawai ($F_{1,31} = 319.41$, $p < 0.001$) and blue moki ($F_{2,25} = 226.46$, $p < 0.001$). The relationship between the fork length of tangled fish and the mesh size was less uniform. However, the fork length of tangled fish was significantly greater for each successive mesh size for butterfish ($F_{2,64} = 48.20$, $p < 0.001$) and blue moki ($F_{2,113} = 59.10$, $p < 0.001$).

Within each mesh size, there were few differences within species in the fork lengths caught by the three methods (Figure 5.9). Tangled fish tended to have the largest mean fork length, gilled fish were intermediate, and wedged fish had the smallest mean fork length. There were significant differences in the fork length of banded wrasse caught by each method in the 2.5" mesh ($F_{2,57} = 11.61$, $p < 0.001$). Tukey's pair-wise comparisons showed the fork lengths of tangled banded wrasse to be significantly greater than gilled banded wrasse, which were in turn significantly greater than wedged fish of this species. This relationship was also observed for butterfish ($F_{2,590} = 88.84$, $p < 0.001$) in the 2.5" mesh.

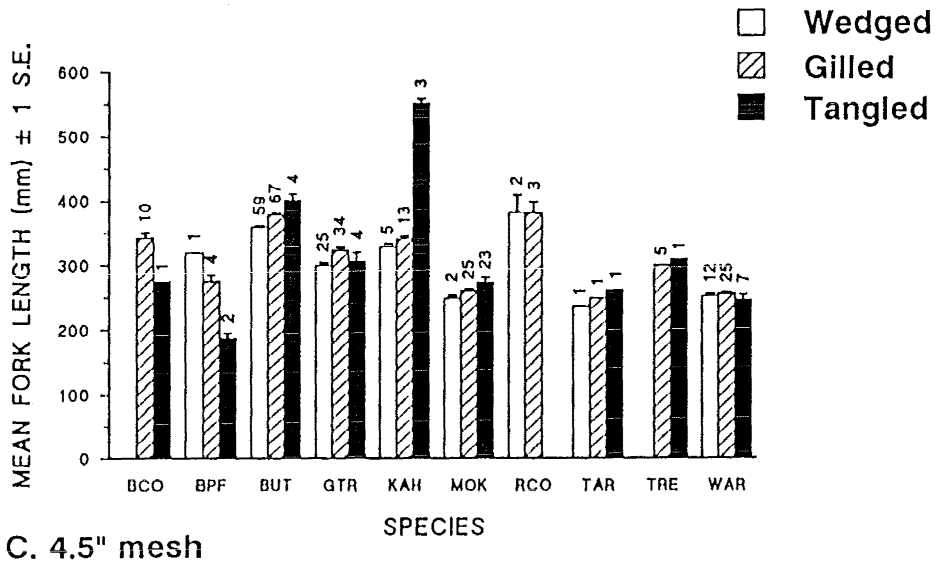
Significant differences in the fork lengths of fish caught by each method were also observed for marblefish in the 2.5" mesh ($F_{2,77} = 11.08$, $p < 0.001$), kahawai in the 2.5" mesh ($F_{2,132} = 60.26$, $p < 0.001$), blue moki in the 2.5" mesh ($F_{2,134} = 3.73$, $p < 0.05$), butterfish in the 3.5" mesh ($F_{2,127} = 21.09$, $p < 0.001$), kahawai in the 3.5" mesh ($F_{2,18} = 313.65$, $p < 0.001$), butterfish in the 4.5" mesh ($F_{2,6} = 40.25$, $p < 0.001$) and blue moki in the 4.5" mesh ($F_{2,37} = 4.46$, $p < 0.05$).

There was a progressive transition in the proportion of butterfish caught by each method as fork length increased in both the 2.5" and 3.5" mesh sizes (Figure 5.10).

A. 2.5" mesh



B. 3.5" mesh



C. 4.5" mesh

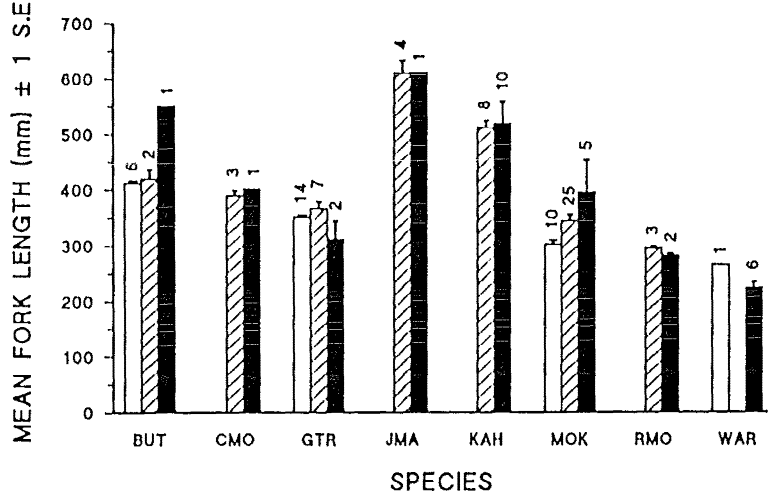
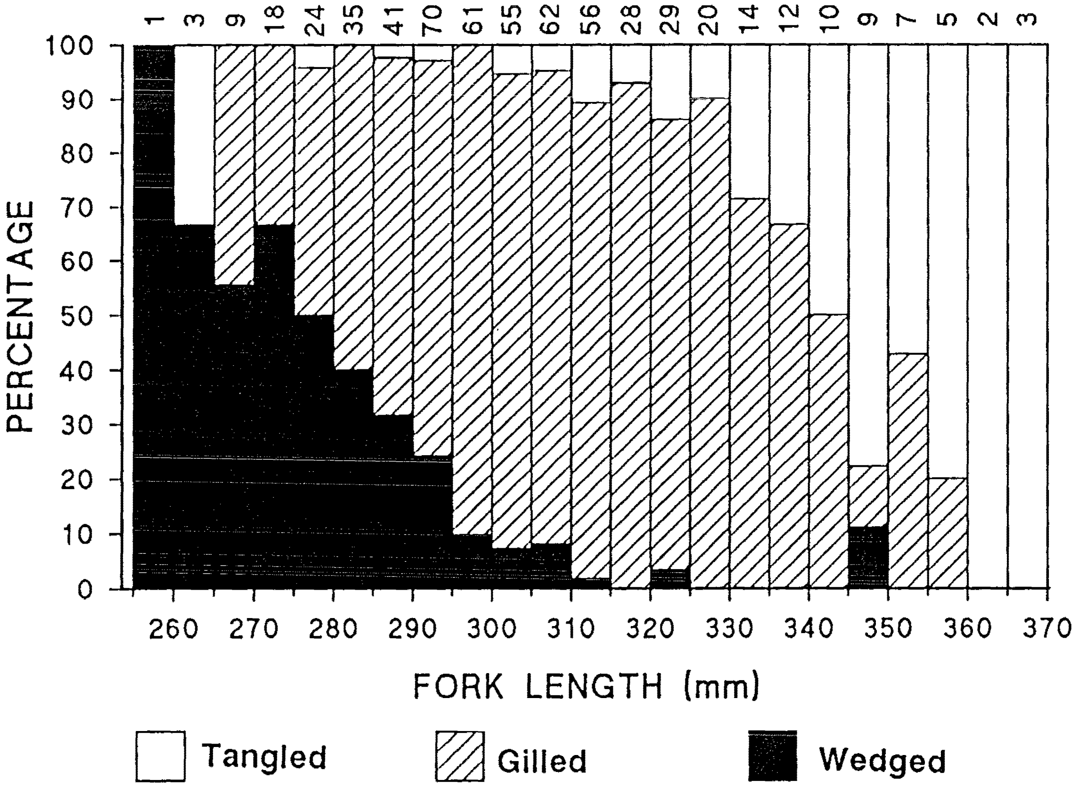


Figure 5.9 The mean fork length of fish captured by each method in the **A.** 2.5", **B.** 3.5" and **C.** 4.5" mesh nets. n = the number of fish from each species caught in each method. See Appendix 1 for species codes.

A. 2.5" mesh



B. 3.5" mesh

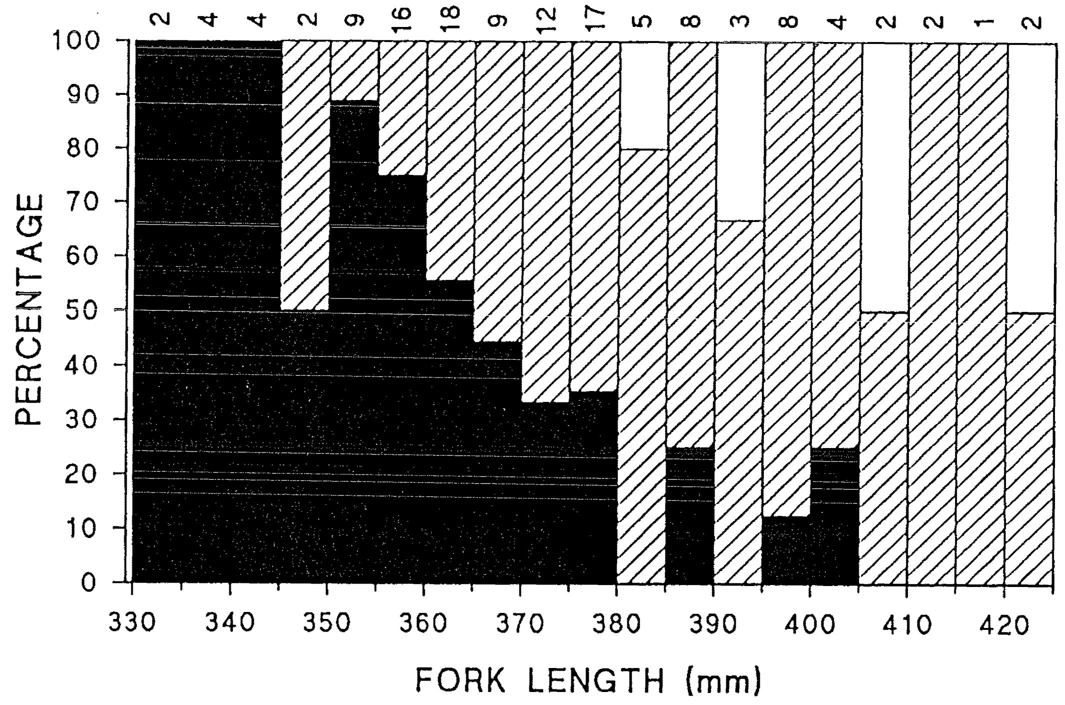


Figure 5.10 The proportion of butterfish, *Odax pullus*, caught by each method in the A. 2.5" and B. 3.5" mesh. n = the number of fish in each size class.

Most of the small fish caught by each mesh were wedged, but this proportion decreased with fork length, and most mid-sized fish were gilled. As the fork length of the catch increased further, the proportion of gilled fish decreased, and most of the larger fish were tangled.

5.3.3 Temporal relationships

The 2.5" mesh size caught the most fish over all set durations (Figure 5.11). However, while the catches of the 3.5" and 4.5" meshes continued to increase with time, the catch of the 2.5" mesh reached a peak at 11-15 hours, and then decreased. The catch of the 2.5" mesh was the most variable over all set times.

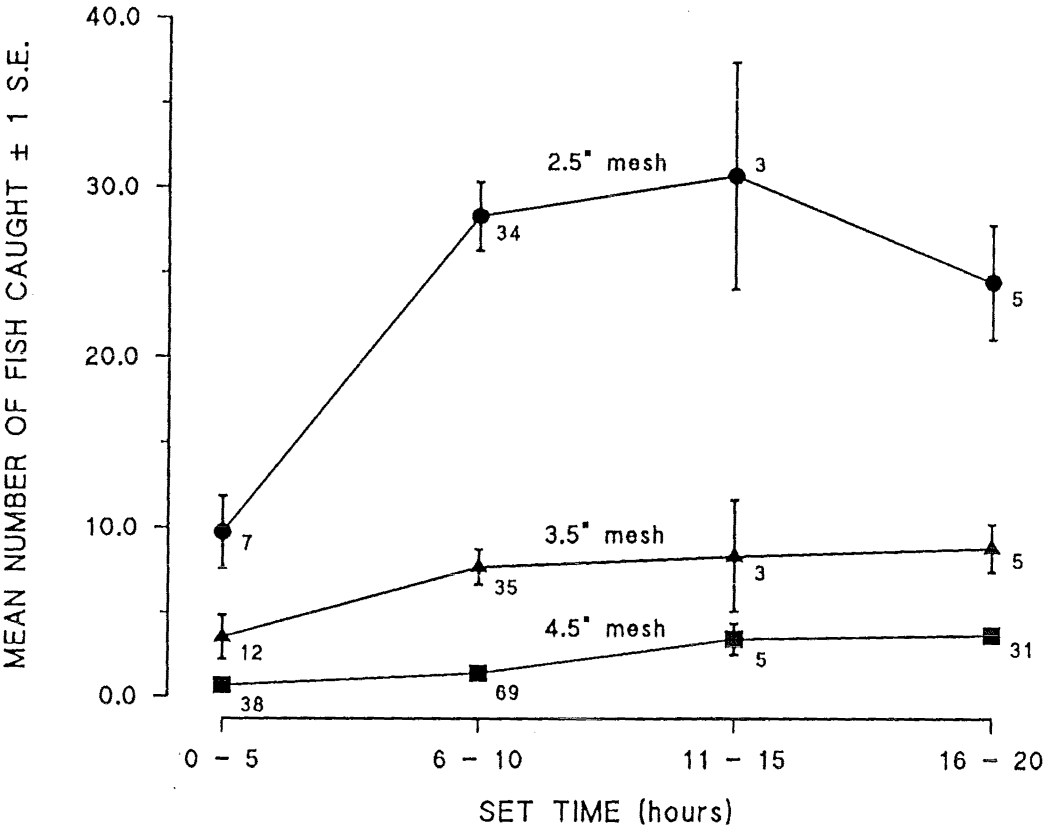


Figure 5.11 The mean number of fish (± 1 S.E.) landed by the three mesh sizes against time. n = the number of experimental sets with each mesh size for each period.

All three mesh sizes displayed a similar pattern with respect to the number of species caught against time (Figure 5.12). The number of species caught increased linearly for the first 11-15 hours of a set, but levelled off at this point. The 2.5" net caught the most species at all set times, but was again the most variable.

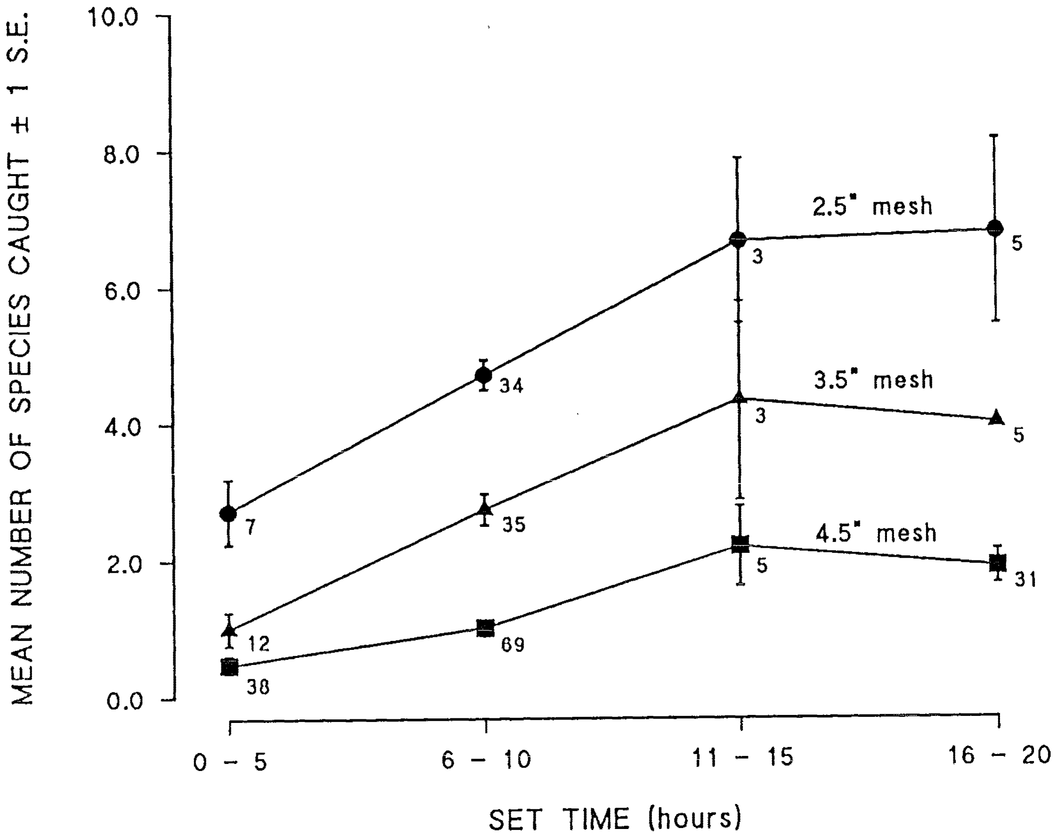


Figure 5.12 The mean number of species (± 1 S.E.) landed by the three mesh sizes against time. n = the number of experimental sets with each mesh size for each period.

The proportion of damaged fish in the landed catch was small for nets of all three mesh sizes set for up to ten hours, but increased markedly for longer set times (Figure 5.13). The 4.5" nets had proportionally more damaged fish in them for 11-15 hour sets than the 2.5" and 3.5" nets. However, the fish that were damaged in the 2.5" and 3.5" nets were more severely damaged, with a significantly greater percentage of fish with 'severe damage' being landed. The proportion of damaged fish landed decreased in all three mesh sizes for sets of 16-20 hours.

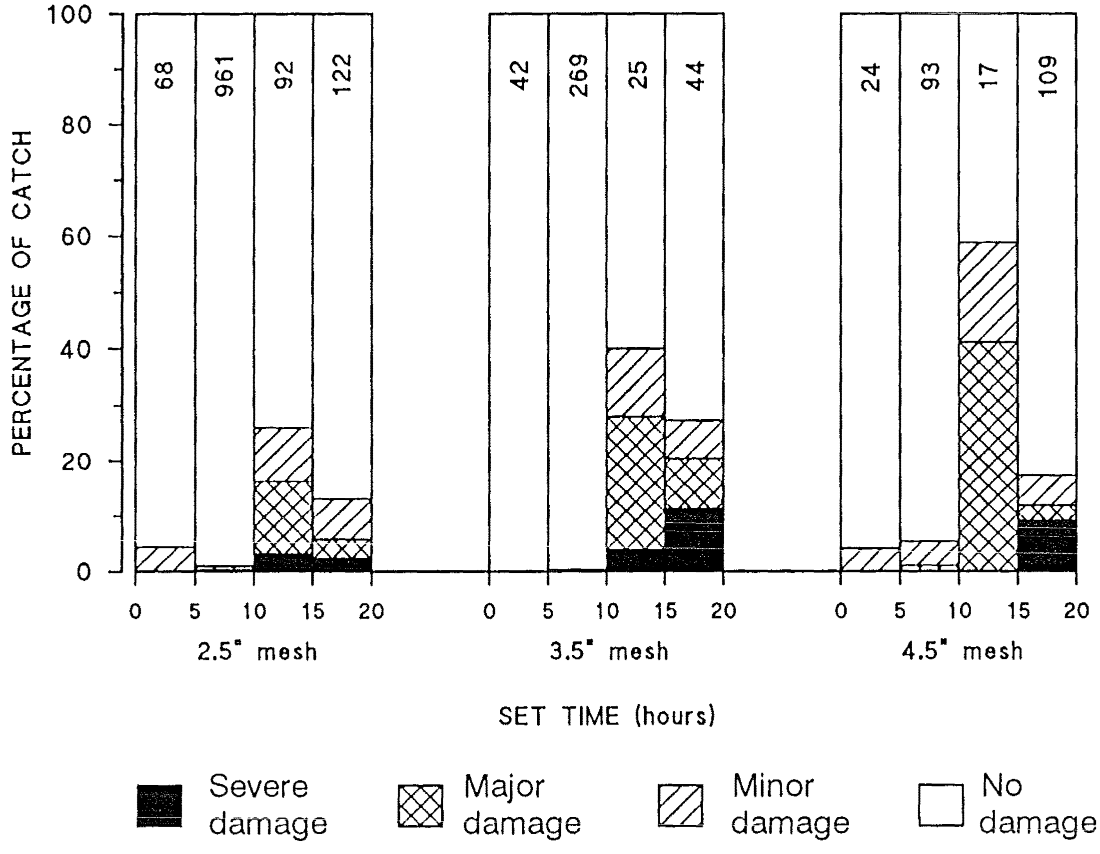


Figure 5.13 The percentage composition of the catch of the three mesh sizes in terms of condition after various set times. n = the number of fish landed by each mesh size after each set time.

5.3.4 Mesh selectivity

The mean fork length of fish caught increased with increasing mesh size for 10 out of the 15 species recorded (Figure 5.14). This relationship was significant for banded wrasse ($F_{2,68} = 62.28$, $p < 0.001$), butterfish ($F_{2,770} = 862.95$, $p < 0.001$), marblefish ($F_{2,169}$ = 37.91, $p < 0.001$), kahawai ($F_{2,186}$ = 102.26, $p < 0.001$), blue moki ($F_{2,254}$ = 272.02, $p < 0.001$) and spotties ($F_{1,68}$ = 56.32, $p < 0.001$).

Only four species (butterfish, marblefish, kahawai and blue moki) were caught in high enough numbers to allow a balanced ANOVA to be done of girth at point of capture, with species and mesh size as factors (Table 5.1).

Mesh size accounted for the majority of variance in the girth of fish at the point of capture (Table 5.1). The mean girth of fish caught in the 4.5" mesh was significantly greater than that of fish caught in the 3.5" mesh, which was in turn significantly greater than that of the 2.5" mesh.

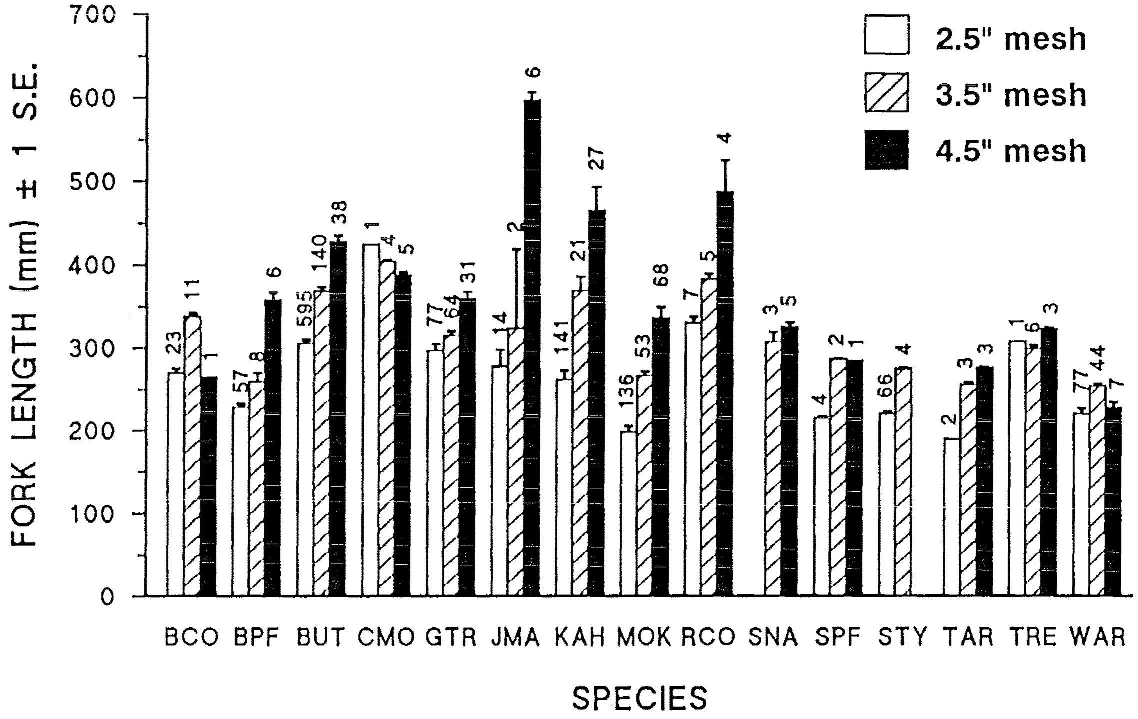


Figure 5.14 The mean fork length (± 1 S.E.) of 15 species of fish caught in gill-nets of three different mesh sizes. n = total number of each species caught in each mesh size. See Appendix 1 for species codes.

There was a significant difference between species in their girths, and also a significant species x mesh interaction (Figure 5.15). The significant interaction term indicates that the girth of fish caught does not increase uniformly with mesh size among all species. However, 14% of the variation in the model was accounted for by mesh size.

Table 5.1 ANOVA table for the analysis of girth at the point of capture, with species (Blue moki, butterfish, kahawai and marblefish) and mesh size (2.5",3.5" and 4.5") as factors. The variance has been partitioned to gauge the importance of each factor and the interaction term (Winer, 1962; Raimondi, 1990; Schiel, 1990).

Source of variation	d.f.	SS	F	% variance
Species	3	6770	7.44***	2.51
Mesh	2	153541	253.15***	73.79
Species x Mesh	6	24107	13.25***	14.34
Residual	84	25474		9.36
Total	95	209892		

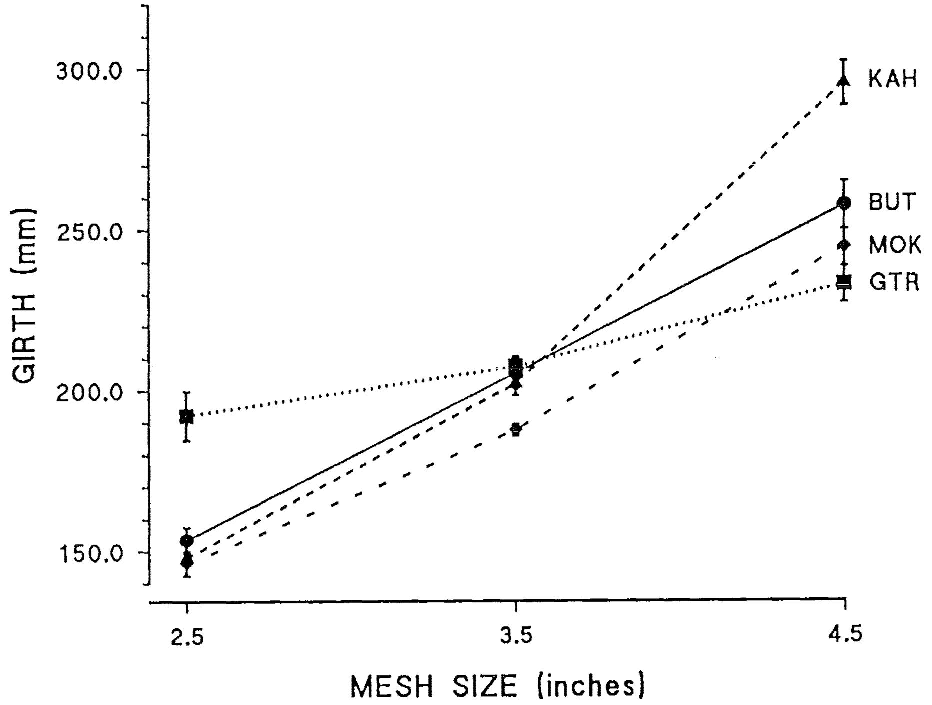


Figure 5.15 The mean girth of eight randomly selected fish from four species of fish caught in gill-nets with three different mesh sizes.

The frequency distributions of the girth/perimeter ratio of the eight species differ with respect to their ranges, modes and skewness (Figure 5.16). The skewness, as measured by the third moment, the modal girth/perimeter ratios and corresponding means for each species are listed in Table 5.2. The modal girth/perimeter ratio for each of the eight species lies between 1.1 and 1.2, but the frequency distribution for most species is skewed to the right. The significance of the skewness (g_1) was tested by determining whether the deviation of the observed value of g_1 was significantly different from the expected value of γ_1 for a normal distribution, which is zero (Sokal & Rohlf, 1981).

Table 5.2 The measures of central tendency and skewness for the girth/perimeter ratio of eight species of reef fish from the catch of the 2.5", 3.5" and 4.5" gill-nets. The significance of the skewness was tested against the *t* - distribution. Significance levels are shown (* = 0.05, ** = 0.01, *** = 0.001, ^{ns} = not significant).

Species	BCO	BPF	BUT	GTR	KAH	MOK	WAR	YEM
Number	32	66	665	117	151	111	71	21
Mean	1.16	1.17	1.22	1.24	1.18	1.11	1.18	1.09
Std dev.	0.12	0.13	0.12	0.18	0.10	0.11	0.10	0.16
Median	1.2	1.1	1.2	1.2	1.2	1.1	1.2	1.1
Mode	1.2	1.1	1.2	1.2	1.1	1.1	1.1	1.2
Minimum	0.9	0.9	0.6	0.8	1.0	0.9	1.0	0.8
Maximum	1.4	1.5	2.1	1.7	1.5	1.5	1.4	1.4
Skewness (t_s)	-1.206^{ns}	2.641^{**}	7.460^{***}	3.202^{**}	4.980^{***}	6.948^{***}	0.822^{ns}	-0.327^{ns}

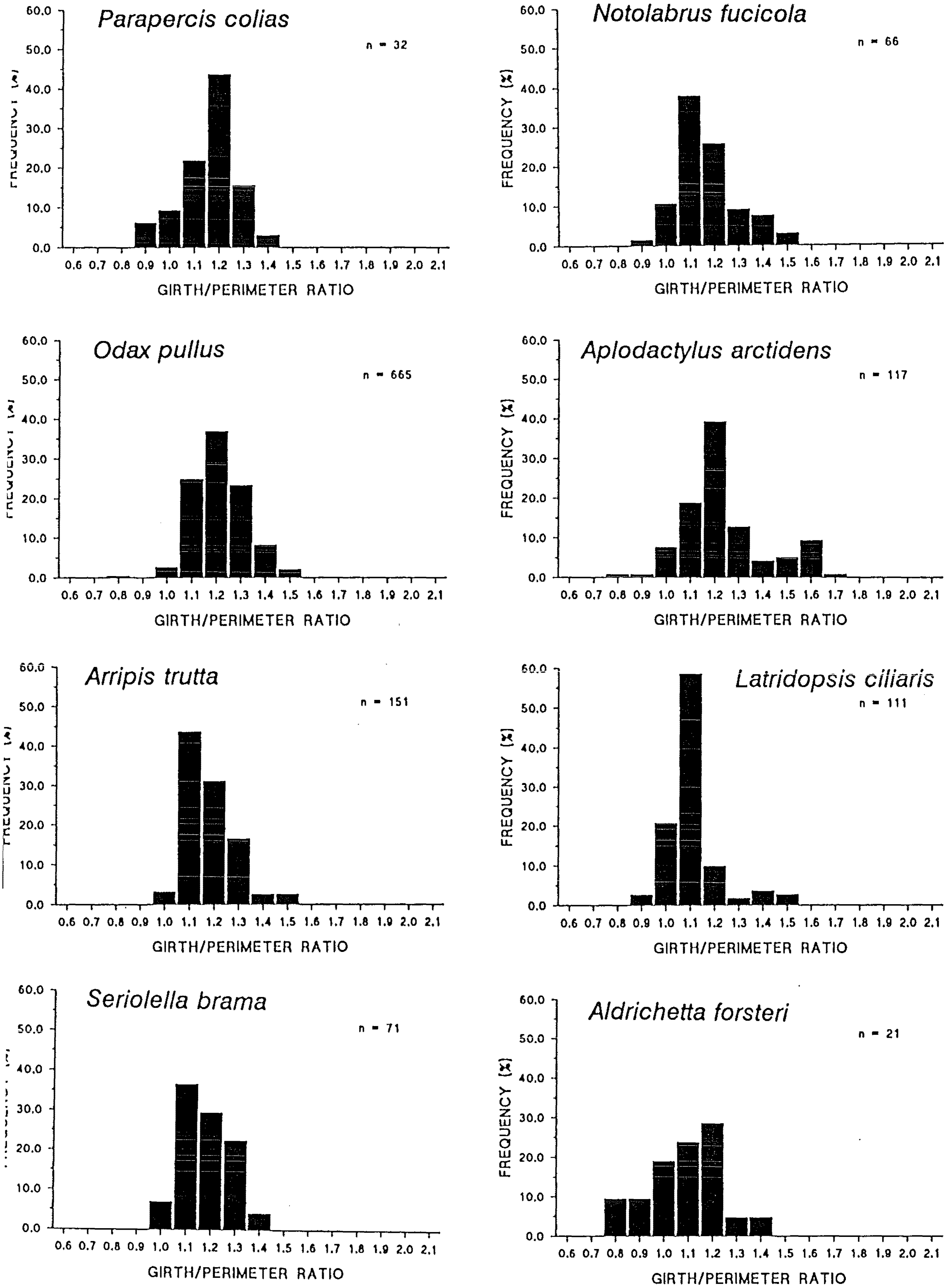


Figure 5.16 Frequency (%) distribution of the ratio of the girth at the point of entanglement to the net perimeter of eight species of fish. n = total number of fish caught.

5.4 DISCUSSION

5.4.1 Spatial distribution

The vertical distribution of fish caught in gill-nets appears to be related to the position in the water column that each species usually inhabits. Blue cod are a bottom-living species (Ayling & Cox, 1987; Paulin *et al.*, 1989) and are rarely observed more than 50 cm above the substratum, where they forage and feed. This species was caught in the bottom portion of the gill-nets, as expected.

Adult spotties, of a size that are likely to be caught in gill-nets, feed predominantly on benthic organisms, particularly hermit crabs, bivalves, ophiurans and gastropods (Thompson & Jones, 1983). Adult spotties spend up to 90 % of their time foraging on the benthos (Jones, 1984a), and are likely to be caught in the bottom third of the net, as was observed.

Kahawai are inshore pelagic carnivores that prey on small schooling fish such as yellow-eyed mullet, *Aldrichetta forsteri*, in the middle of the water column (Ayling & Cox, 1987). The higher vertical position of these two species when caught in gill-nets is consistent with their usual higher position in the water column. Warehou are pelagic planktivores (Francis, 1988) that also were expected, and were observed, to be caught higher in the gill-nets.

The two herbivorous species, marblefish and butterfish, also showed distinct distributions in the gill-nets. Marblefish were caught mostly in the bottom third of the nets, but butterfish were caught in the middle and bottom thirds in approximately equal numbers. The marblefish is a bottom grazer that feeds predominantly on fine red and green algae that form the undergrowth beneath fucoid and laminarian stands (Choat & Clements, 1992). Butterfish feed selectively on erect canopy-forming seaweeds, particularly the reproductive tissues of fucoid and laminarian algae (Choat & Clements, 1992), and consequently spend most of their time 1-2 metres above the substratum. The disjunction between the feeding behaviour of these two species may explain the variation in the vertical distribution of individuals caught in gill-nets. Marblefish are bottom grazers that feed by using their fleshy pectoral fins to thrust themselves along the bottom while they graze on algal turf (Doak, 1991). Butterfish usually cruise beneath the algal canopy and swim into the gill-net approximately one metre above the substrate. Therefore, butterfish are likely to be caught higher in the gill-net than the bottom-grazing marblefish, as was found in this study.

Overall, the vertical distribution of captured fish in a gill-net appears to reflect the vertical distribution of species in rocky reef habitats. Transient pelagic species tend to be caught in the upper regions of gill-nets, while resident demersal species are caught mostly in the lower regions.

5.4.2 Form of entanglement

Each species shows a distinctive pattern in its form of entanglement in the three mesh sizes. These patterns appear to be a consequence of the behavioural and morphological characteristics unique to each species.

Blue cod were mostly gilled and tangled in the total catch. Blue cod are an elongated round-bodied fish with a large blunt head (Figure 5.3A), and the difference between its opercular girth and maximum girth is slight (Appendix 3, Figure A.3.1A & B). If a mesh is large enough to allow a fish to enter past its gills, then with little effort the fish can force the remainder of its body through the net.

Jack mackerel and kahawai were mostly gilled. Both these species are pelagic carnivores that are dependent on a strong swimming thrust for catching their prey. Once gilled, they would both be expected to drive forwards firmly in the nets and become wedged. The low number of these species wedged may be a result of their firm flesh, which is not compressed easily by the mesh and may prevent them from becoming wedged. Larger fish, despite their greater swimming thrust (Lander, 1969), would not be able to enter the small mesh sizes far enough to become wedged.

Butterfish were mostly wedged. The low number of butterfish that become tangled is likely to be a result of the soft fin rays, fused teeth and small scales typical of this species (Paulin *et al.*, 1989), which offer little for the mesh to snag upon. However, several other characteristics unique to butterfish make this species very vulnerable to capture by gill-nets. The fusiform body shape of butterfish allows even large individuals to enter the mesh of a gill-net a considerable distance before forward movement is prevented. The sinuous swimming motion and weak pectorals of butterfish do not allow them to swim backwards out of a gill-net once caught or to stop quickly (Ayling & Cox, 1987). This, coupled with the tendency of butterfish to swim below the algal canopy where they are likely to have difficulty detecting the mesh, makes this species one of the most vulnerable to gill-nets.

Marblefish were mostly gilled. This may be due to the strong dorsal spines in this species' anterior dorsal fin preventing the mesh from passing further along the fish's body. The significant differences between mesh sizes in the proportions of marblefish caught by each method may be a result of mesh selectivity. The high number of fish tangled in the 2.5" mesh is probably a result of larger fish becoming tangled by their fins and spines. The equivalent small fish in the larger mesh sizes are able to pass through the net unhindered.

The two labrid species *Notolabrus celidotus* and *Notolabrus fucicola* were mostly gilled. This is likely to be a result of their labriform swimming motion, which enables them to 'back' out of the net rather than having to force their way through. Labrids were also observed to display a unique rolling motion when first tangled in the net (Chapter 6), which often resulted in the fish freeing itself from the net.

The deep bodied blue moki, *Latridopsis ciliaris*, was mostly tangled and gilled in the total catch. The low number of blue moki wedged is probably due to none of the mesh sizes being large enough to allow larger blue moki to enter the nets any further than their gills. The significantly greater number of fish tangled in the 2.5" mesh is likely to be a result of larger fish becoming tangled by their large fins and protruding fin rays. Large laterally compressed fish, such as blue moki and tarakihi, are not strong swimmers (Doak, 1991). They rely on muscular undulations from head to tail to swim, and brake with pectoral fins. They are capable of fast bursts of speed, but cannot maintain high speeds for any length of time. This weak swimming ability, coupled with their large fins, resulted in blue moki often becoming caught, tangled by a single fin rather than being truly enmeshed in the net.

Winters & Wheeler (1990) stated that the difference in fishing power between nets of various mesh sizes may be a result of differences in the proportion of fish caught by each method in each mesh size. They stated that the three modes of capture have different fishing powers that may vary with mesh size, but in general, wedging is more effective than gilling, and both these modes are much more effective than tangling. However, the results of this study show that for total fish numbers caught in all mesh sizes combined, most fish were gilled (1058), while wedged (309) and tangled (382) fish made up a significantly lower proportion of the catch. This result suggests that gill-nets do in fact 'gill' fish, rather than capture them by tangling or wedging.

Mesh size selectivity was evident from the mean length of fish captured by each method in each mesh size. Although the fork length of gilled and wedged fish increased with increasing mesh size, the fork length of tangled fish was less uniform in its relationship with mesh size.

The results of my study suggest that although tangling is not the result solely of size, it is not random. The proportions of butterfish caught by each method, when plotted against fork length, show a clear transition as fork length increases from most fish being wedged to the majority being tangled. This transition would not occur if the size of tangled fish was independent of mesh size, as fish of all sizes would then become tangled in any given mesh.

5.4.3 Temporal relationships

Although the concept of gill-net "saturation", or diminishing returns with increasing effort, is generally recognised as a phenomenon that can limit the catch per unit of time (Minns & Hurley, 1988), there have been relatively few studies directed at exploring the mechanisms that limit the catch. My study shows evidence of a set-time saturation effect with the 2.5" net. After ten hours, the catch rate increased minimally, and for set times longer than fifteen hours the catch began to decrease. This decrease in numbers may have been a result of fish escaping from the net or being removed by predators (Appendix 4). Saturation was also observed in the number of species caught with time, but appeared to occur after a longer period (11-15 hours).

Space limitation in the gill-net itself is regarded as a major component of the saturation effect. Once a fish has been captured, the particular cell that it occupies, plus surrounding ones, is not capable of catching other fish. Koike & Takeuchi (1982) examined this feature experimentally, and found repulsion of fish around a captured individual for some but not all mesh sizes. Kennedy (1951) cited additional ways in which the efficiency of a gill-net decreases with time. These included the presence of captured struggling fish, which makes the net more obvious and could frighten other fish away, and of dead fish, which may cause other fish to avoid the area. Kennedy speculated that the greater the catch during the first time period, the greater the difference between observed and expected catches.

The effect of set time on total and species catches in gill-nets has a direct bearing on the use of this gear in assessing the abundance and species diversity of fish populations. Earlier work focused on comparing multi- to one-night catches (Richards & Schnute, 1986; Minns & Hurley, 1988). However, the evidence presented here suggests that net saturation can occur during a single night, although this may be confounded by the varying behaviours of the fish species present.

The condition of fish in the landed catch is closely related to the length of time a net is in the water. The observed data suggest that the catch of nets set for longer than ten hours will contain many damaged fish. The decrease in damaged fish landed in nets set for longer than sixteen hours is likely to be a result of damaged fish being removed by predators, or falling from the net when their condition deteriorates.

The relationship between set time and condition is confounded by the fact that nets set for periods longer than ten hours were usually left in the water overnight. During the hours of darkness, crayfish, *Jasus edwardsii*, feed more actively (Gunson, 1983), and can severely damage fish or remove them from the nets altogether. Crayfish often become tangled in nets while feeding on dead or dying fish in the bottom region of the nets (Appendix 4). Most intertidal and subtidal marine isopods have activity peaks during the hours of darkness (Jones & Naylor, 1970; Fincham, 1973). Sea lice can completely devour all but the skin and calcified structures of a fish. The fact that both these predators feed predominantly at night means that damage incurred by fish as a result would be greater for overnight sets. The longer set times were invariably overnight sets.

By combining the information contained within Figures 5.11 and 5.13, it appears that there is little further fishing when a net is left out for longer than ten hours. The increase in numbers of fish caught after ten hours is small for all three mesh sizes. However, the proportion of damaged fish increases markedly in all mesh sizes after ten hours, with up to 50 % of the fish landed being damaged. Therefore, the number of fish caught after ten hours is likely to be offset by the number of fish being severely damaged.

5.4.4 Mesh selectivity

The mean fork length of fish caught in each gill-net increased with increasing mesh size for most species. The ANOVA of girth at point of capture with species and mesh size confirmed that larger fish are caught by larger mesh sizes, but the size of fish caught is species-dependent. The fish caught in each successive mesh size were significantly larger for the four species examined.

The probability of a fish being retained in a gill-net is a function of mesh size and girth. There appears to be a critical value at which these two factors combine to determine that a fish will be retained by a gill-net. The frequency distributions for the eight species based on the girth at the position of entanglement have modes slightly greater than unity. Therefore, for most of the fish captured, the girth at the position of capture is equal to, or slightly greater than, the perimeter of the mesh. Borgstrøm & Plahte (1992) observed a similar relationship for a stunted brown trout (*Salmo trutta*) population.

Very few fish were captured when the girth/perimeter ratio was less than 0.8 or 0.9. M^{c}Combie & Berst (1969) suggest that when a fish has a maximum girth 10 to 20% smaller than the perimeter of the mesh, it can probably swim through the net with as little hindrance as it would through a stand of rooted macroalgae.

For the species studied, as the ratio of girth where caught to perimeter of mesh exceeds 1.2, the efficiency of capture declines rapidly. Only approximately 15% of marblefish were taken at ratios greater than 1.5, and less than 1% of butterfish were caught at a ratio of 1.6 or greater.

That a fish can be caught when its girth is 50-60% greater than the perimeter of the mesh may be surprising on first consideration. However, the elastic properties of monofilament nylon and the fact that a mesh can compress the body of the fish (Plate 5.2) should be borne in mind. It may be significant that the two species taken with girth/perimeter ratios over 1.5 (butterfish and marblefish) have the most delicate scales of the eight species examined. McCombie & Berst (1969) also observed fish with delicate scales being caught at larger girth/perimeter ratios in gangs of experimental gill-nets.

Comparisons of fish catches by cotton, linen, multifilament nylon and monofilament nylon are common in the literature (Steinberg, 1964; May, 1970; Hylen & Jakobsen, 1979). However, little information is available on the changes in selectivity when the filament diameter of monofilament nylon is varied. Hansen (1974) compared catches of two different filament diameters for the same mesh size, and observed that for the two most commonly caught species, the smaller filament diameter captured larger fish. Hansen postulated that the difference was probably due to the elasticity of the monofilament nylon. The smaller diameter could be stretched more, and subsequently caught larger fish. The smaller diameter filament was also more flexible, and cut into the body of the fish more readily than the larger filament did. From this observation, filament diameters should be proportional in all of the mesh sizes when using monofilament nylon for a gill-net selectivity study. Changing the filament diameter for any given mesh size could result in changes in the selectivity of that mesh. In this study the filament diameters of the gill-nets were approximately proportional to the mesh sizes, therefore little variation in selectivity should have occurred.

CHAPTER SIX

Reef Fish Behaviour Around Gill-nets

6.1 INTRODUCTION

The process of a fish becoming caught in a gill-net involves a complex of interactions between the physical properties of the net itself, the morphological characteristics of the species and the behavioural traits of the fish (Parrish, 1969). Most studies of gill-net efficiency have been confined to the first of these factors, with little reference to the behaviour of fish around gill-nets.

Capture of fish by gill-nets is dependent on the activities of fish that bring them into direct physical contact with the net and then allow then to be caught, either by becoming "gilled" by the mesh or entangled in the netting. Therefore, the efficiency of this method of fishing is dependent on the net generating a minimum of stimuli that might provoke avoidance responses at a sufficient distance from the net to prevent contact being made with it. Of the possible types of stimuli that might be involved, the visual ones are the most obvious, and most of the experimental work done to date has been concerned with assessing their importance.

Verheijen (1953) pointed to the importance of visual stimuli in determining the avoidance of herring (*Clupea harengus*) of obstacles in aquarium tanks. This was confirmed by more extensive observations by Blaxter & Parrish (1959) and Blaxter *et al.* (1964) on the reactions of small groups of herring in tanks to various types of stationary netting obstacles at different light intensities between daylight and darkness. Frames of netting made from different materials, filament sizes, distances between strands, mesh sizes and colours were placed across the centre of the tank. Observations were made of fish movements, their reactions as they passed the netting, their reaction distance and the numbers making contact with or passing through the net. These observations showed that in daylight the extent of avoidance of the netting obstacle varied directly with its conspicuousness. The reaction distance was greatest and the number of fish making contact with or passing through the netting was least with the thickest filament, smallest mesh size and 'brightest' colour. With the least conspicuous sample of netting, made from monofilament nylon (0.2 mm diameter), avoidance reactions were relatively small, as was also the case when a sheet of transparent plastic was used. The effectiveness of each obstacle as a barrier decreased with decreasing light intensity, and at intensities less than 0.01 lux (darkness < 0.001 lux) even the obstacles that had elicited the most pronounced avoidance responses in daylight ceased to be effective.

Mohr (1960, 1961) conducted similar tank experiments with herring, and also found a direct relation between avoidance and the conspicuousness of the netting obstacles. He found that netting made from monofilament nylon with a diameter of 0.2 mm elicited no avoidance reactions, presumably due to the fish not being able to perceive it. He also found that with netting obstacles made from thicker nylon, the extent of the avoidance varied inversely with the number of fish present. The greater the number of fish (shoal size), the greater the frequency of contact with the netting. This he attributed to the influence of "shoal pressure" that may modify reactions to external stimuli. Similar observations were made by Aslanova (1958) on anchovy. However, Hunter & Wisby (1964) observed that groups of the carp *Cyprinis carpio* Linnaeus were more successful in avoiding a net than were isolates.

The results described above agree with those described from tank experiments on several species belonging to widely different genera (e.g., *Cyprinus*, *Salmo*, *Trachurus*, *Atherion*, *Carassius*, *Archeilognathus*), which show the importance of vision in determining fish behaviour in relation to netting and other obstacles. Kusaka (1957, 1958), Hiyama *et al.* (1957) and Kanda *et al.* (1958) investigated the effect of the colour of obstacles on the reaction of fish. Kusaka found that red netting was the most readily avoided, blue, green and yellow were intermediate (in that order) and transparent netting the least avoided. A similar order of colour was obtained by Kanda *et al.* (1958), who found that under daylight conditions the colour (i.e., the wave-length), and not its brightness was the main stimulus, whereas under twilight conditions brightness was the most important factor.

The results of the tank experiments, reported above on a wide variety of species, all point to visual stimuli as being of major importance in determining the avoidance responses of fish to stationary netting, and therefore in governing the 'efficiency' of stationary passive fishing gear such as gill-nets. However, it is necessary to clarify the factors governing the visibility of gill-nets in the sea, where conditions are markedly different from those encountered in small tanks. Hemmings & Lythgoe (1966) and Hemmings (1966) used direct underwater observations, in daylight and darkness, to assess the visibility to the human eye[1] of coloured synthetic fibre gill-nets. The observations were made at two locations (Mediterranean and Scottish coastal waters) with contrasting water conditions, and at two depths (10 m and 30 m). They found that the relative visibilities of the different coloured nets varied according to water conditions. They also found that the brightness contrast between the net and its background, rather than the colour of the net, was of major significance in determining its visibility.

[1] At present, few data exist on the spectral sensitivity of marine fishes for photopic vision. However, Lythgoe (1966) shows that the visual pigments extracted from fish eyes, which are thought to be responsible for scotopic vision (low light intensities), have spectral absorption characteristics similar to those of humans.

The results of observations and experimental work on the reactions of fish to stationary nets and other objects demonstrate the major role of visual stimuli as factors governing fish behaviour. However, there are other stimuli that can influence the behaviour of fish near gill-nets.

The movement of water through a net generates low frequency sound (Leggett & Jones, 1971). It is well established that fish are able to detect such hydroacoustic stimuli, generated by fish and other obstacles, by means of their lateral-line receptors (Fitzgerald, 1967) and the otolith organs of the inner ear (Hawkins, 1986). The degree to which this ability is developed varies greatly among species of fish, and only a few are able to locate stationary objects in their path (Kuiper, 1967). Several authors (John, 1957; Kuiper, 1967; Dijkgraaf, 1967), in discussing the ability of blind or blinded fish to detect stationary objects, have stressed the importance of eliminating all externally introduced vibrations that could serve to alert the fish to the obstacle. These authors attribute the detection of vibrational stimuli to the lateral line system.

Disturbance stimuli also may be generated by the presence of other fish already caught by the net, producing a 'saturation' effect (Kennedy, 1951). Sound and chemical stimuli may elicit fish responses resulting in avoidance of the gill-net (or possibly attraction). The response to visual stimuli may be affected by physiological factors (as indicated by Aslanova's (1961) observations on the reactions to nets of *Leukaspius delineatus* in different feeding states), ecological factors (temperature, currents, background noise) and social factors (number and density of fish concentrations).

Observations of fish both in the wild and in large tanks show that many species develop home grounds where the fish spend most time. Fish are extremely cautious when new objects enter their home ground (Wardle, 1986). Wardle (1986) trained cod, *Gadus morhua*, to race between feeding lights through an area with which they were familiar. The same fish would not race into an area that had not been previously explored. Tank experiments in which these species were trained to race between feeding lights demonstrated a timidity of fish to pass a new object, such as a rope laid across the tank floor while the fish were feeding at one light. When the other light was flashed, the fish started rapidly in its direction but swerved aside when they came to the rope. Several minutes were spent patrolling before they cautiously crossed the rope and raced to the calling light and food. Replacing the rope with a large mesh gill-net, through which the fish could easily swim, caused longer delays. If the large mesh gill-net was left in position, the fish would race through it after a day without hesitation. The acceptance by the fish of the intruding object (that is, when timidity is lost), might be considered to be a process of habituation (Wardle, 1986). These experiments suggest a relatively long period of timidity, stimulated by quite simple objects intruding into the fishes' home ground.

Another factor about which little is currently known is whether fish learn to avoid fishing gear. Some authors have drawn attention to the possibility of conditioned responses being developed following repeated exposure to the stimuli generated by fishing gear, although no convincing evidence of this type of behaviour occurring has been presented. Several authors have shown from aquarium experiments that fish can be conditioned to respond to several different stimuli (Tamura, 1964; Hester, 1968; Wardle, 1986), including acoustic ones (Tavolga, 1976; Buwalda *et al.*, 1983; Hawkins, 1986), so that the possibility of some conditioned behaviour in species subject to intensive exploitation cannot be ruled out. However, a conditioned avoidance response to gill-nets seems unlikely because negative reinforcement must occur, requiring a fish to be caught in a gill-net and subsequently escape. This sequence of events would have to be repeated often before an avoidance reaction was conditioned. The efficiency of gill-nets at catching and retaining most species makes this scenario unlikely.

The primary aim of this study was to determine whether the behaviour of mobile reef fish is modified in the vicinity of gill-nets. By directly observing fish behaviour around gill-nets, species' interactions with the mesh could be described. Differences in the behaviour of individual species and size classes within a species may result in different vulnerability among groups. Variation in the behaviour of fish around gill-nets with different mesh sizes may be a confounding factor in gill-net size selectivity. The integral aim of this study was to determine whether a fish's behaviour could alter its susceptibility to gill-nets.

6.2 MATERIALS AND METHODS

Gill-nets were set at 19 randomly selected sites around the Kaikoura Peninsula, and at 5 sites within the Marlborough Sounds. To maximise observation time by divers, sites were selected that were no greater than 10 metres deep. At each site, three gill-nets of different mesh sizes (2.5", 3.5", 4.5") were set randomly, with at least thirty metres separating each net. Once set, each net was left to settle for ten minutes before being observed by SCUBA divers. Two divers swam along each net, approximately two metres from the net and level with the midpoint of the net.

If a fish was seen to approach within one metre of the net, the diver hovered and observed the fish's behaviour while it remained within one metre of the gill-net. The species and standard length of each fish observed was recorded. The behaviour of the fish while it remained within one metre of the net was recorded in five second blocks. Once the fish travelled further than one metre from the gill-net, that observation was terminated and another fish was sought for observation. 886 fish were observed around three mesh sizes for a total of 162 minutes. The behaviour of each fish was described in terms of the following behavioural categories:

swims towards net
swims away from net
swims along net
swims under net
swims over net
swims through net
stops
hits net
caught in net
escapes from net

These behavioural categories are not mutually exclusive, as a fish may swim under a net initially, and then swim back through the mesh while still being observed. Any fish that was seen to become trapped in the net was observed for several minutes to determine if it subsequently escaped.

The data for each fish were summarised into a binary format. Was the fish caught? Did it subsequently escape? Did the fish cross the line of the net? Did the fish swim through the mesh of the net? Did the fish hit the mesh? Did the fish alter its swimming direction within one metre of the net? The time each fish spent within one metre of the gill-net was also calculated. Behavioural data were grouped by species, mesh size, and for *Notolabrus celidotus*, by size class. The observed behaviour was then tested with χ^2 analysis within and between groupings. ANOVA was used to test the length of time each group spent within one metre of the net, and to compare the standard lengths of fish observed to swim through the gill-nets.

6.3 RESULTS

Analysis at the species level revealed significant differences in the behaviour of fish around gill-nets (Table 6.1). There were significant differences between species in the relative number of fish that altered their swimming direction markedly within one metre of the net. Most blue cod, *Parapercis colias*, banded wrasse, *Notolabrus fucicola*, spotties, *Notolabrus celidotus*, and all leatherjackets, *Parika scaber*, altered their swimming direction while within one metre of the net (Table 6.1). Butterfish, *Odax pullus*, generally did not alter their swimming direction within one metre of the gill-nets.

Table 6.1 Contingency table for the behaviour of eight species of reef fish observed within one metre of a gill-net. Altered = altered direction markedly within one metre of the net. Hit = made solid contact with the mesh filament. Caught = entangled in the gill-net. Passed = crossed the line of the net. Through = swam through the mesh of the net. χ^2 tests of independence are shown.

SPECIES	ALTERED		HIT		CAUGHT		PASSED		THROUGH		TOTAL
	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	
BCO	48	43	14	77	6	85	58	33	33	58	91
BPF	98	65	28	135	9	154	84	79	64	99	163
BUT	9	14	6	17	6	17	12	11	8	15	23
GTR	2	4	3	1	2	2	1	3	1	3	4
LEA	17	0	2	15	0	17	3	14	0	17	17
MOK	13	16	5	24	3	26	18	11	16	13	29
STY	300	238	51	527	4	534	365	173	262	276	538
TAR	10	11	1	20	0	21	15	6	14	7	21
TOTAL	497	389	70	816	30	856	556	330	398	488	886
χ^2 TEST	$\chi^2 = 20.87$ $P < 0.01$		$\chi^2 = 32.07$ $P < 0.001$		$\chi^2 = 85.04$ $P < 0.001$		$\chi^2 = 33.80$ $P < 0.001$		$\chi^2 = 28.68$ $P < 0.001$		

There were significant differences in the relative proportions of species that hit the mesh of the gill-nets. High proportions of banded wrasse, butterfish and marblefish, *Aplodactylus arctidens*, hit the gill-net, but a low relative number of spotties made heavy contact with the gill-net (Table 6.1).

There was a significant difference in the relative proportions of species that were observed to be caught by the gill-nets. A high proportion of butterfish, marblefish and blue moki, *Latridopsis ciliaris*, were observed to be caught by the gill-nets. An extremely low number of spotties were caught in relation to the number observed within one metre of the gill-nets (Table 6.1).

There was a significant difference in the relative proportions of each species that swam across the line of the gill-net. A significantly lower proportion of leatherjackets and banded wrasse was observed to swim past the line of the gill-nets. A high proportion of spotties was observed to cross the line of the gill-net (Table 6.1).

There was a significant difference in the relative proportions of each species observed to swim through the gill-nets (Table 6.1). Only 3 leatherjackets swam across the line of the gill-net, all of which swam over the top of the net. A high proportion of tarakihi, *Nemadactylus macropterus*, swam through the mesh of the gill-nets. High numbers of spotties were observed to swim under the gill-nets.

There were significant differences in the behaviour of blue cod around the three different mesh sizes (Table 6.2). A higher proportion of fish hit the 2.5" mesh than the other two mesh sizes (Figure 6.1). Consequently, a higher proportion of blue

Table 6.2 Contingency table for the behaviour of blue cod, *Parapercis colias*, observed within one metre of gill-nets with three different mesh sizes. χ^2 tests of independence are shown.

MESH	ALTERED		HIT		CAUGHT		PASSED		THROUGH		TOTAL
	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	
2.5"	12	6	9	9	4	14	5	13	0	18	18
3.5"	20	22	4	38	1	41	32	10	22	20	42
4.5"	16	15	1	30	1	30	21	10	11	20	31
TOTAL	48	43	14	77	6	85	58	33	33	58	91
χ^2 TEST	$\chi^2 = 1.86$ n.s.		$\chi^2 = 21.20$ $P < 0.001$		$\chi^2 = 8.92$ $P < 0.05$		$\chi^2 = 13.10$ $P < 0.01$		$\chi^2 = 14.97$ $P < 0.001$		

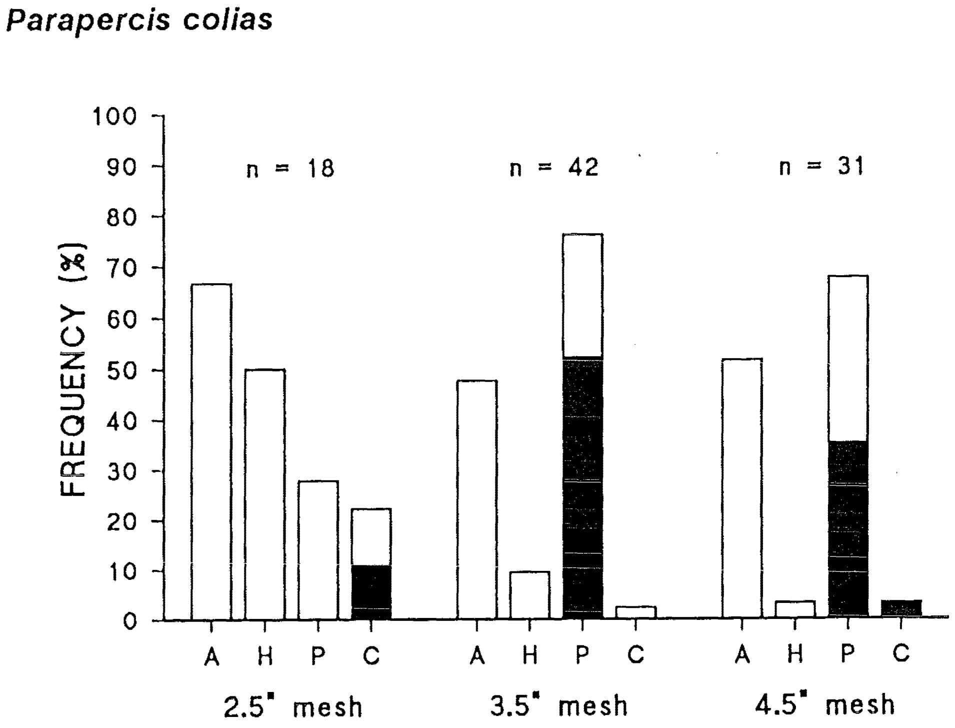


Figure 6.1 The behaviour of blue cod, *Parapercis colias*, around three mesh sizes of gill-net. A = altered swimming direction within one metre of the net, H = hit the gill-net, P = passed the line of the gill-net (the proportion of all fish that went through the gill-net is solid), C = caught in the mesh (the proportion of all fish that subsequently escaped is solid).

cod was caught in the 2.5" gill-net, but approximately 50% of these subsequently escaped (Figure 6.1). A low proportion of blue cod crossed the line of the 2.5" net, and all of these went under the net.

There was no significant difference between mesh sizes in the proportion of banded wrasse that altered their swimming direction markedly within one metre of the gill-net (Table 6.3). A significantly greater proportion of banded wrasse hit the 2.5" mesh than the larger mesh sizes (Figure 6.2). However, there was no significant difference in the proportion of fish caught in each of the three mesh sizes. Most banded wrasse that were caught subsequently escaped (Figure 6.2). A high proportion of banded wrasse was observed to cross the line of the 4.5" net, and most of these swam through the mesh (Figure 6.2).

There was no significant difference between mesh sizes in the proportion of butterfish altering their swimming direction within one metre of the net, and in the proportions that hit the gill-net. There was no significant difference in the proportions of butterfish caught by each of the three mesh sizes, and many of these fish subsequently escaped (Figure 6.3). The proportion of butterfish crossing the line of the gill-nets and swimming through the mesh was not significantly different between mesh sizes (Table 6.4).

The number of marblefish observed was too low to allow individual analysis.

There was no significant difference in the behaviour of leatherjackets around the three different mesh sizes (Table 6.5). All the leatherjackets were observed to alter

Table 6.3 Contingency table for the behaviour of banded wrasse, *Notolabrus fucicola*, observed within one metre of gill-nets with three different mesh sizes. χ^2 tests of independence are shown.

MESH	ALTERED		HIT		CAUGHT		PASSED		THROUGH		TOTAL
	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	
2.5"	39	25	23	41	6	58	29	35	17	47	64
3.5"	34	14	3	45	3	45	20	28	15	33	48
4.5"	25	26	2	49	0	51	35	16	32	19	51
TOTAL	98	65	28	135	9	154	84	79	64	99	163
χ^2 TEST	$\chi^2 = 4.94$ n.s.		$\chi^2 = 26.16$ $P < 0.001$		$\chi^2 = 4.85$ n.s.		$\chi^2 = 8.83$ $P < 0.05$		$\chi^2 = 17.41$ $P < 0.001$		

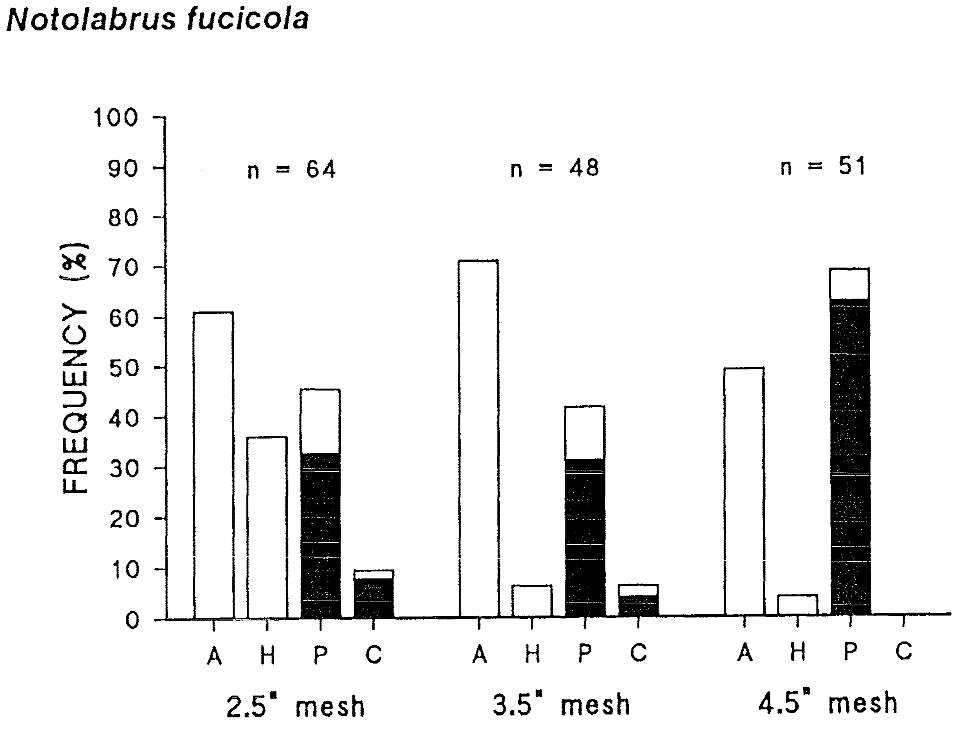

Notolabrus fucicola

Figure 6.2 The behaviour of banded wrasse, *Notolabrus fucicola*, around three mesh sizes of gill-net. A = altered swimming direction within one metre of the net, H = hit the gill-net, P = passed the line of the gill-net (the proportion of all fish that went through the gill-net is solid), C = caught in the mesh (the proportion of all fish that subsequently escaped is solid).

Table 6.4 Contingency table for the behaviour of butterfish, *Odax pullus*, observed within one metre of gill-nets with three different mesh sizes. χ^2 tests of independence are shown.

MESH	ALTERED		HIT		CAUGHT		PASSED		THROUGH		TOTAL
	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	
2.5"	4	4	3	5	3	5	4	4	1	7	8
3.5"	0	5	2	3	2	3	3	2	3	2	5
4.5"	5	5	1	9	1	9	5	5	4	6	10
TOTAL	9	14	6	17	6	17	12	11	8	15	23
χ^2 TEST	$\chi^2 = 4.11$ n.s.		$\chi^2 = 2.39$ n.s.		$\chi^2 = 2.39$ n.s.		$\chi^2 = 0.16$ n.s.		$\chi^2 = 3.27$ n.s.		

Odax pullus

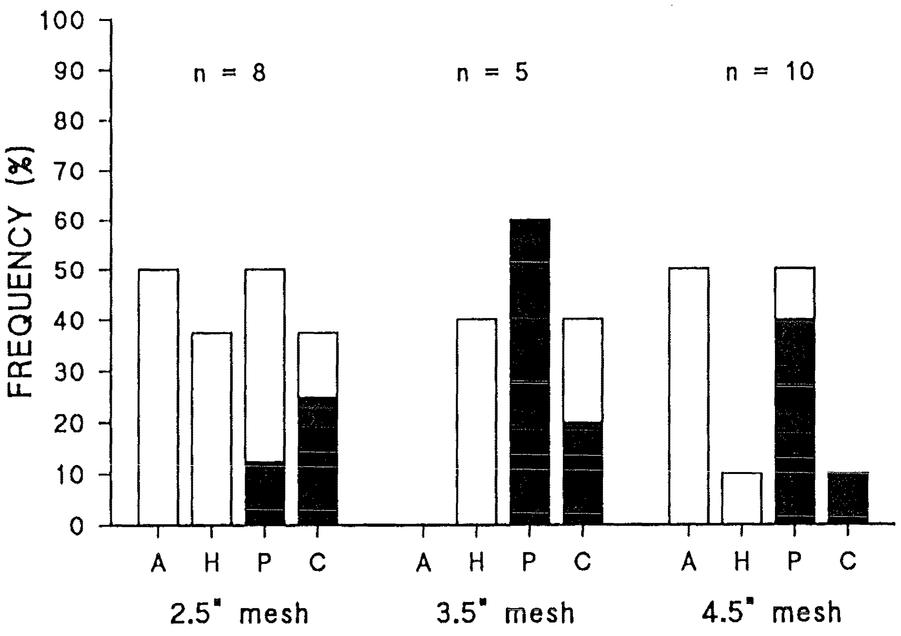


Figure 6.3 The behaviour of butterfish, *Odax pullus*, around three mesh sizes of gill-net. A = altered swimming direction within one metre of the net, H = hit the gill-net, P = passed the line of the gill-net (the proportion of all fish that went through the gill-net is solid), C = caught in the mesh (the proportion of all fish that subsequently escaped is solid).

their swimming direction within one metre of the net (Figure 6.4), and all the fish that swam across the line of the gill-nets went over the net (Table 6.5).

There was no significant difference in the proportions of blue moki seen to alter their direction of swimming markedly within one metre of the gill-net. A significantly greater proportion of blue moki was observed to hit the 2.5" mesh than the larger mesh sizes (Table 6.6). However, there was no significant difference in the proportion of fish caught in each mesh size. A significantly greater proportion of blue moki was observed to cross the line of the 4.5" mesh, and most of these swam through the mesh (Figure 6.5).

The proportion of spotties altering their swimming direction was not significantly different between mesh sizes (Table 6.7). Most spotties avoided hitting the gill-nets, but a significantly greater proportion hit the 2.5" mesh size. Consequently, only four spotties were caught by the gill-nets, and these were all in the 2.5" mesh. Two of these fish subsequently escaped (Figure 6.6). Most spotties swam past the line of the gill-nets, with a significantly greater proportion crossing the line of the 4.5" mesh. Significantly more spotties swam through the mesh of the 4.5" mesh than through the two smaller mesh sizes (Figure 6.6).

There were no significant differences in the behaviour of tarakihi around the three different mesh sizes (Table 6.8). All the tarakihi observed to cross the line of the gill-nets swam through the mesh of the nets (Figure 6.7).

Table 6.5 Contingency table for the behaviour of leatherjackets, *Parika scaber*, observed within one metre of gill-nets with three different mesh sizes. χ^2 tests of independence are shown.

MESH	ALTERED		HIT		CAUGHT		PASSED		THROUGH		TOTAL
	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	
2.5"	4	0	0	4	0	4	2	2	0	4	4
3.5"	8	0	2	6	0	8	0	8	0	8	8
4.5"	5	0	0	5	0	5	1	4	0	5	5
TOTAL	17	0	2	15	0	17	3	14	0	17	17
χ^2 TEST			χ^2 = 2.55 n.s.				χ^2 = 4.61 n.s.				

Parika scaber

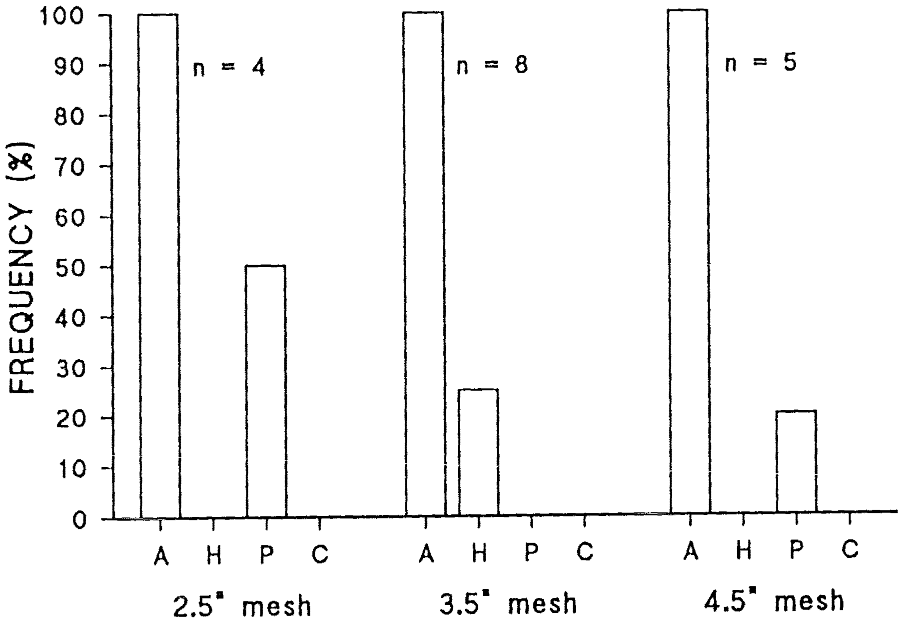


Figure 6.4 The behaviour of leatherjackets, *Parika scaber*, around three mesh sizes of gill-net. A = altered swimming direction within one metre of the net, H = hit the gill-net, P = passed the line of the gill-net (the proportion of all fish that went through the gill-net is solid), C = caught in the mesh (the proportion of all fish that subsequently escaped is solid).

Table 6.6 Contingency table for the behaviour of blue moki, *Latridopsis ciliaris*, observed within one metre of gill-nets with three different mesh sizes. χ^2 tests of independence are shown.

MESH	ALTERED		HIT		CAUGHT		PASSED		THROUGH		TOTAL
	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	
2.5"	3	2	3	2	1	4	1	4	0	5	5
3.5"	5	3	2	6	2	6	2	6	2	6	8
4.5"	5	11	0	16	0	16	15	1	14	2	16
TOTAL	13	16	5	24	3	26	18	11	16	13	29
χ^2 TEST	$\chi^2 = 2.67$ n.s.		$\chi^2 = 10.08$ $P < 0.01$		$\chi^2 = 4.20$ n.s.		$\chi^2 = 15.25$ $P < 0.001$		$\chi^2 = 15.86$ $P < 0.001$		

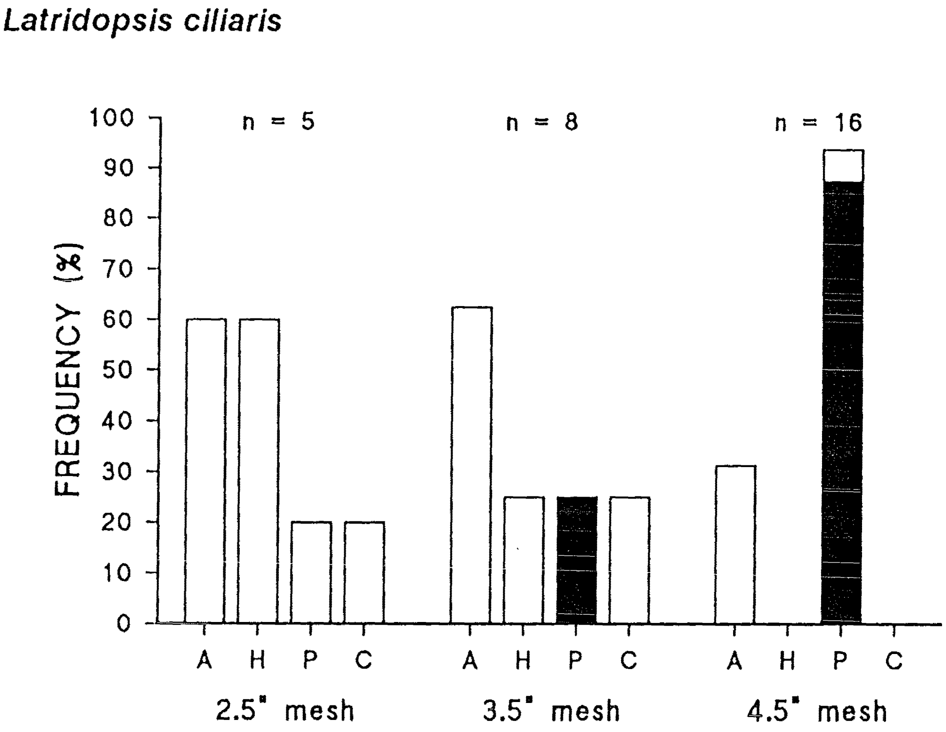


Figure 6.5 The behaviour of blue moki, *Latridopsis ciliaris*, around three mesh sizes of gill-net. A = altered swimming direction within one metre of the net, H = hit the gill-net, P = passed the line of the gill-net (the proportion of all fish that went through the gill-net is solid), C = caught in the mesh (the proportion of all fish that subsequently escaped is solid).

Table 6.7 Contingency table for the behaviour of spotties, *Notolabrus celidotus*, observed within one metre of gill-nets with three different mesh sizes. χ^2 tests of independence are shown.

MESH	ALTERED		HIT		CAUGHT		PASSED		THROUGH		TOTAL
	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	
2.5"	103	78	7	174	4	177	119	62	78	103	181
3.5"	119	79	4	194	0	198	125	73	91	107	198
4.5"	78	81	0	159	0	159	121	38	93	66	159
TOTAL	300	238	11	527	4	534	365	173	262	276	538
χ^2 TEST	$\chi^2 = 4.51$ n.s.		$\chi^2 = 6.32$ $P < 0.05$		$\chi^2 = 7.95$ $P < 0.05$		$\chi^2 = 7.35$ $P < 0.05$		$\chi^2 = 8.97$ $P < 0.05$		

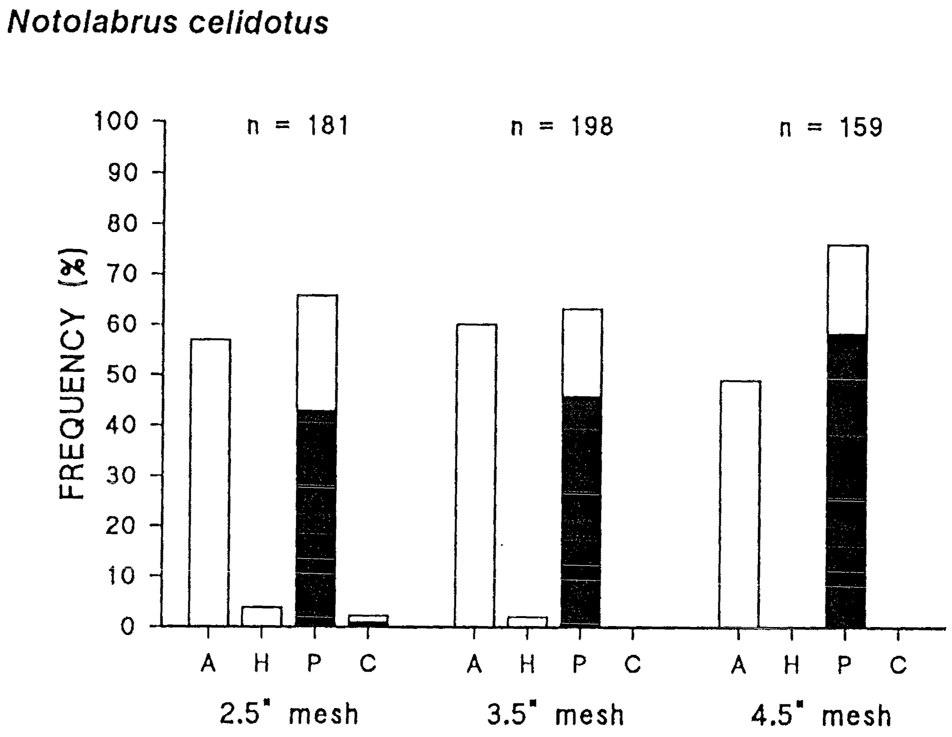


Figure 6.6 The behaviour of spotties, *Notolabrus celidotus*, around three mesh sizes of gill-net. A = altered swimming direction within one metre of the net, H = hit the gill-net, P = passed the line of the gill-net (the proportion of all fish that went through the gill-net is solid), C = caught in the mesh (the proportion of all fish that subsequently escaped is solid).

Table 6.8 Contingency table for the behaviour of tarakihi, *Nemadactylus macropterus*, observed within one metre of gill-nets with three different mesh sizes. χ^2 tests of independence are shown.

MESH	ALTERED		HIT		CAUGHT		PASSED		THROUGH		TOTAL
	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	
2.5"	1	1	0	2	0	2	2	0	2	0	2
3.5"	3	2	1	4	0	5	3	2	2	3	5
4.5"	6	8	0	14	0	14	10	4	10	4	14
TOTAL	10	11	1	20	0	21	15	6	14	7	21
χ^2 TEST	$\chi^2 = 0.44$ n.s.		$\chi^2 = 3.36$ n.s.				$\chi^2 = 1.12$ n.s.		$\chi^2 = 2.74$ n.s		

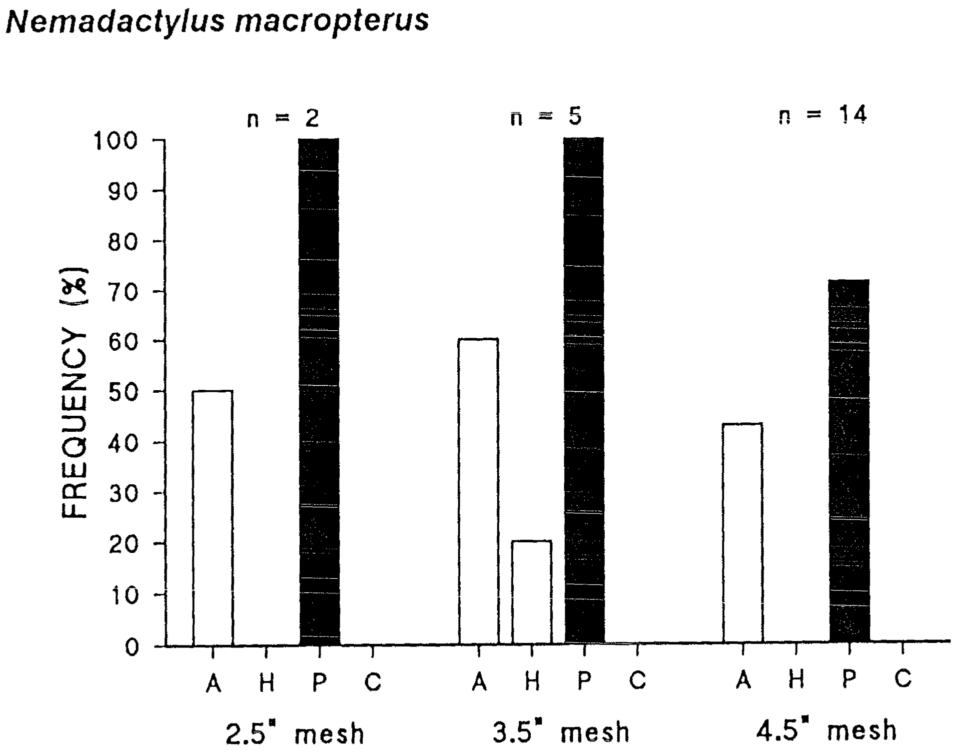


Figure 6.7 The behaviour of tarakihi, *Nemadactylus macropterus*, around three mesh sizes of gill-net. A = altered swimming direction within one metre of the net, H = hit the gill-net, P = passed the line of the gill-net (the proportion of all fish that went through the gill-net is solid), C = caught in the mesh (the proportion of all fish that subsequently escaped is solid).

Significant differences were observed when the behaviour of all species was compared between the three mesh sizes. A significantly smaller proportion of fish altered their swimming direction within one metre of the 4.5" mesh (Figure 6.8). Significantly fewer fish hit the 4.5" mesh, and consequently this mesh caught significantly fewer fish than the other two mesh sizes (Table 6.9). Most fish observed to be caught in the gill-nets subsequently escaped (Figure 6.8). A greater proportion of fish was observed to cross the line of the 4.5" mesh by swimming through the mesh (Figure 6.8).

There were significant differences between species in the amount of time each fish spent within one metre of the net (Table 6.10). Species with less than three fish observed in the vicinity of any one mesh size were not included in this analysis. Leatherjackets spent the longest time within the immediate vicinity of the gill-net, while butterfish spent the least. There were no significant differences between mesh sizes in the length of time each fish spent within one metre of the net (Figure 6.9).

The standard length of banded wrasse and spotties observed to swim through the mesh of the gill-nets was compared with that of those that did not (Figure 6.10). An ANOVA of standard length with species, mesh size and behaviour (through or not through) as factors (Table 6.11) showed several significant results. Fish that swam through the gill-net had a significantly smaller standard length than those that did not. There was no significant difference in the standard length of fish observed around each of the three mesh sizes. The banded wrasse population observed had significantly larger standard lengths than the spotties. The banded wrasse that did swim through the mesh were significantly larger than the spotties that swam through the net. The banded wrasse that did not swim through the net were also significantly larger than the spotties that did not swim through the net.

Table 6.9 Contingency table for the behaviour of eight species of reef fish observed within one metre of gill-nets with three mesh sizes. χ^2 tests of independence are shown.

MESH	ALTERED		HIT		CAUGHT		PASSED		THROUGH		TOTAL
	YES	NO	YES	NO	YES	NO	YES	NO	YES	NO	
2.5"	167	116	46	237	19	264	162	121	98	185	283
3.5"	190	125	19	296	8	307	185	130	135	180	315
4.5"	140	148	5	283	3	285	209	79	165	123	288
TOTAL	497	389	30	856	30	856	556	330	398	488	886
χ^2 TEST	$\chi^2 = 9.81$ $P < 0.01$		$\chi^2 = 40.64$ $P < 0.001$		$\chi^2 = 15.11$ $P < 0.001$		$\chi^2 = 17.73$ $P < 0.001$		$\chi^2 = 30.47$ $P < 0.001$		

All species

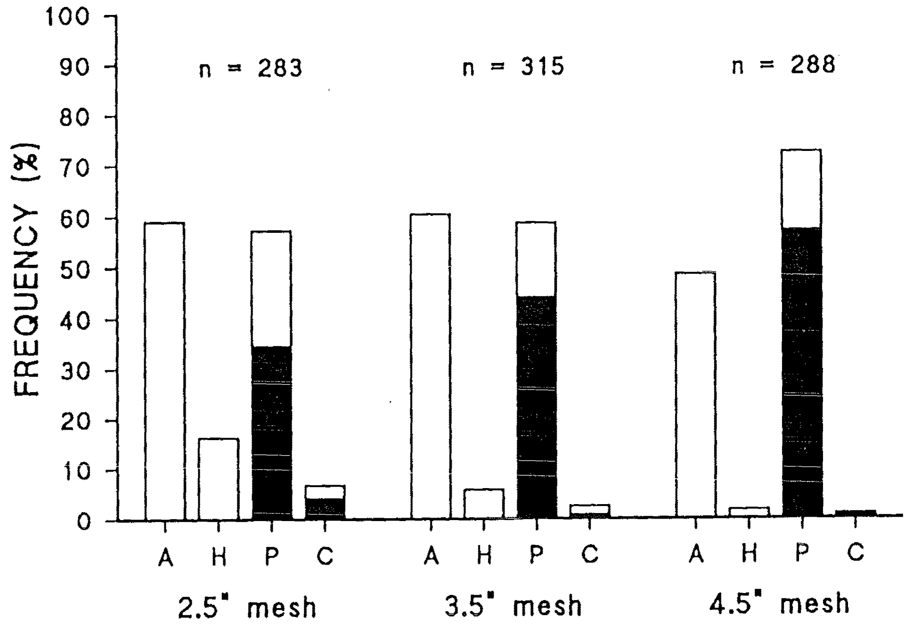


Figure 6.8 The behaviour of eight species of reef fish around three mesh sizes of gill-net. A = altered swimming direction within one metre of the net, H = hit the gill-net, P = passed the line of the gill-net (the proportion of all fish that went through the gill-net is solid), C = caught in the mesh (the proportion of all fish that subsequently escaped is solid).

Table 6.10 ANOVA table for the analysis of time spent within one metre of a gill-net for six species (blue cod, banded wrasse, butterfish, leatherjackets, blue moki, spotties) and three mesh sizes (2.5", 3.5" and 4.5").

Source	DF	SS	MS	F
Mesh	2	104.86	52.43	$1.90^{n.s.}$
Species	5	390.28	78.06	2.83^{*}
Mesh x Species	10	245.14	24.51	$0.89^{n.s.}$
Residual	54	1487.50	27.55	
Total	71	2227.78		

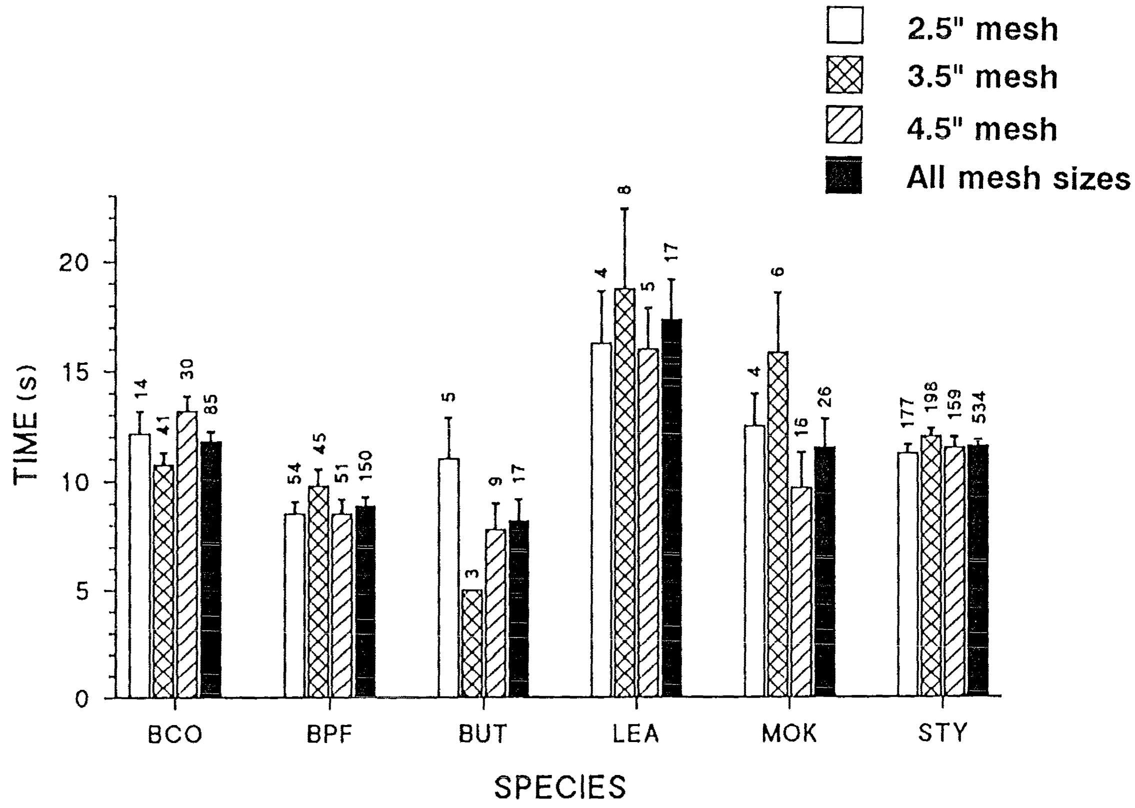


Figure 6.9 The mean time (± 1 S.E.) spent within one metre of gill-nets of three different mesh sizes by six species of reef fish. The data from the three mesh sizes was pooled to produce the mean time spent by each species around all mesh sizes.

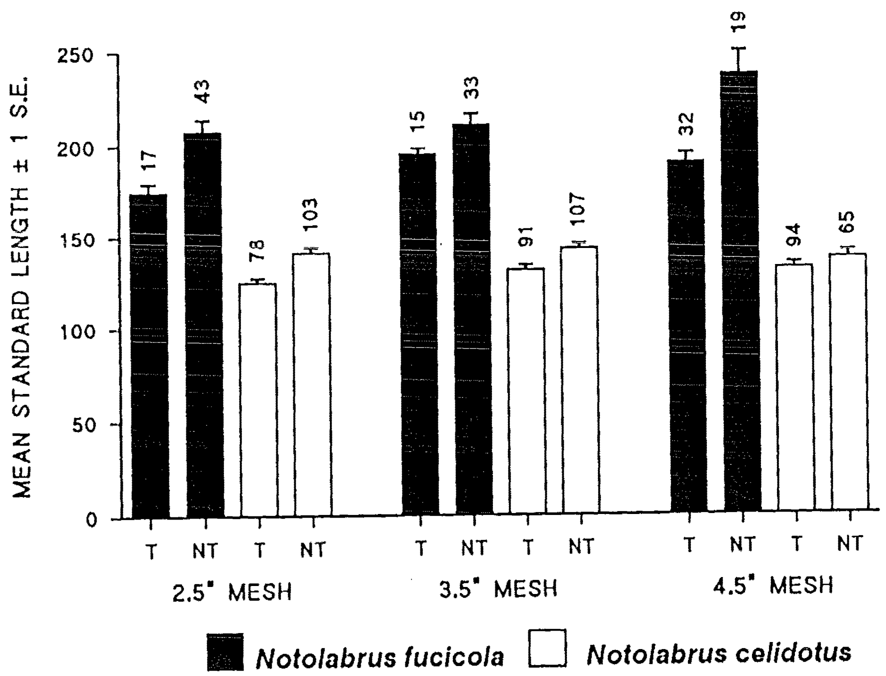


Figure 6.10 The mean standard length (± 1 S.E.) of banded wrasse, *Notolabrus fucicola*, and spotties, *Notolabrus celidotus*, observed to swim through (T), and not to swim through (NT), three mesh sizes.

Table 6.11 ANOVA table for the standard length of two species of fish (banded wrasse and spotties) around gill-nets with three mesh sizes (2.5",3.5" and 4.5") displaying two forms of behaviour (swimming through and not swimming through the net). The variance has been partitioned according to Winer (1962).

Source of variation	DF	SS	F	%Variance
Behaviour	1	29134	32.08^{***}	7.90
Mesh	2	2730	$1.50^{n.s.}$	0.19
Species	1	223309	245.90^{***}	62.24
Behaviour x Mesh	2	1669	$0.92^{n.s.}$	-0.06
Behaviour x Species	1	4805	5.29^{*}	2.18
Mesh x Species	2	3070	$1.69^{n.s.}$	0.53
Behaviour x Mesh x Species	2	6767	3.73^{*}	4.16
Residual	168	152563		22.87
Total	179	424048		

The spotty assemblage observed in the vicinity of the gill-nets (Figure 6.11) was arbitrarily divided into four size classes according to standard length:

S.L. ≤ 110 mm
110 < S.L. ≤ 130 mm
130 < S.L. ≤ 150 mm
S.L. > 150 mm

The behaviour of spotties in each size class was compared within and among each of the three mesh sizes (Table 6.12).

There were significant differences between mesh sizes in the proportions of spotties from each size class observed to alter swimming direction within 1 metre of the gill-net (Table 6.12). Most of the two larger size classes altered direction within one metre of the 2.5" mesh. There were also significant differences between size

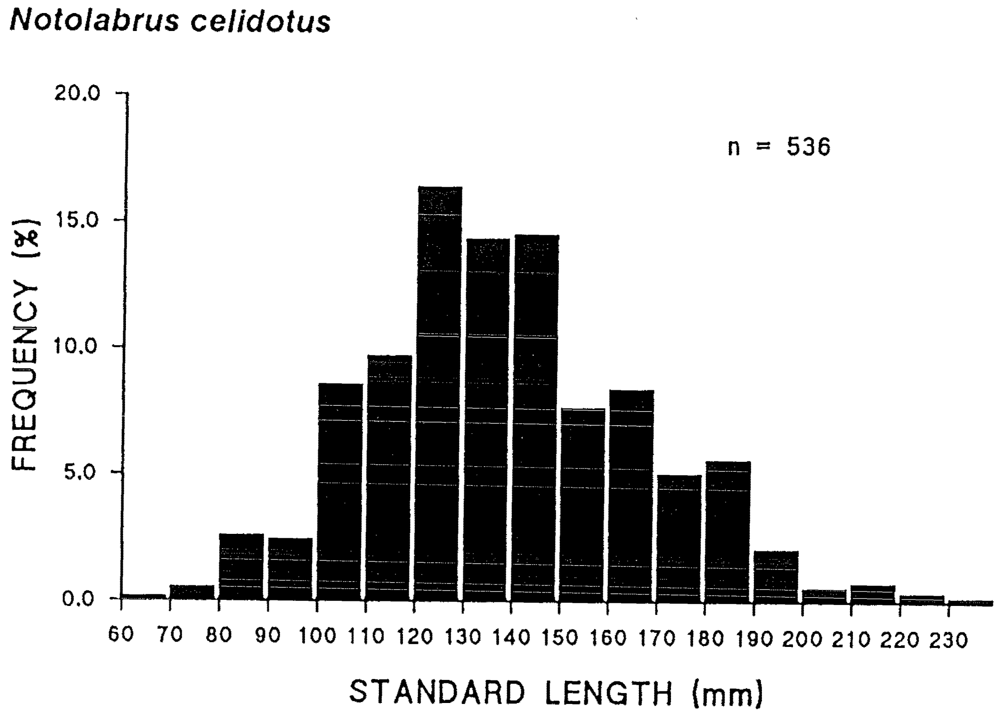


Figure 6.11 The size frequency distribution of 536 spotties, *Notolabrus celidotus*, observed within one metre of gill-nets of three mesh sizes.

classes in the proportion of fish altering direction. Most of the two larger size classes altered direction, while the majority of the small size class did not alter direction. There was no significant difference between mesh sizes in the proportion of spotties observed to alter swimming direction.

There was a significant difference between mesh sizes in the proportion of spotties from each size class observed to hit the gill-net (Table 6.12). A significantly greater

Table 6.12 Contingency table for the behaviour of four size classes of spotties, *Notolabrus celidotus*, around gill-nets of three mesh sizes. χ^2 tests of independence and partial χ^2 are shown.

MESH SIZE	S.L. (mm)	ALTERED		HIT		CAUGHT		PASSED		THROUGH	
		YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
2.5" MESH	< 110	21	27	0	48	0	48	35	13	28	20
	110-130	18	30	2	46	1	47	39	9	28	20
	130-150	31	10	0	41	0	41	20	21	10	31
	> 150	33	11	5	39	3	41	25	19	12	32
3.5" MESH	< 110	23	16	1	38	0	39	31	8	21	18
	110-130	34	30	2	62	0	64	43	21	35	29
	130-150	26	16	0	42	0	42	22	20	17	25
	> 150	36	17	1	52	0	53	29	24	18	35
4.5" MESH	< 110	17	22	0	39	0	39	32	7	25	14
	110-130	23	21	0	44	0	44	33	11	26	18
	130-150	17	22	0	39	0	39	33	6	24	15
	> 150	21	16	0	37	0	37	23	14	18	19
χ^2 TEST		31.53 $P < 0.01$		26.64 $P < 0.01$		26.51 $P < 0.01$		35.25 $P < 0.001$		36.61 $P < 0.001$	
PARTIAL χ^2 (MESH SIZE)		4.51 n.s.		6.32 $P < 0.05$		7.95 $P < 0.05$		7.35 $P < 0.05$		8.97 $P < 0.05$	
PARTIAL χ^2 (SIZE CLASS)		14.74 $P < 0.01$		7.70 n.s.		5.94 n.s.		17.05 $P < 0.001$		20.65 $P < 0.001$	

proportion of spotties in the > 150 mm size class hit the 2.5" mesh. There was a significant difference between mesh sizes in the proportion of fish hitting the nets. A significantly higher proportion of spotties hit the 2.5" mesh. There was no significant difference between size classes in the proportion of fish hitting the gill-nets. Most spotties did not hit the gill-nets.

There was a significant difference between mesh sizes in the proportion of spotties from each size class observed to be caught by the gill-nets (Table 6.12). A high number of spotties in the largest size class were caught in the 2.5" mesh. Significantly more fish were caught in the 2.5" mesh. There was no significant difference between size classes in the proportion of fish being caught in the gill-nets. Most spotties were not caught in the gill-nets.

There were significant differences between mesh sizes in the proportions of spotties from each size class that were observed to pass the line of the gill-nets (Table 6.12). With the 2.5" and 3.5" gill-nets, approximately half the fish in the 130 - 150 mm size class crossed the line of the net. However, with the 4.5" mesh, most fish in this size class crossed the line of the net. A significantly greater proportion of fish crossed the line of the 4.5" mesh. A significantly smaller proportion of spotties in the > 150 mm size class passed the line of the gill-nets.

There were significant differences between mesh sizes in the proportions of spotties from each size class that were observed to swim through the mesh of the gill-nets (Table 6.12). With the 4.5" mesh, approximately half the fish in the >150 mm size class swam through the mesh of the net. With the 2.5" and 3.5" meshes, most of the fish in this size class, and in the 130 - 150 mm size class, did not swim through the mesh of the net. A significantly greater proportion of spotties swam through the mesh of the 4.5" net. Most of the spotties in the two largest size classes did not swim through the net, whereas most of the spotties in the smaller size classes did.

The period of time that each of the four size classes of spotties spent within one metre of the net was tested with ANOVA. Mesh size did not have a significant effect on the period of time fish spent within one metre of the net ($F_{2,432} = 1.03$, $p = 0.358$). There was a significant difference in the period of time each size class spent within one metre of the gill-nets ($F_{3,432} = 2.70$, $p < 0.05$). However, there was no apparent pattern to this variability, with the largest and smallest size classes spending the most time around the nets, and the central two size classes spending less time within one metre of the nets. The amount of time each size class spent near the gill-nets did not differ significantly with mesh size ($F_{6,432} = 1.57$, $p = 0.154$).

The standard lengths of spotties observed to swim through each of the three mesh sizes were compared with ANOVA and Tukey's pairwise comparisons of means. Fish that swam through the 2.5" mesh ($F_{1,177} = 14.57$, $p < 0.001$) and the 3.5" mesh ($F_{1,196} = 8.91$, $p < 0.01$) were significantly smaller than those observed not to swim through the mesh. There was no significant difference in the standard lengths of spotties that did and did not swim through the 4.5" mesh ($F_{1,157} = 1.36$, $p = 0.246$). There was also no significant difference in the standard lengths of fish observed to swim through each of the three mesh sizes ($F_{2,260} = 2.02$, $p = 0.134$). The difference in standard length between the fish that did and did not swim through the mesh decreased as the mesh size increased, until there was no significant difference between them in the 4.5" mesh.

6.4 DISCUSSION

In Chapter 4, the gill-net catch was compared with visual census estimates of a population at a particular site. The disparity between the species composition of the two samples indicated that some species, particularly the labrids, were less susceptible to being caught in gill-nets, and behavioural differences were suggested as a possible explanation of this invulnerability.

The gill-nets commonly used by commercial and amateur fishermen are constructed from monofilament nylon that is relatively invisible to fish, particularly at low light intensities. When a net is invisible, the target fish are unaware of its presence, swim into it, and may become trapped by the meshes. If a species can sense the net at a large enough distance, it may be possible for the fish to avoid becoming caught. Alternatively, if the swimming motion and behaviour of a species is suitable, it may be possible for a fish to escape from the gill-net once caught.

The observations of fish within one metre of gill-nets revealed significant differences in the behaviour of eight species of mobile reef fish. The relative numbers of each species hitting the gill-nets suggest that some species, particularly spotties, are less susceptible to becoming caught. High relative proportions of butterfish, marblefish and blue moki were caught in the gill-nets. These species appear to be more vulnerable to capture in gill-nets. This is likely to be a result of behavioural differences, swimming motions, and perhaps visual acuity.

Butterfish are herbivorous fish that mostly swim beneath the algal canopy. This behaviour is likely to be a primary cause of their increased susceptibility to gill-nets.

The limited visibility amongst algal hold-fasts would prevent butterfish from detecting a gill-net until there was little time to avoid the mesh. Their fusiform body shape and sinusoidal swimming motion result in butterfish having little ability to escape from a net once caught. They are unable to swim backwards out of a net, and consequently drive forwards, usually wedging themselves further into the mesh (Plate 5.2).

Blue moki, and other laterally compressed fishes, are generally weak swimmers (Doak, 1991). Once tangled by a fin or gill, these fish appear unable to gain enough thrust to escape from the net. Like butterfish, they try to push through the mesh, but because of their body shape can progress no further than their gills.

A higher proportion of most species hit the 2.5" mesh size. This result is surprising in that although this mesh was constructed from the smallest diameter monofilament nylon (0.36 mm), it also had more knots per unit area than the other two mesh sizes. Several researchers have shown that fish reaction distances are linearly related to the diameter of the mesh filament (Blaxter & Parrish, 1959; Blaxter *et al.*, 1964). However, knots in monofilament nylon display a bright jewel-like glint dependent on the colour of the nylon (Wardle *et al.*, 1991). The glint occurs where parts of the knotted line are oriented in positions parallel to the sea surface. Although the thin nylon of the 2.5" mesh may be difficult for fish to see, the abundance of knots should be obvious. The fish that hit the 2.5" net may see the glint of the knots, but not recognise this as a net and proceed to swim into the mesh.

The data comparing the proportions of fish altering direction and swimming through the different mesh sizes suggests that the species that appear to be aware of the presence of a net may also be able to determine whether or not they can fit through the mesh. Significantly fewer fish altered their swimming direction within one metre of the 4.5" net. This suggests that the fish are either unaware of the larger mesh size, or that they are aware that they can swim through the mesh. The fact that significantly less fish hit the 4.5" net suggests the latter may be the case. The 4.5" mesh size net was constructed from a larger filament size, therefore its water resistance would be greater. This may result in this net being easier for the fish to see or sense.

Despite being the single most abundant large reef fish found in New Zealand waters (Ayling & Cox, 1987; Choat & Ayling, 1987), spotties made up less than 4% of the 1749 fish caught during this study. Fewer than 1% of spotties observed within one metre of the gill-nets were caught. This may be the result of several factors that, when combined, alert the spotty to a gill-net's presence and allow it to negotiate the mesh of the gill-net safely.

The differences in behaviour of the various size classes of spotties suggest that fish actively control their interactions with the gill-net. Spotties that were observed to swim through the mesh of the 2.5" and 3.5" gill-nets were significantly smaller than fish that did not swim through the mesh. Very few spotties hit the mesh of the gill-nets, suggesting that an active decision not to swim through the mesh was made by larger fish. Many spotties were observed to swim through tears in the mesh. This behaviour suggests that, rather than sensing the net as a whole, spotties are capable of seeing individual mesh filaments, and actively decide whether or not to attempt to swim through a given mesh cell.

The visual acuity that appears to enable spotties to see the mesh of a gill-net may be a direct result of their feeding behaviour. Adult spotties feed predominantly on small bivalves and crustaceans (Russell, 1983; Jones, 1984a). This would require these fish to have acute vision. The environment in which the spotty lives requires the fish to make regular judgements of distances. Daily foraging trips involve the negotiation of cracks, crevasses and holdfasts in the reef environment. This manoeuvring would require distance judgement, and an awareness of the minimum space through which a fish could swim. The application of this judgement to the negotiation of a gill-net may explain the ease with which spotties were observed to swim along, under and through the mesh of gill-nets.

The labriform swimming motion (Breder, 1926; Lindsey, 1978) of spotties appears to assist them in avoiding capture in gill-nets. Spotties swim with a rowing action of their modified, fan shaped, pectoral fins (Webb, 1973). Spotties swimming with a labriform motion can reach speeds of 2.0 body lengths per second (Starling, 1985). However, swimming with the pectoral fins is more often used by the fish for its daily foraging swims.

The advantage this mode of swimming offers spotties in avoiding capture by gill-nets is that by reversing the sculling of their pectoral fins, these fish can swim backwards. If a labrid enters the mesh of a gill-net that is too small to allow the fish to pass through, then the fish can usually scull backwards out of the mesh before it becomes tangled. If a labrid does not see a gill-net until it is very close, labriform swimming allows the fish to stop quickly before it enters the mesh.

Species with carangiform or subcarangiform swimming motion, such as blue moki, *Latridopsis ciliaris*, and kahawai, *Arripis trutta*, can only attempt to force their way through the mesh. This invariably results in them becoming further wedged into the mesh (Plates 5.2 & 5.4). Large blue moki, with head girths too large to enter the net, were often observed trapped against a gill-net, held by nothing more than their own swimming motion, which propelled them into the net. These fish would presumably have escaped as the net was pulled to the surface.

Although banded wrasse also swim with a labriform motion, a significantly higher proportion of this species, compared to spotties, made contact with the net and were subsequently caught. Jackson *et al.* (1983) observed that the facility with which a fish becomes wedged in a gill-net is generally a result of its momentum, which is in turn the product of the velocity and mass of the fish. Both these parameters are progressively reduced with decreasing size of fish (Marais, 1985). Banded wrasse are generally larger than spotties (Ayling & Cox, 1987), and are therefore likely to enter the mesh of a gill-net further than spotties. Banded wrasse spend more time among kelp than spotties, using the kelp and their camouflage as a defence against predators. As with butterfish, this may reduce their ability to avoid a gill-net. The larger scales and more obtrusive gill covers of this species may also make this species more susceptible to becoming tangled in the mesh.

The possibility of a learned avoidance reaction to gill-nets is unlikely in most species of fish, because of the efficiency of gill-nets at catching and holding fish.

However, less than 8% of the spotties that hit the gill-nets were actually caught. Feasibly, a spotty could have enough interactions with a gill-net, and still survive, for an avoidance response to be negatively reinforced.

The importance of an understanding of fish behaviour around gill-nets has been stressed by many authors. Net avoidance by fish can severely decrease CPUE (Leggett & Jones, 1971; Lynch, 1991), while a knowledge of fish behaviour can be used to minimise the catches of one species while still maintaining the fishery of another species. The use of different coloured nets to select a particular species and reduce the by-catch of untargeted species would prevent wastage of fish and the handling of unwanted catch (Jester, 1973). This alone would be a significant development in any gill-net fishery. To date, most research into fish behaviour around fishing gear has concentrated on moving gear such as trawls and seines. Because of this, knowledge of the behaviour of fish around gill-nets is still limited to observations of fish in tanks and aquaria.

Each species of reef fish observed near the gill-nets displayed a characteristic behaviour. These behavioural differences may explain the disproportionately low numbers of some common reef fish caught in gill-nets. However, although the behaviour of some fish in the vicinity of a gill-net appears to be altered, without suitable controls, these behavioural differences cannot be attributed solely to the gill-net's presence.

CHAPTER SEVEN

Patterns of Abundance of Fish Caught in Commercial Gill-nets

The data used in this chapter were supplied by Dr J. Brian Jones, MAF Fisheries Greta Point. The data were collected during several research expeditions by staff from MAF Fisheries.

7.1 INTRODUCTION

Gill-nets are widely used in small-scale fisheries because they require little investment in labour and equipment, and are effective in catching widely scattered fish populations (Reis & Pawson, 1992). Compared with other fishing gear, gill-nets can be highly size selective and, for a given mesh size, catches decrease sharply for fish smaller and larger than the modal size class of those retained (Figure 5.16). Estimates of abundance and size frequency distributions of fish populations using data from gill-net catches can be strongly biased, since the length distribution of the catch seldom represents that of the fished population (Reis & Pawson, 1992). It is therefore important to be able to determine the selectivity of gill-nets for fish size.

The most direct method of estimating selectivity is to compare the size distributions of gill-net catches with the length distribution of the population being fished. The difficulty is to establish the population length distribution, unless data are available from catches taken by different gear for which the selectivity is known. Usually, gill-net catches are compared with those of some 'unselective' gear; however, truly unselective gear may not exist (Hamley, 1975). For example, the purse seines of French (1969) and the trawls of Richardson (1956) failed to catch large salmon and pilchard, respectively, that were caught in gill-nets. Presumably the larger fish escape purse seines before they are closed, and swim out of the way of approaching trawls (Beverton & Holt, 1957; Wardle, 1983; Wardle, 1986). Rollefsen (1953) compared catches of cod (*Gadus morhua*) by gill-nets, long-lines and purse seines and observed marked differences in the size-distributions of the respective catches.

Although the most reliable way of estimating gill-net selectivity is 'directly' by fishing a known population, this method is expensive, and most estimates have been done 'indirectly' by comparing the catches of two or more mesh sizes (Havinga & Deelder, 1949; Graham & Mann, 1959; Olsen, 1959; Gulland & Harding, 1961; Kitahara, 1971; Nagiec & Ostrowski, 1973). These indirect methods often assume the selectivity curves for all mesh sizes have the same shapes and heights. Many authors now consider these assumptions to be incorrect and the subsequent selectivity curves to be biased (Hamley, 1975). Researchers are now developing new mathematical models to describe the functional relationship between mesh size and size-class of fish (Wulff, 1986; Yatsu & Watanabe, 1987; Van Densen, 1987; Jensen, 1990; Henderson & Wong, 1991; Helser *et al.*, 1991).

Gill-net selectivity has been defined as the probability that a fish of a given species and size will be caught when encountering a specified mesh size (Kitahara, 1971). However, Hamley (1975) proposed that gill-net selectivity should be redefined as the probability of capture, given the fishing effort, because part of the observed selectivity may be due to different probabilities of large and small fish encountering the net (Lagler, 1968). Rudstam *et al.* (1984) found the probability of encountering a gill-net to be directly proportional to the distance travelled by the fish during the sampling period. This distance increases with fish size because swimming speed increases with fish size (Bainbridge, 1958).

Inter-specific differences in behaviour, morphology and even in the habitat each species occupies are factors that may explain observed differences in mesh selectivity between species. Differences in encounter probabilities between large and small fish will affect the selectivity of gill-nets to different species as well as different size-classes within a species. The magnitude of this difference in selectivity will be directly proportional to the difference in swimming speeds of the size-classes or species of fish being compared (Rudstam *et al.*, 1984). The difference thus could be large. For example, skipjack tuna, *Katsuwonus pelamis*, with fork lengths of 75 cm have routine swimming speeds twice that of yellowfin tuna, *Thunnus albacares*, of the same length (Magnuson, 1970). Therefore at equal densities, skipjack tuna should encounter gill-nets twice as often as yellowfin tuna.

A correction for encounter probability based on swimming speed may not completely account for the increased efficiency observed for larger fish after correction for mesh size selection in gill-nets. Hamley & Regier (1973) observed greater increases in selectivity of large mesh nets for walleye (*Stizostedion vitreum*) than could be accounted for by encounter probability corrections proposed by Rudstam *et al.* (1984). Other factors may be involved, such as differences in daily activity patterns and/or habitat utilisation of different sized fish, or decreased visibility of larger mesh nets. Larger fish are also tangled more frequently in gill-nets of all mesh sizes (section 5.4.2), which may account for the disproportionate percentage of large size classes observed in gill-net catches.

Looking at the study of gill-net selectivity in a broader context, the problems confronted and solutions found are not peculiar to gill-nets, but apply with variations to all sampling gear. The selectivity of gill-nets is probably understood better than that of any other fishing gear. Where hook selectivity has been estimated, the methods have been borrowed from work on gill-nets (direct estimates from comparison with gear of known selectivity), taking the gape of the hook (perpendicular distance from point to shank) as the critical dimension corresponding to mesh size in nets (Pope *et al.*, 1975). Trawl selectivity has also been studied extensively (Treschev, 1963; Kimura, 1977; Hoydal *et al.*, 1982; Massey, 1986) but, limited by the experimental techniques (covered codend and alternate haul (Jones, 1982)), usually only in terms of retaining fish that have already been caught in the trawl (Pope *et al.*, 1975). The result is one-sided selectivity curves that show maximal efficiency toward all fish greater than some critical size (Tokai & Kitahara, 1989); yet at least in some studies, trawls have failed to catch large fish known to be present (Hamley, 1975). In good visibility, fish on the substrate ahead of a trawl mouth have been observed to rise over the headline of the approaching net and avoid capture (Wardle, 1986). Groups of large fish have been observed swimming in the net mouth for long periods. These fish did not become exhausted and enter the net, so they were able to swim away when the net was hauled from the sea bed (Main & Sangster, 1983).

The opportunity arose to analyse the catch data of a series of gill-net sets made in the 1980s during two research expeditions by a team from the Ministry of Agriculture and Fisheries, Fisheries Research Division, Greta Point, Wellington. The sets were made in the Bay of Plenty and Palliser Bay. The aim of the analysis was to describe the catch of each species in terms of fork length. The size frequency distributions of each species in each mesh size could then be related to the characteristics of each species likely to affect their susceptibility to gill-nets. The size frequency distributions of Kahawai, *Arripis trutta*, caught in the gill-nets and those measured during a recreational fishing survey were compared to allow a 'direct' estimate of the selectivity of gill-nets.

7.2 MATERIALS AND METHODS

The gill-nets used during this study were considerably larger than those used in the study around Kaikoura. Three different mesh sizes (3.5", 4.5" and 5.5") were linked together to form a single net with three panels. Each panel was 100 metres long and double slung (two gill-nets were stacked on top of each other) producing a single gill-net 300 metres long and over 5 metres high. The order of the mesh sizes in the gill-net was determined randomly and altered after each set by splitting the net into its three constituent mesh sizes and rejoining the nets in a random order.

The composite net was set at fifteen sites around the coast of the North Island (Figure 7.1). Ten sites were selected north of Cape Egmont, off New Plymouth, and the nets were set in late November 1983. A single site at Whale Island, off Whakatane, was fished in late March 1984, and four sites in Palliser Bay, south of Wellington, were fished in August and September of 1985. All of the sets, except two in Palliser Bay, were overnight sets of approximately 16 hour duration. Only one composite net was set at each site; therefore the variability of the catch at each site could not be analysed.

The number of each species caught, the duration of each set and the depth at each site were recorded. The fork length of most of the species caught was measured as the fish were removed from the net. The great numbers of spotted spiny dogfish caught at the Palliser Bay sites caused logistical problems, and consequently most fish from this species were not measured.

Size frequency curves were compiled for the fish from the most common species caught in each mesh size. The fork length of fish from each species caught in each mesh size was compared with ANOVA. This analysis was only done if more than five fish from each species were caught in each of the mesh sizes being compared. Before ANOVAs were done, Cochran's tests for homogeneity of variances were done and where appropriate, data were transformed.

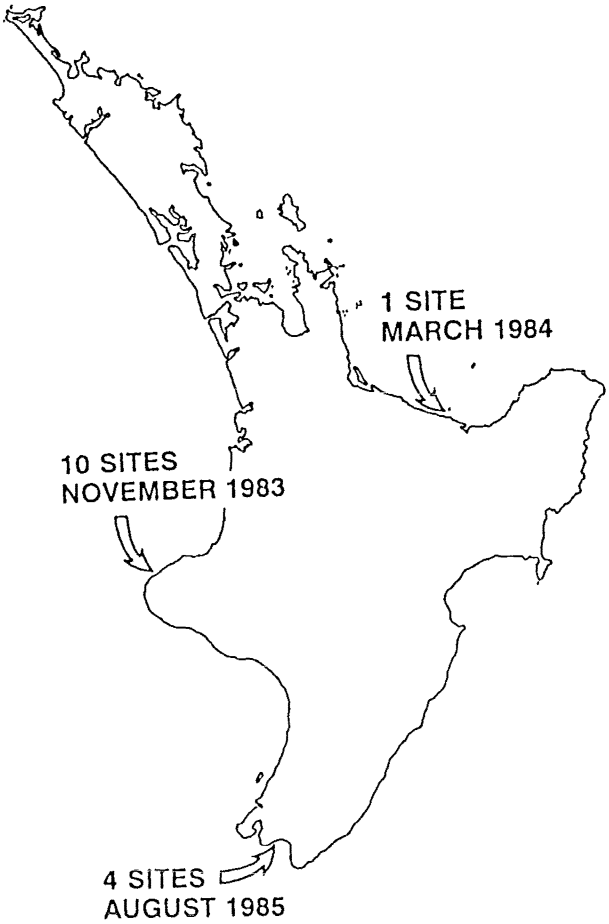


Figure 7.1 Map of the North Island of New Zealand. The locations of the experimental gill-netting sites are shown.

Correlation analyses were done on the total number of fish from each species caught, total number of species, depths, set times, day/night sets and latitude for each of the three mesh sizes and for all mesh sizes combined. The number of fish from each species caught in each mesh size was analysed with χ^2 tests of independence.

7.3 RESULTS

The size frequency distributions of species caught in the gill-nets varied significantly between mesh sizes and species. Tukey's pairwise comparisons showed the mean fork length of kahawai, *Arripis trutta*, caught in the 3.5" mesh to be significantly smaller than that of those caught in the 4.5" and 5.5" mesh ($F_{2,196} = 141.09$, $p < 0.001$). There was no significant difference between the fork length of kahawai caught in the 4.5" and 5.5" mesh (Figure 7.2). Significantly fewer kahawai were caught in the 5.5" mesh than in each of the other mesh sizes (Table 7.1).

The low number of butterfly perch, *Caesioperca lepidoptera*, caught in the 4.5" and 5.5" mesh prevented comparisons between mesh sizes with ANOVA. The size distribution of butterfly perch caught in the 3.5" mesh had a very narrow range (Figure 7.3). The fork lengths of the four fish caught in the 4.5" and 5.5" mesh were within the size range caught in the 3.5" mesh. Significantly fewer butterfly perch were caught in the 4.5" and 5.5" mesh (Table 7.1).

Tukey's pairwise comparisons showed the mean fork length of carpet sharks, *Cephaloscyllium isabellum*, caught in the 3.5" mesh to be significantly smaller than that of those caught in the 4.5" and 5.5" mesh ($F_{2,41} = 5.62$, $p < 0.01$). There was

Arripis trutta

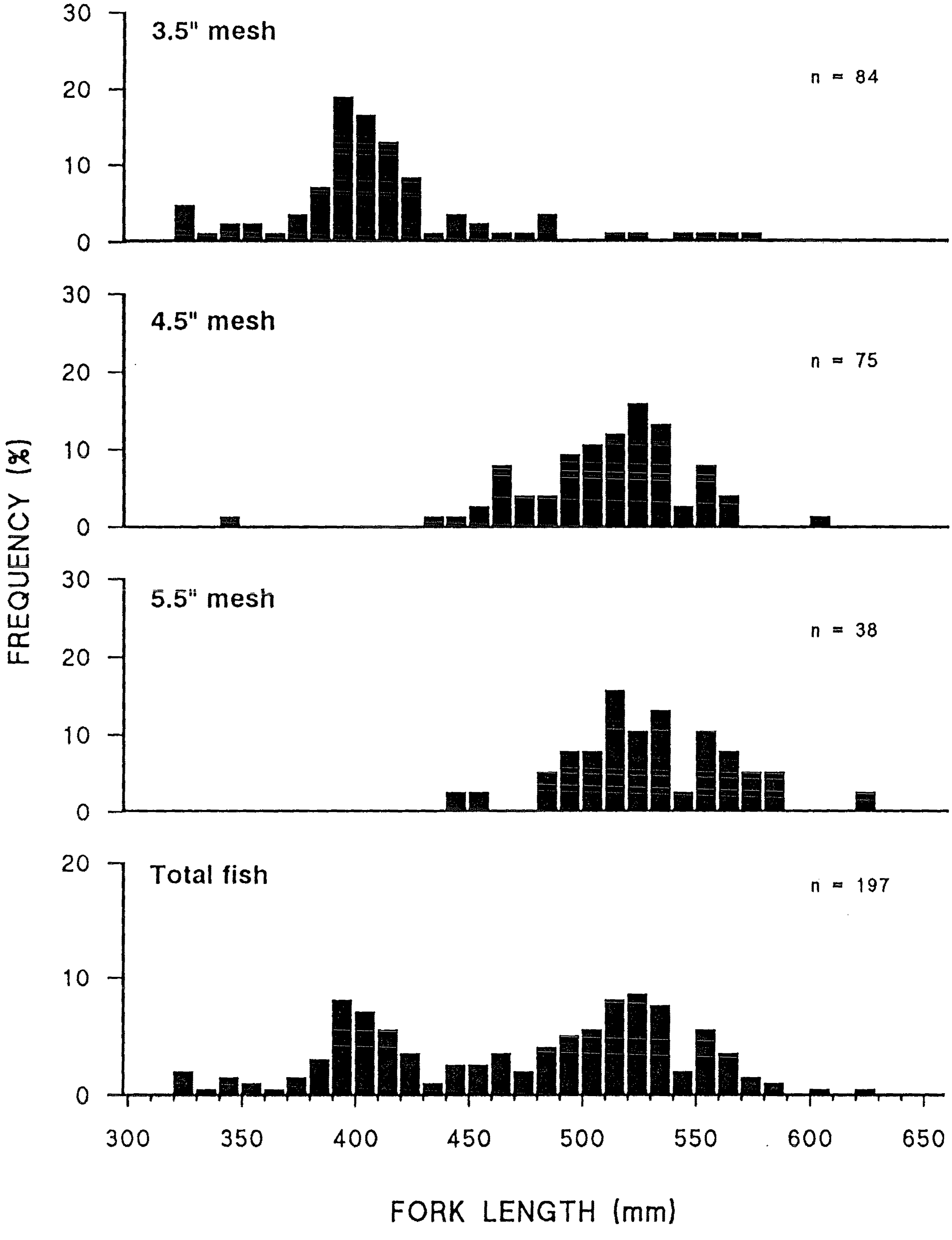


Figure 7.2 Size frequency distributions (%) of kahawai, *Arripis trutta*, caught in three mesh sizes of gill-net and in the total catch. Mean fork length (± 1 s.e.) for each mesh size: 3.5" = 408.3 ± 5.5; 4.5" = 505.9 ± 4.3; 5.5" = 525.0 ± 5.9.

Table 7.1 Contingency table for the number of fish from 55 species that were caught in gill-nets of three mesh sizes. χ^2 tests of independence are shown (Probability levels: * < 0.05, ** < 0.01, *** < 0.001, ^{ns} = not significant).

SPECIES	3.5" MESH	4.5" MESH	5.5" MESH	TOTAL	χ^2 TEST
ASQ	2	4	1	6	2.00^{ns}
BAR	29	11	2	42	27.00^{***}
BCO	17	18	17	52	0.04^{ns}
BOA	0	1	0	1	2.00^{ns}
BPE	219	2	2	223	422.32^{***}
BRC	3	22	5	30	21.80^{***}
BRI	0	0	11	11	22.00^{***}
BSH	12	35	47	94	20.19^{***}
BUT	12	5	3	20	6.70^{*}
CAR	16	19	7	42	5.57^{ns}
CMO	0	2	0	2	4.00^{ns}
CON	0	1	0	1	2.00^{ns}
EGR	0	1	0	1	2.00^{ns}
ELE	1	0	2	3	2.00^{ns}
EMA	26	84	10	120	75.80^{***}
ESO	0	1	0	1	2.00^{ns}
FRO	1	0	0	1	2.00^{ns}
GTR	0	1	21	22	38.27^{***}
GUR	22	43	14	79	17.04^{***}
HAP	1	1	1	3	0.00^{ns}
HOK	75	75	56	206	3.50^{ns}
JDO	0	2	2	4	2.00^{ns}
JMA	25	8	1	34	26.88^{***}
JMN	13	14	7	34	2.53^{ns}
KAH	81	87	39	207	19.83^{***}
KIN	0	2	0	2	4.00^{ns}
LEA	7	1	0	8	10.75^{**}
LIN	8	0	0	8	16.00^{***}
LSO	0	3	0	3	6.00^{*}
MAO	155	3	0	158	298.34^{***}
MOK	0	6	4	10	5.60^{ns}
OCT	2	0	1	3	2.00^{ns}
RAT	2	8	5	15	3.60^{ns}
RBY	4	1	0	5	5.20^{ns}
RCO	47	43	12	102	21.59^{***}
RHY	2	1	0	3	2.00^{ns}
RMO	2	6	5	13	2.00^{ns}
RMU	12	11	1	24	9.25^{**}
RSC	2	0	0	2	4.00^{ns}
RSK	0	2	0	2	4.00^{ns}
SCH	2	2	1	5	0.40^{ns}
SFL	0	1	1	2	1.00^{ns}
SKI	0	2	0	2	4.00^{ns}
SNA	2	34	2	38	53.89^{***}
SPD	202	442	357	1001	88.76^{***}
SPE	57	19	5	81	53.63^{***}
SPF	6	1	0	7	8.86^{*}
SPO	20	32	25	77	2.83^{ns}
SPZ	0	1	1	2	1.00^{ns}
SSK	0	1	1	2	1.00^{ns}
SWE	8	34	7	49	16.33^{***}
TAR	47	85	15	147	50.12^{***}
TRE	34	42	43	119	1.23^{ns}
WAR	31	40	101	172	57.33^{***}
WIT	1	5	0	6	7.00^{*}
TOTAL	1208	1267	835	3310	99.47^{***}

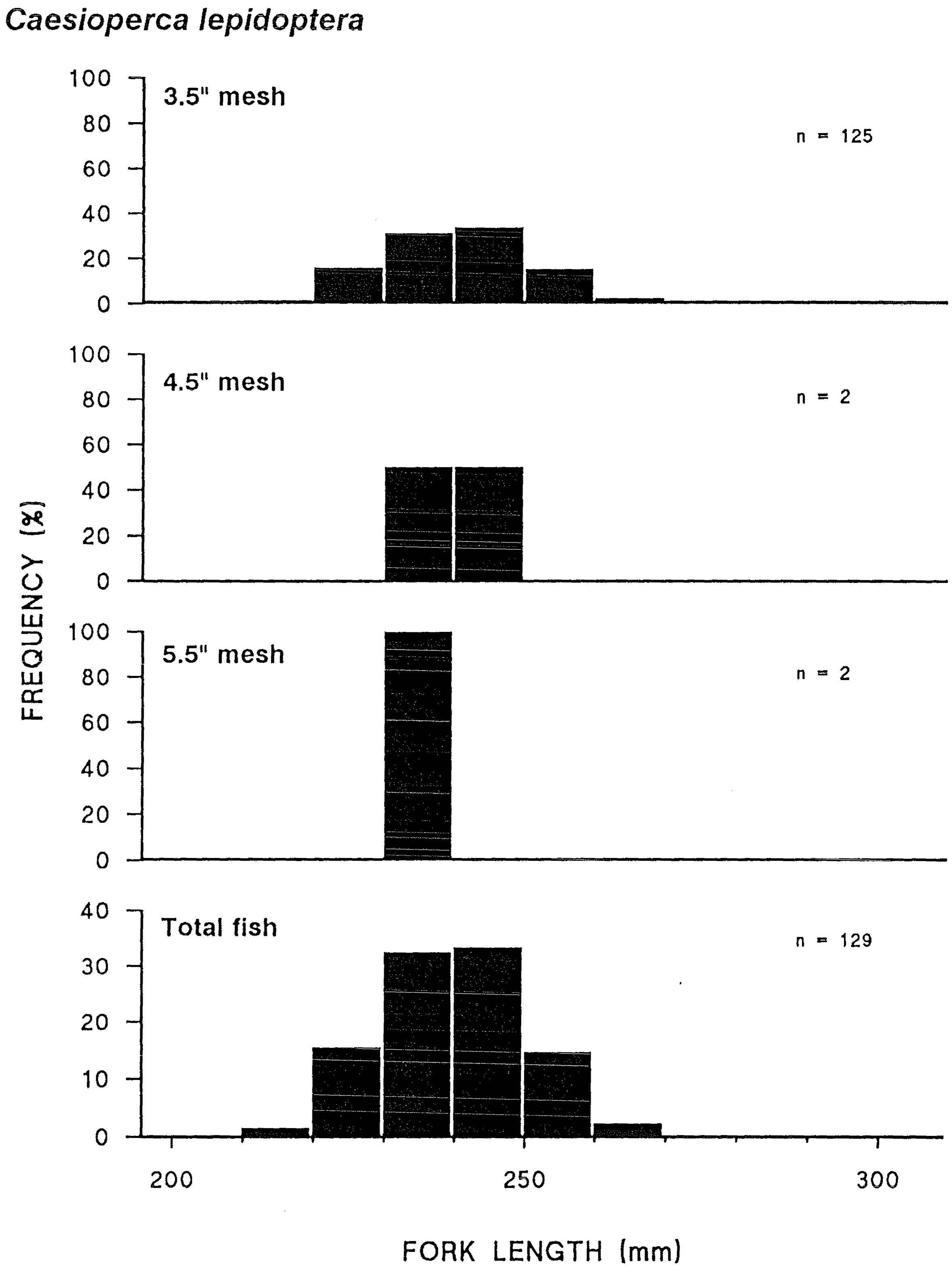


Figure 7.3 Size frequency distributions (%) of butterfly perch, *Caesioperca lepidoptera*, caught in three mesh sizes of gill-net and in the total catch. Mean fork length (± 1 s.e.) for each mesh size: 3.5" = 235.2 ± 0.9; 4.5" = 235.0 ± 5.0; 5.5" = 230.0 ± 0.0.

no significant difference between the fork length of carpet sharks caught in the 4.5" and 5.5" mesh (Figure 7.4). There was no significant difference in the number of carpet sharks caught in each of the three mesh sizes (Table 7.1).

There was no significant difference between the fork lengths of red gurnard, *Chelidonichthys kumu*, caught in each of the mesh sizes ($F_{2,97} = 0.78$, $p = 0.462$). Red gurnard with fork lengths between 260 and 450 mm appeared to be susceptible to capture in each of the three mesh sizes (Figure 7.5). However, the 4.5" mesh caught significantly more red gurnard than the 3.5" and 5.5" mesh (Table 7.1).

The small number of snapper, *Chrysophrys auratus*, caught in the 3.5" and 5.5" mesh prevented comparisons between mesh sizes with ANOVA. However, the two fish caught in each of the 3.5" and 5.5" mesh sizes are at the lower and upper extremes respectively of those caught in the 4.5" mesh (Figure 7.6). The 4.5" mesh caught significantly more snapper than the 3.5" and 5.5" mesh (Table 7.1).

There was no significant difference between the fork lengths of black sharks, *Dalatias licha*, caught in the 4.5" and 5.5" mesh sizes ($F_{1,15} = 0.41$, $p = 0.534$). The low number of fish caught in the 3.5" mesh prevented comparison with the other mesh sizes. The fork lengths of the black sharks caught in the 3.5" and 5.5" mesh sizes are within the range of those caught in the 4.5" mesh (Figure 7.7). The 3.5" mesh caught significantly less black sharks than the other two mesh sizes (Table 7.1).

Cephaloscyllium isabellum

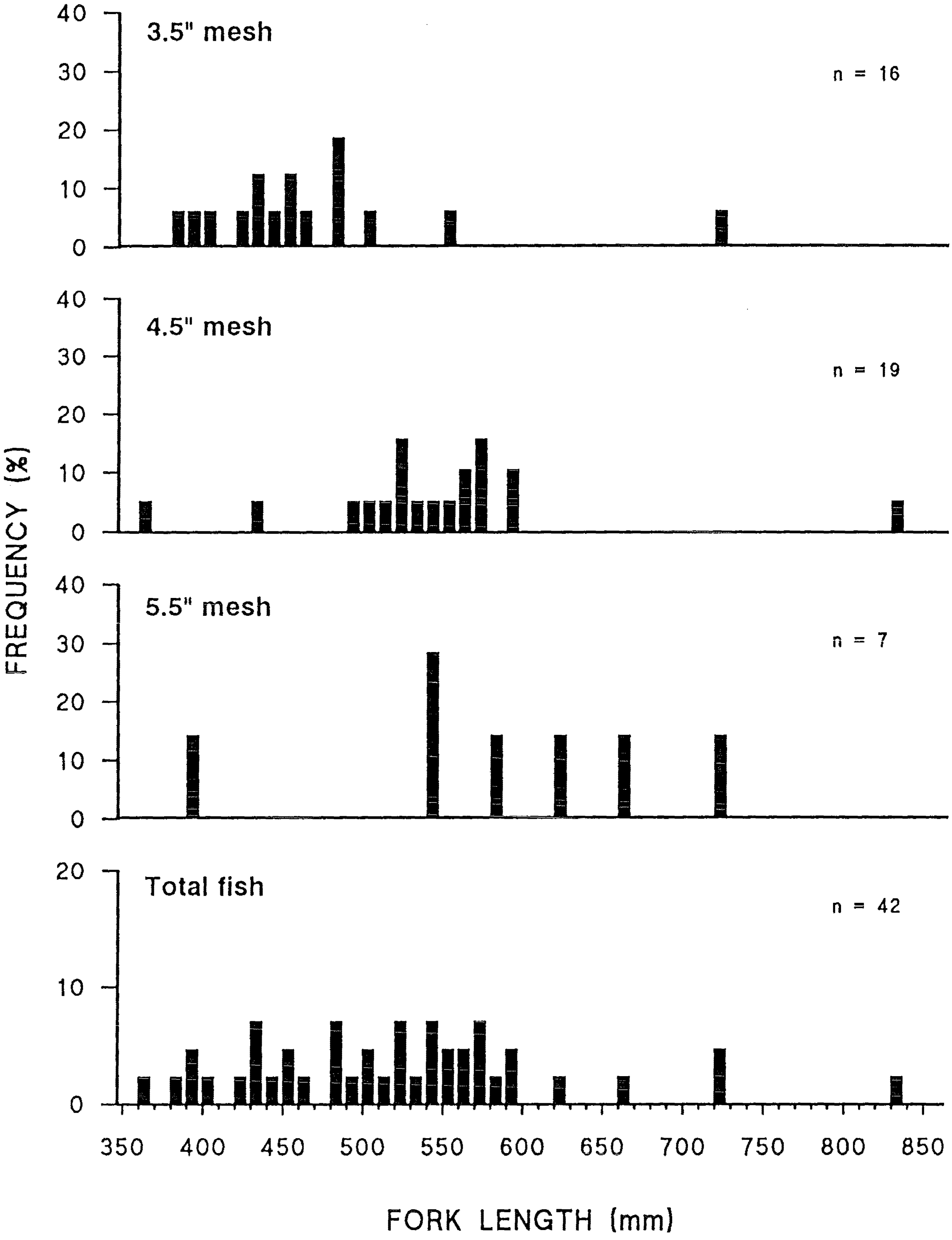


Figure 7.4 Size frequency distributions (%) of carpet shark, *Cephaloscyllium isabellum*, caught in three mesh sizes of gill-net and in the total catch. Mean fork length (± 1 s.e.) for each mesh size: 3.5" = 466.3 ± 20.1; 4.5" = 542.6 ± 20.5; 5.5" = 578.6 ± 39.9.

Chelidonichthys kumu

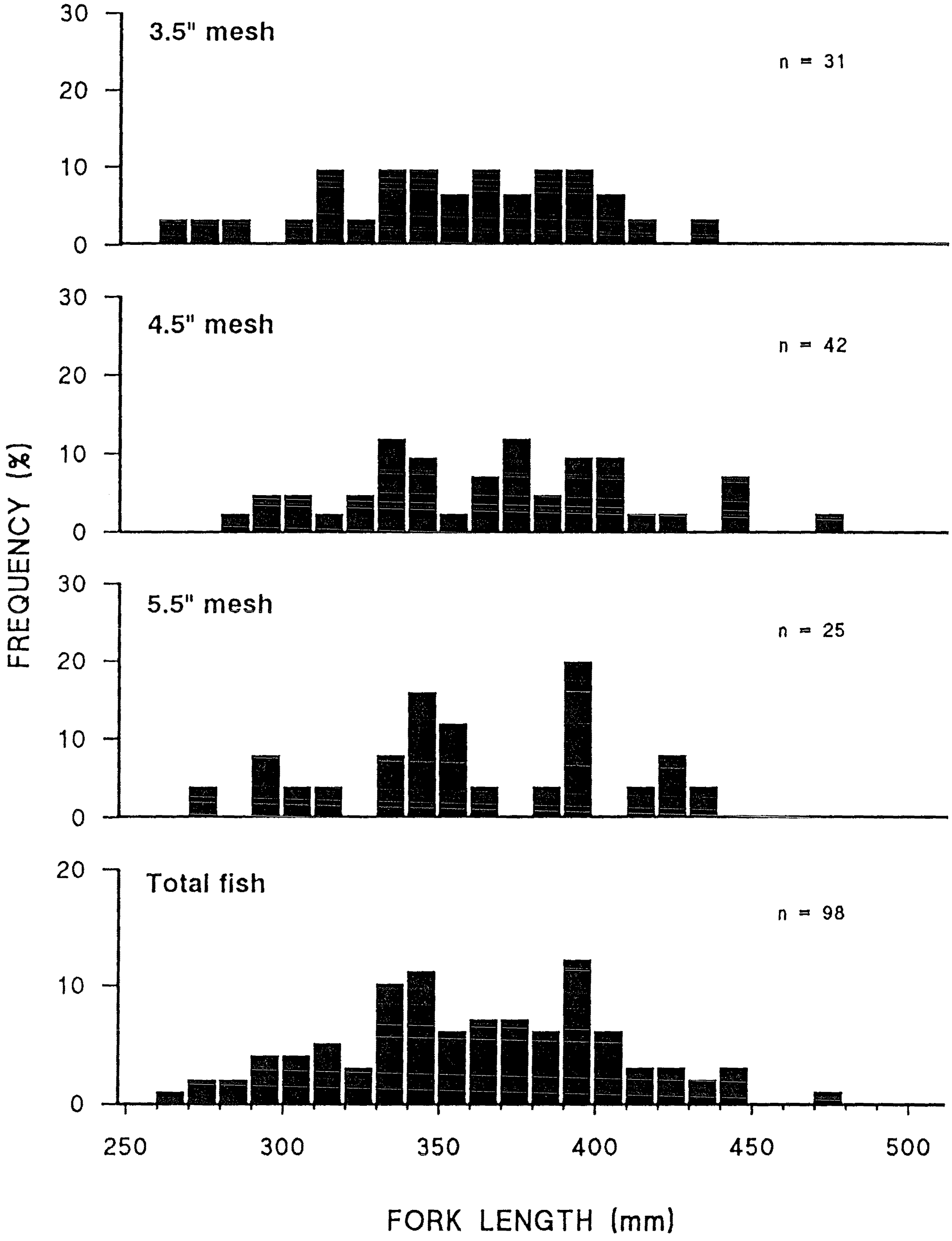


Figure 7.5 Size frequency distributions (%) of red gurnard, *Chelidonichthys kumu*, caught in three mesh sizes of gill-net and in the total catch. Mean fork length (± 1 s.e.) for each mesh size: 3.5" = 349.7 ± 7.5; 4.5" = 362.9 ± 7.0; 5.5" = 356.0 ± 8.8.

Chrysophrys auratus

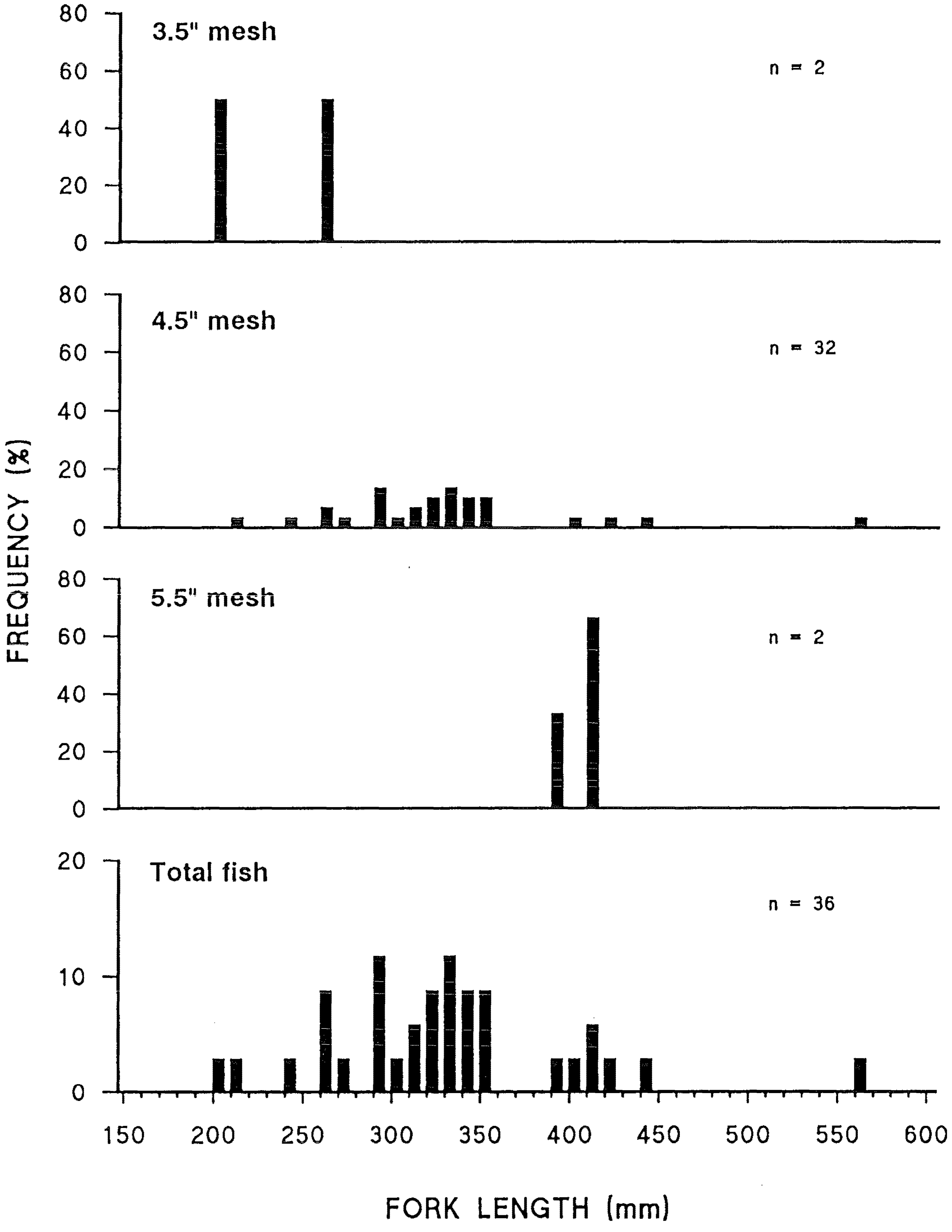


Figure 7.6 Size frequency distributions (%) of snapper, *Chrysophrys auratus*, caught in three mesh sizes of gill-net and in the total catch. Mean fork length (± 1 s.e.) for each mesh size: 3.5" = 230.0 ± 30.0; 4.5" = 327.2 ± 12.3; 5.5" = 403.3 ± 6.7.

Dalatias licha

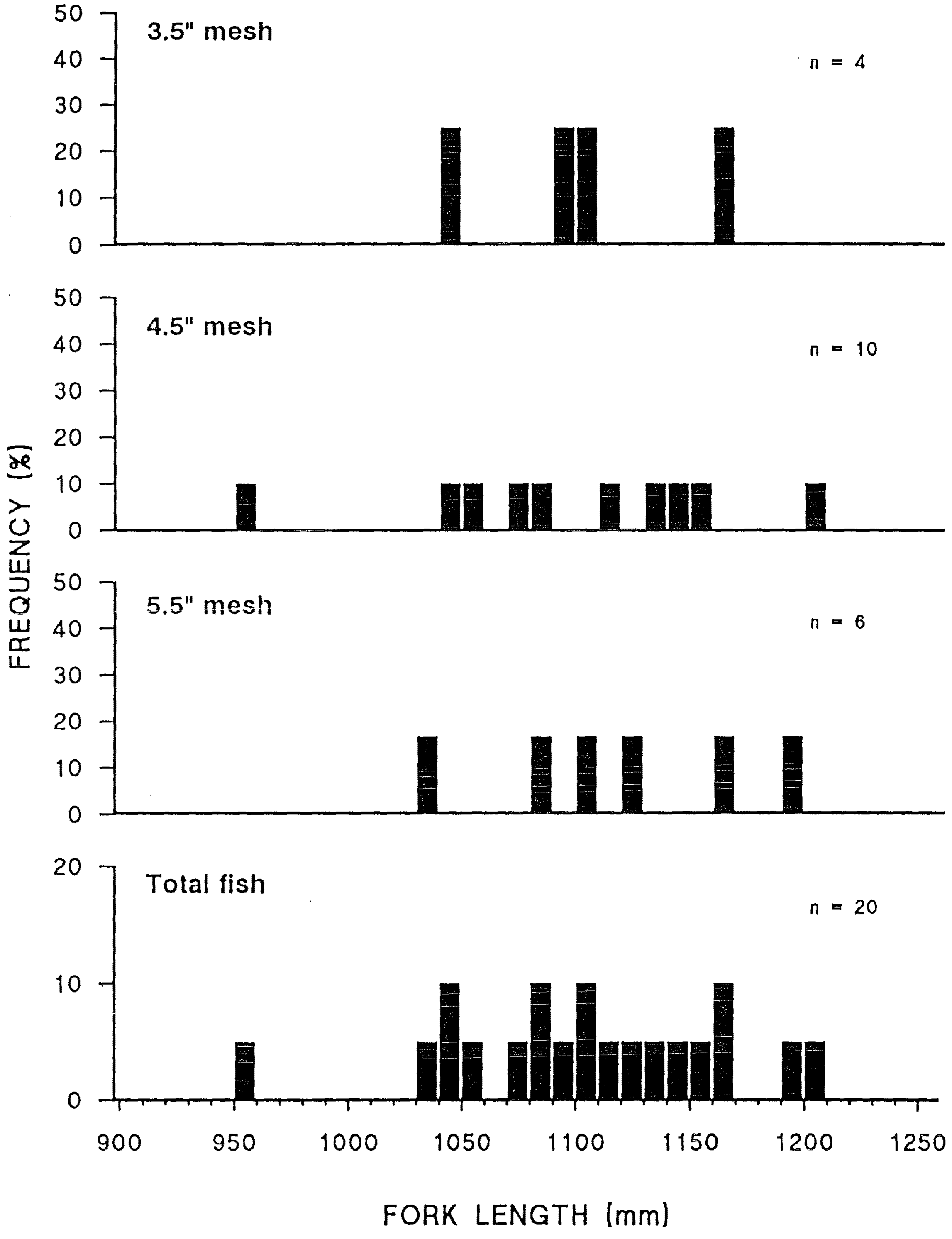


Figure 7.7 Size frequency distributions (%) of black sharks, *Dalatias licha*, caught in three mesh sizes of gill-net and in the total catch. Mean fork length (± 1 s.e.) for each mesh size: 3.5" = 1097.5 ± 24.6; 4.5" = 1092.0 ± 22.2; 5.5" = 1113.3 ± 23.3.

There was no significant difference between the fork lengths of sea perch, *Helicolenus percoides*, caught in each of the mesh sizes ($F_{2,80} = 1.07$, $p = 0.349$). Sea perch with fork lengths between 220 mm and 470 mm appear to be susceptible to capture in all three mesh sizes (Figure 7.8). However, the 3.5" mesh caught significantly more fish than the other two mesh sizes (Table 7.1).

Tukey's pairwise comparisons showed the mean fork length of hoki, *Macruronus novaezelandiae*, caught in the 3.5" mesh to be significantly smaller than that of those caught in the 4.5" and 5.5" mesh ($F_{2,143} = 10.73$, $p < 0.001$). There was no significant difference between the fork length of hoki caught in the 4.5" and 5.5" mesh (Figure 7.9). There was no significant difference in the number of hoki caught in each of the three mesh sizes (Table 7.1).

Tukey's pairwise comparisons showed the mean fork length of rig, *Mustelus lenticulatus*, caught in the 3.5" mesh to be significantly smaller than that of those caught in the 4.5" and 5.5" mesh ($F_{2,71} = 3.97$, $p < 0.05$). There was no significant difference between the fork length of rig caught in the 4.5" and 5.5" mesh (Figure 7.10). There was no significant difference in the number of rig caught in each of the three mesh sizes (Table 7.1).

Tukey's pairwise comparisons showed the mean fork length of tarakihi, *Nemadactylus macropterus*, caught in the 3.5" mesh to be significantly smaller than that of those caught in the 4.5" and 5.5" mesh ($F_{2,146} = 8.11$, $p < 0.001$). There was no significant difference between the fork length of tarakihi caught in the 4.5" and 5.5" mesh (Figure 7.11). The 5.5" mesh caught significantly less tarakihi than the 3.5" and 4.5" mesh (Table 7.1).

Helicolenus percoides

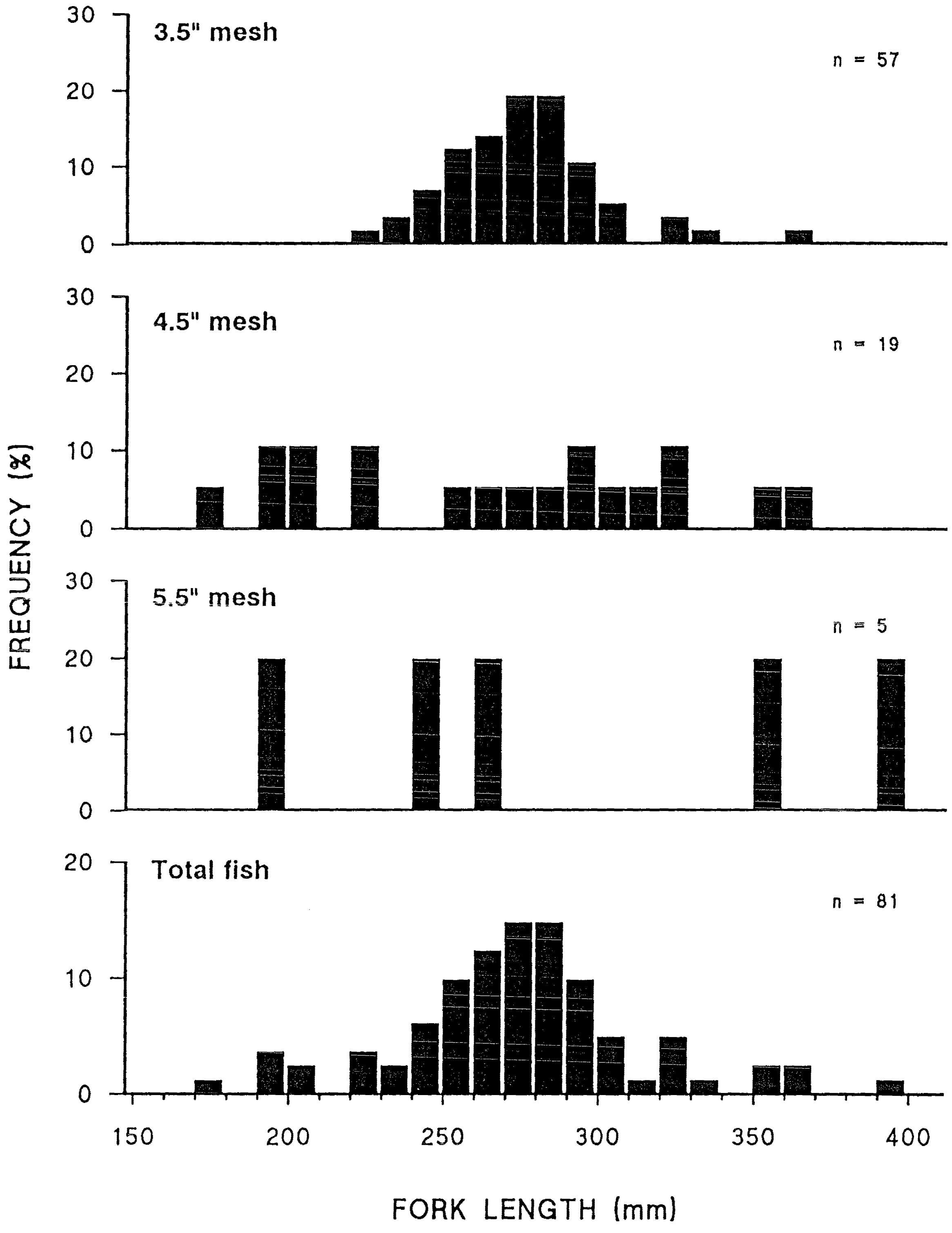


Figure 7.8 Size frequency distributions (%) of sea perch, *Helicolenus percoides*, caught in three mesh sizes of gill-net and in the total catch. Mean fork length (± 1 s.e.) for each mesh size: 3.5" = 271.8 ± 3.3; 4.5" = 262.6 ± 13.2; 5.5" = 286.0 ± 36.7.

Macruronus novaezelandiae

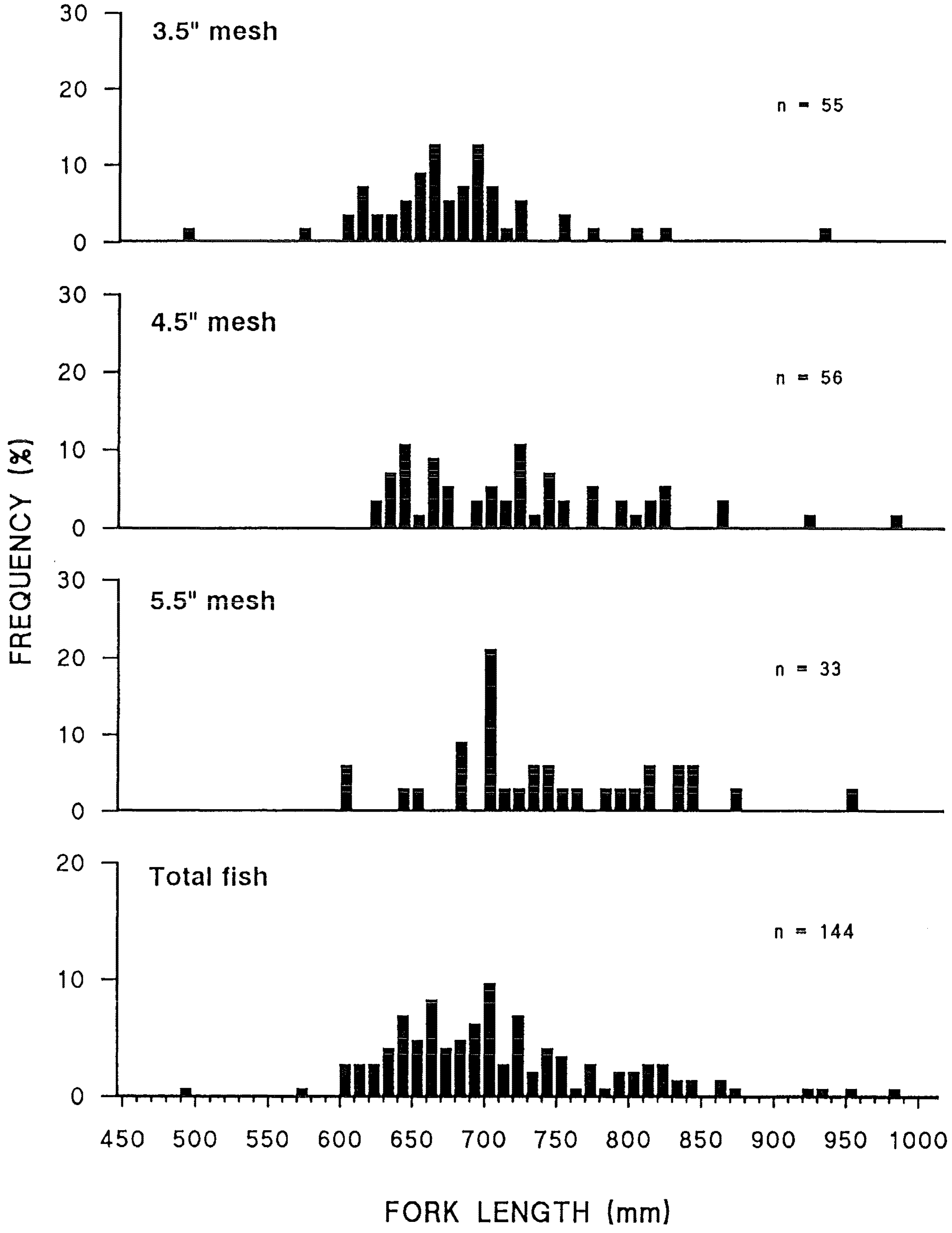


Figure 7.9 Size frequency distributions (%) of hoki, *Macruronus novaezelandiae*, caught in three mesh sizes of gill-net and in the total catch. Mean fork length (± 1 s.e.) for each mesh size: 3.5" = 673.5 ± 8.7; 4.5" = 720.7 ± 10.6; 5.5" = 741.2 ± 13.6.

Mustelus lenticulatus

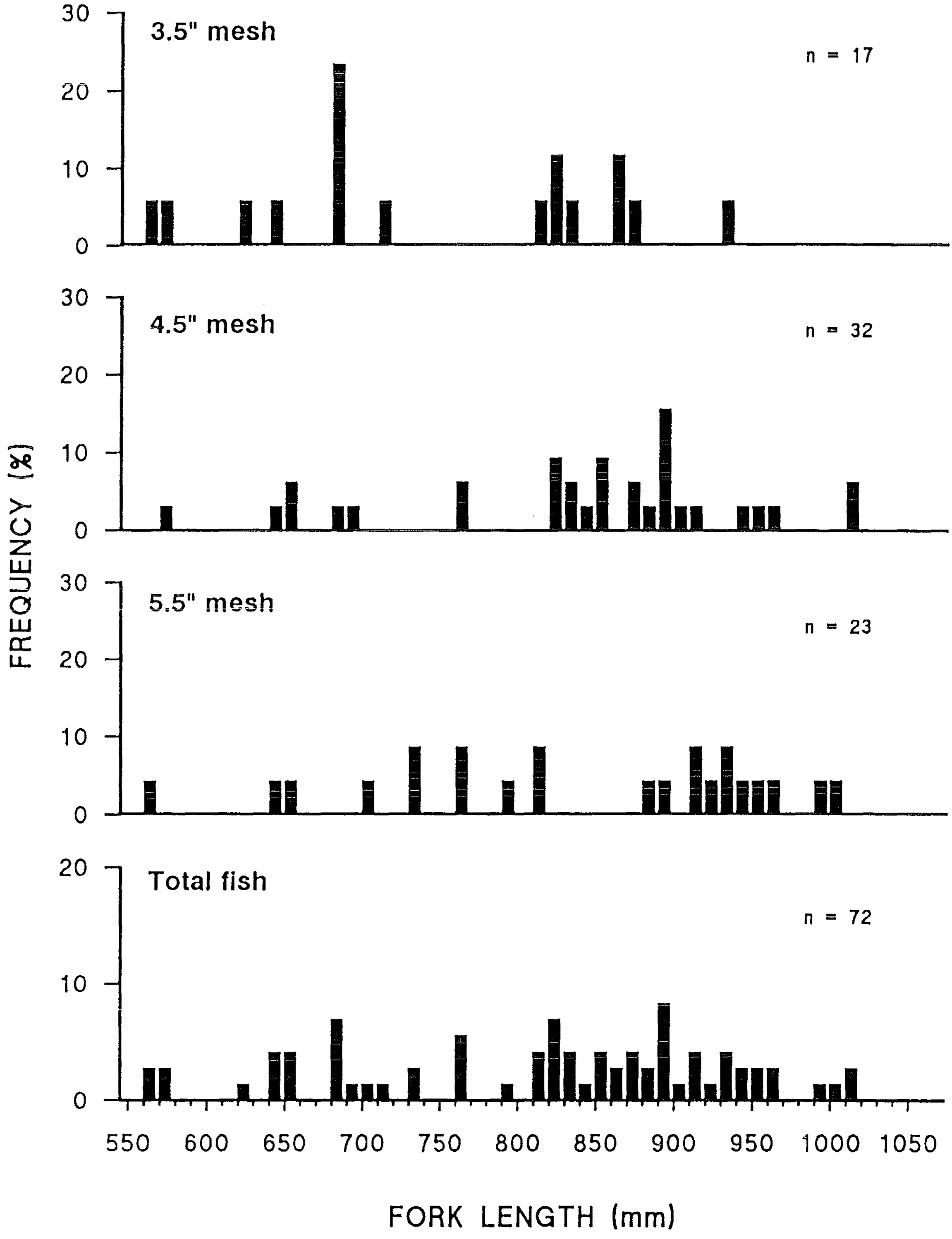


Figure 7.10 Size frequency distributions (%) of rig, *Mustelus lenticulatus*, caught in three mesh sizes of gill-net and in the total catch. Mean fork length (± 1 s.e.) for each mesh size: 3.5" = 742.4 ± 27.7; 4.5" = 833.1 ± 19.2; 5.5" = 832.6 ± 25.7.

Nemadactylus macropterus

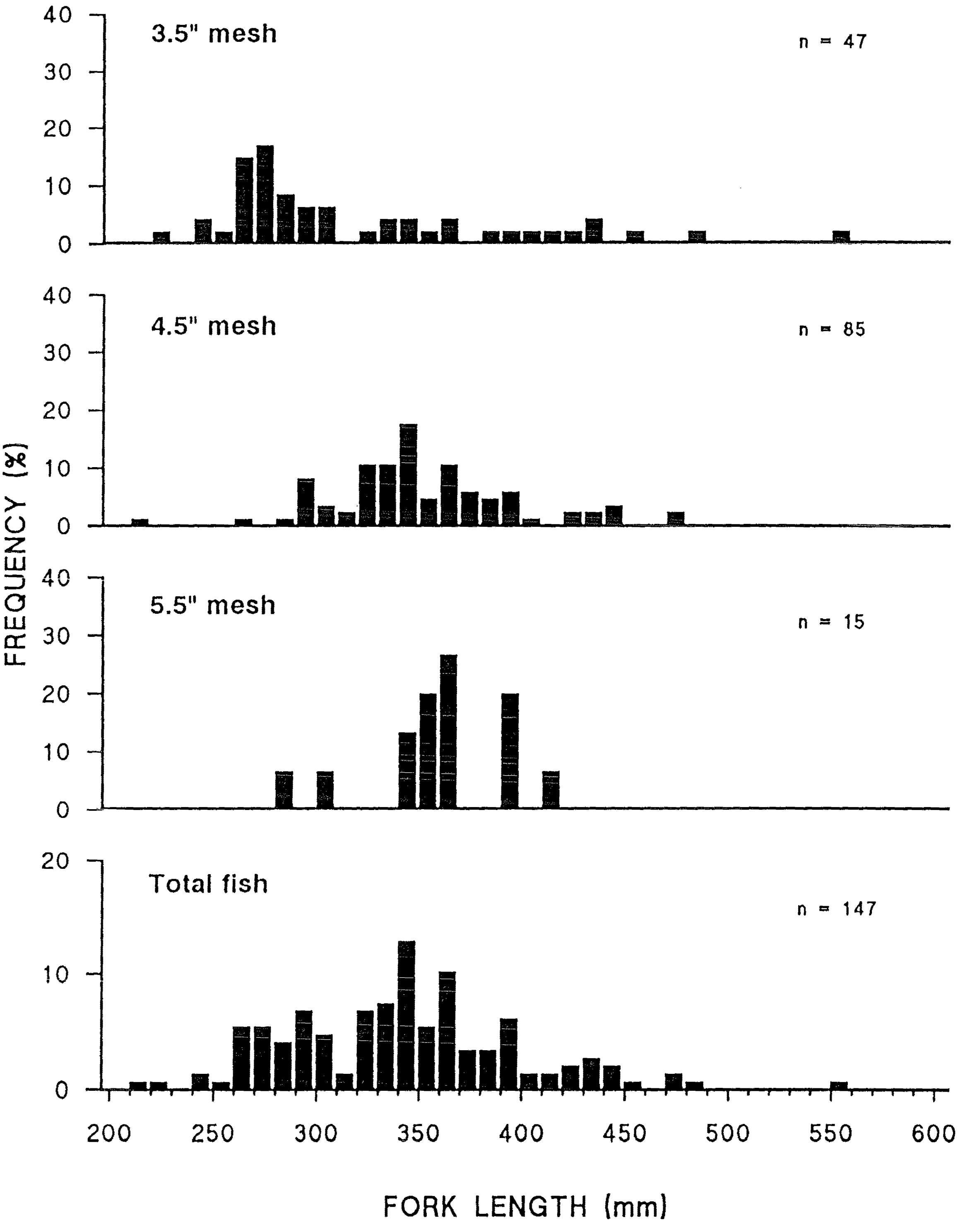


Figure 7.11 Size frequency distributions (%) of tarakihi, *Nemadactylus macropterus*, caught in three mesh sizes of gill-net and in the total catch. Mean fork length (± 1 s.e.) for each mesh size: 3.5" = 316.8 ± 10.5; 4.5" = 347.9 ± 4.9; 5.5" = 355.3 ± 8.7.

Tukey's pairwise comparisons showed the mean fork length of butterfish, *Odax pullus*, caught in the 3.5" mesh to be significantly smaller than those caught in the 4.5" mesh ($F_{1,9}$ = 16.92, $p < 0.01$)(Figure 7.12). The low number of butterfish caught in the 5.5" mesh prevented comparison with the other mesh sizes. The 3.5" mesh caught significantly more fish than the 3.5" and 4.5" mesh (Table 7.1).

Tukey's pairwise comparisons showed the mean fork length of blue cod, *Parapercis colias*, caught in the 5.5" mesh to be significantly larger than those caught in the 4.5" mesh ($F_{2,50}$ = 4.35, $p < 0.05$). However, there was no significant difference between the fork lengths of blue cod caught in the 3.5" and 5.5" mesh (Figure 7.13). There was no significant difference in the number of blue cod caught in the three mesh sizes (Table 7.1).

Tukey's pairwise comparisons showed the mean fork length of trevally, *Pseudocaranx dentex*, caught in the 3.5" mesh to be significantly smaller than those caught in the 4.5" mesh and 5.5" mesh ($F_{2,101}$ = 34.12, $p < 0.001$). There was no significant difference between the fork lengths of trevally caught in the 4.5" and 5.5" mesh (Figure 7.14). There was no significant difference in the number of trevally caught in the three mesh sizes (Table 7.1).

There was no significant difference between the fork lengths of red cod, *Pseudophycis bachus*, caught in each of the three mesh sizes ($F_{2,97}$ = 1.19, p = 0.309). Red cod between 230 and 630 mm fork length appear to be susceptible to capture in each of the three mesh sizes (Figure 7.15). The 5.5" mesh caught significantly less red cod than the 3.5" and 4.5" mesh (Table 7.1).

Odax pullus

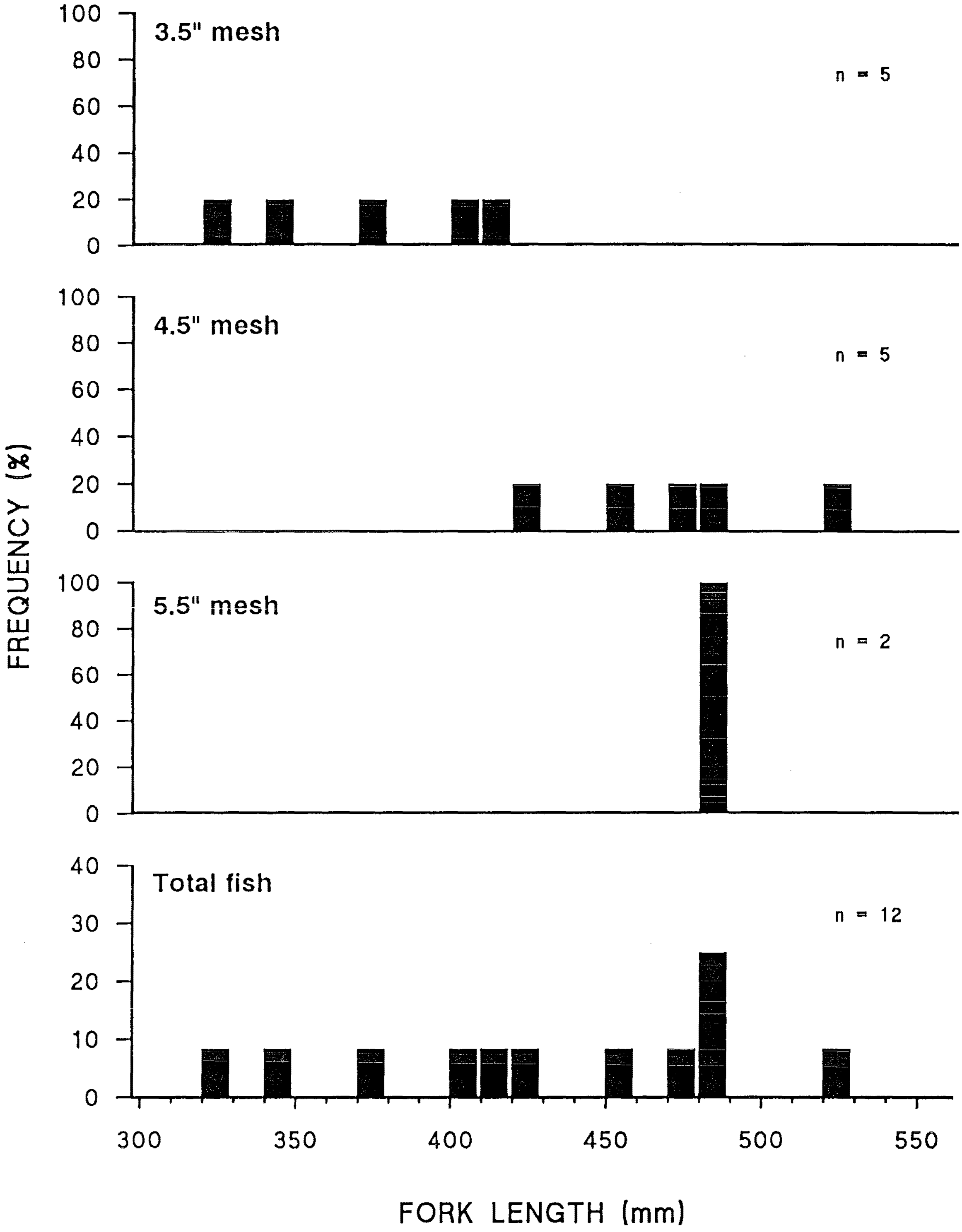


Figure 7.12 Size frequency distributions (%) of butterfish, *Odax pullus*, caught in three mesh sizes of gill-net and in the total catch. Mean fork length (± 1 s.e.) for each mesh size: 3.5" = 368.0 ± 17.1; 4.5" = 468.0 ± 16.6; 5.5" = 485.0 ± 5.0.

Parapercis colias

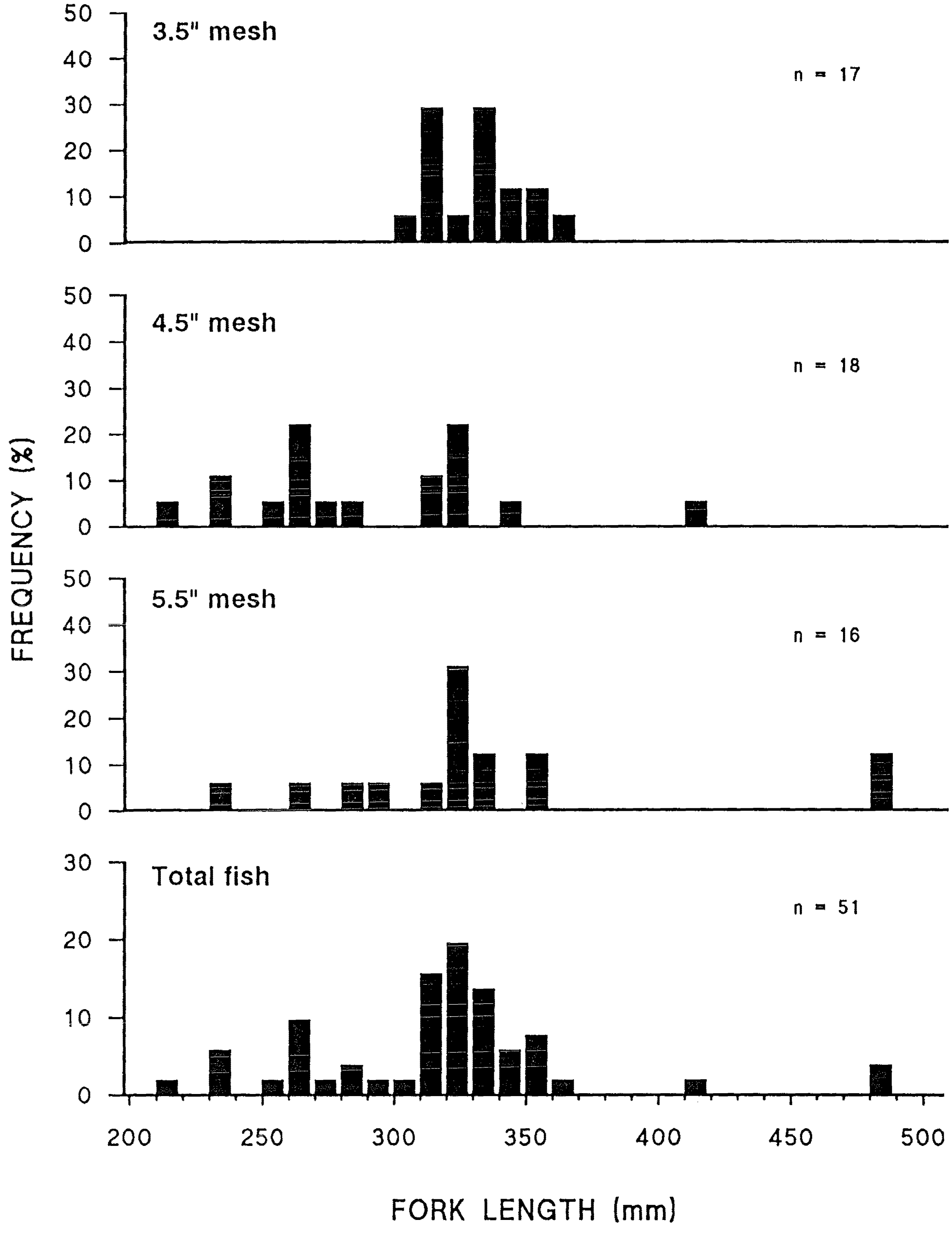


Figure 7.13 Size frequency distributions (%) of blue cod, *Parapercis colias*, caught in three mesh sizes of gill-net and in the total catch. Mean fork length (± 1 s.e.) for each mesh size: 3.5" = 317.1 ± 4.2; 4.5" = 286.7 ± 11.5; 5.5" = 330.6 ± 16.5.

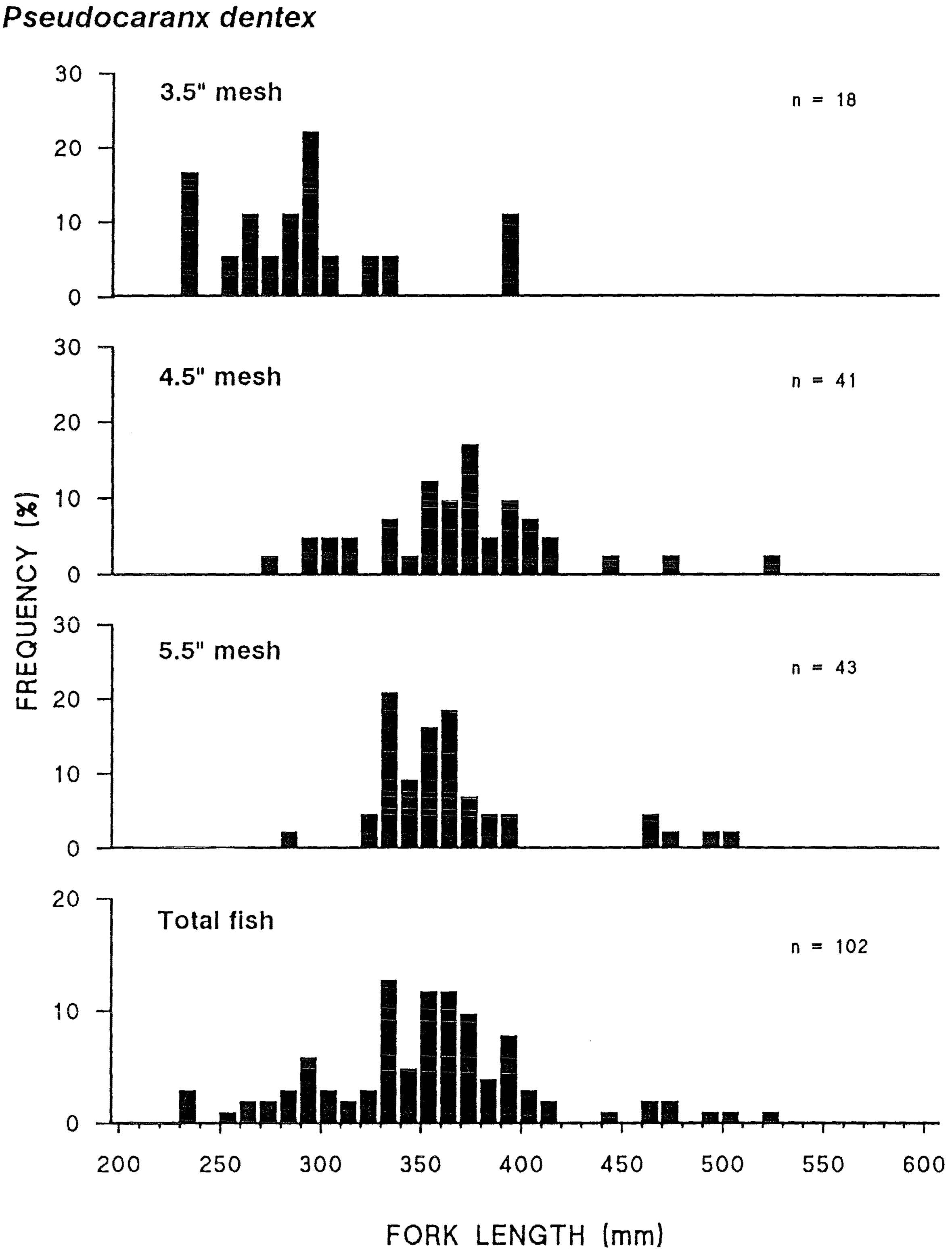


Figure 7.14 Size frequency distributions (%) of trevally, *Pseudocaranx dentex*, caught in three mesh sizes of gill-net and in the total catch. Mean fork length (± 1 s.e.) for each mesh size: 3.5" = 287.8 ± 11.0; 4.5" = 364.6 ± 7.5; 5.5" = 380.2 ± 6.4.

Pseudophycis bachus

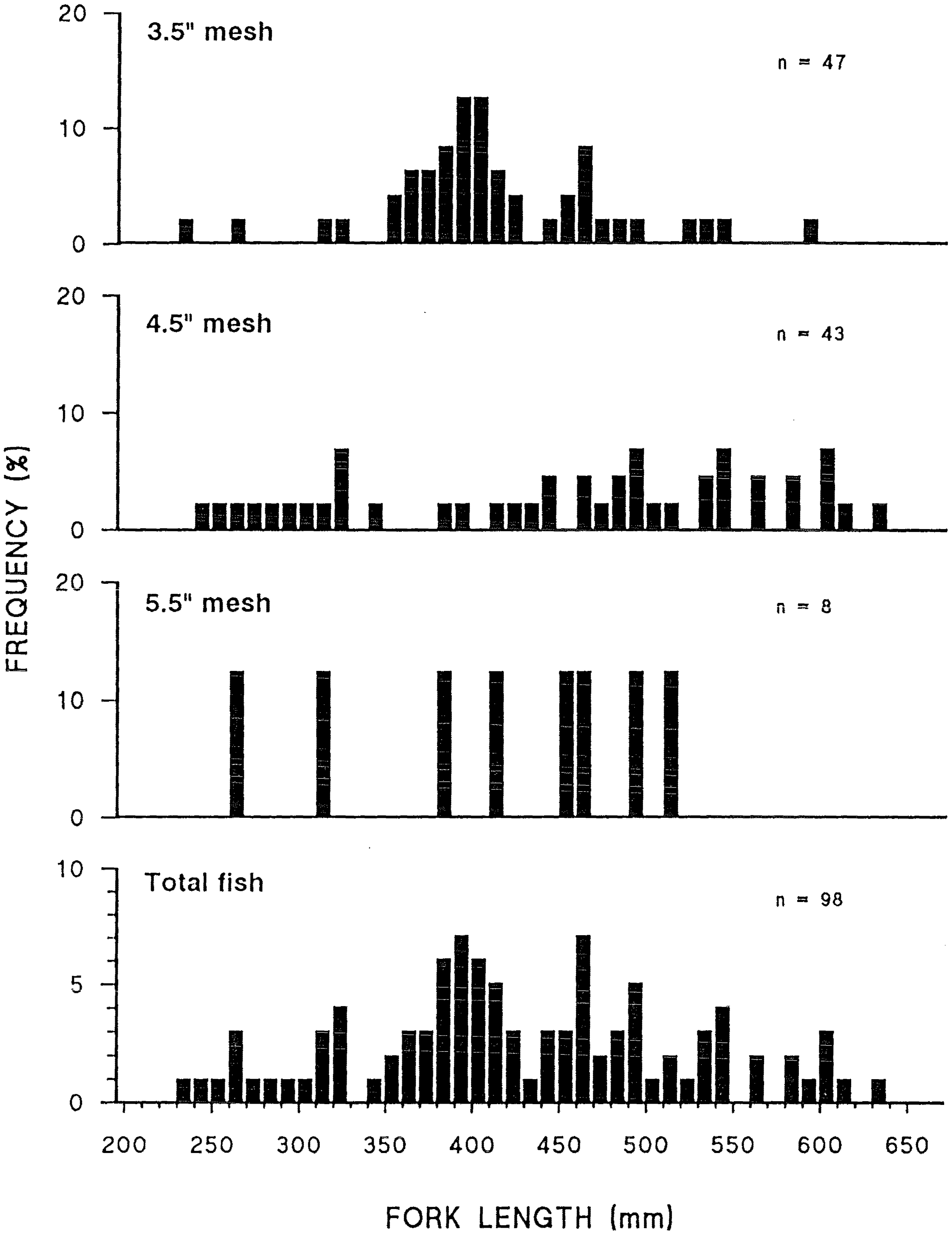


Figure 7.15 Size frequency distributions (%) of red cod, *Pseudophycis bachus*, caught in three mesh sizes of gill-net and in the total catch. Mean fork length (± 1 s.e.) for each mesh size: 3.5" = 407.2 ± 9.7; 4.5" = 447.4 ± 17.6; 5.5" = 408.8 ± 31.0.

There was no significant difference between the fork lengths of northern bastard cod, *Pseudophycis breviuscula*, caught in the 4.5" and the 5.5" mesh ($F_{1,26} = 0.48$, $p = 0.494$). The low number of fish caught in the 3.5" mesh prevented comparison with the other mesh sizes (Figure 7.16). The 4.5" mesh caught significantly more fish than the other mesh sizes (Table 7.1).

There was no significant difference between the fork lengths of blue mackerel, *Scomber australasicus*, caught in each of the mesh sizes ($F_{2,118} = 0.87$, $p = 0.420$). The blue mackerel caught in each of the mesh sizes were all within the narrow size range of 450 - 560 mm fork length (Figure 7.17). The 4.5" mesh caught significantly more fish than the 3.5" and 5.5" mesh (Table 7.1).

There was no significant difference between the fork lengths of sweep, *Scorpis lineolatus*, caught in each of the three mesh sizes ($F_{2,46} = 1.12$, $p = 0.335$). Most sweep caught in each of the mesh sizes were within the range 250 - 330 mm fork length (Figure 7.18). The 4.5" mesh caught significantly more fish than the other two mesh sizes (Table 7.1).

Tukey's pairwise comparisons showed the mean fork length of warehou, *Seriolella brama*, caught in the 4.5" mesh to be significantly greater than those caught in the 5.5" mesh ($F_{2,170} = 3.26$, $p < 0.05$). There was no significant difference between the fork lengths of warehou caught in the 3.5 and 5.5" mesh (Figure 7.19). The 5.5" mesh caught significantly more fish than the other two mesh sizes (Table 7.1).

Tukey's pairwise comparisons showed the mean fork length of barracouta, *Thyrsites atun*, caught in the 4.5" mesh to be significantly greater than those caught

Pseudophycis breviuscula

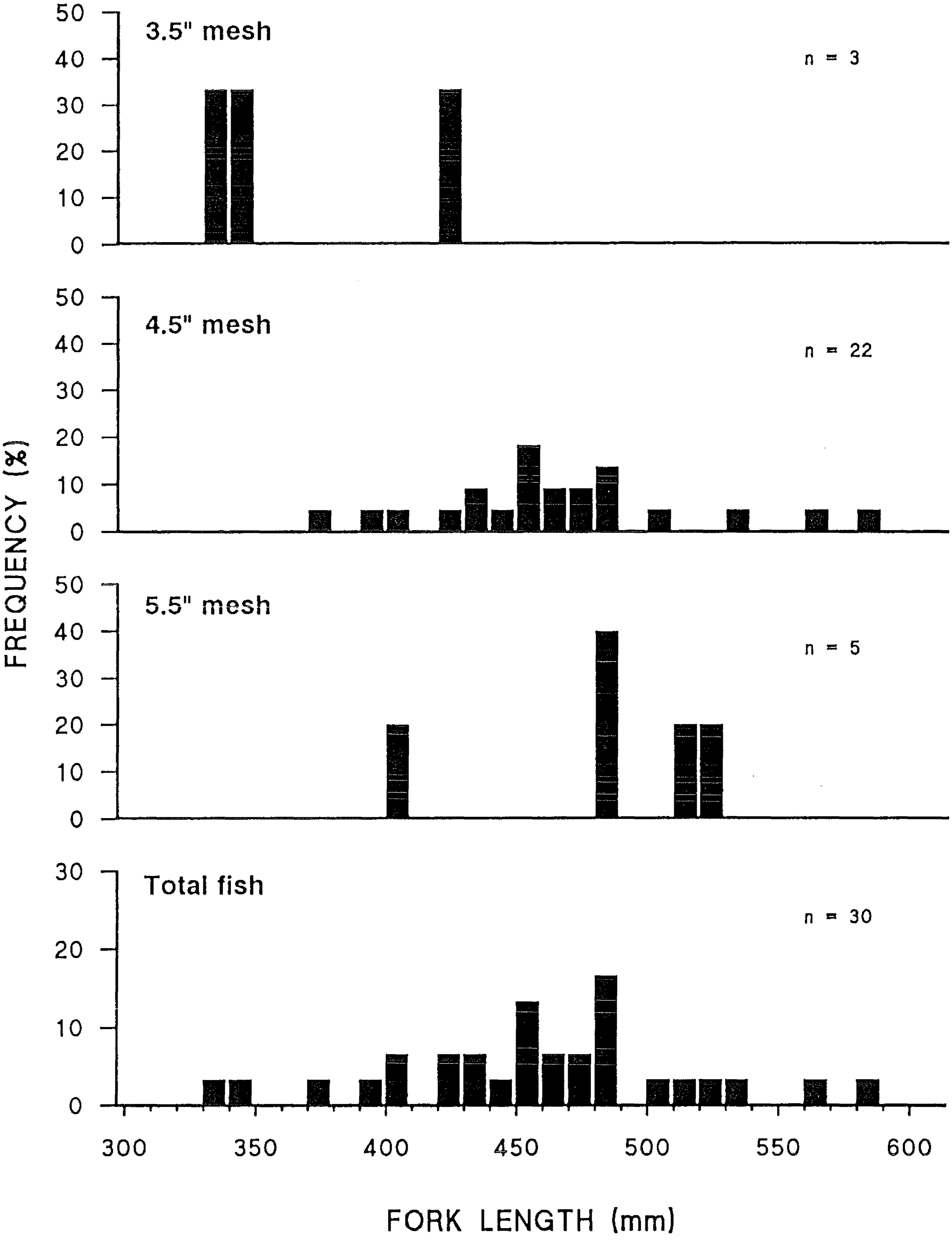


Figure 7.16 Size frequency distributions (%) of northern bastard red cod, *Pseudophycis breviuscula*, caught in three mesh sizes of gill-net and in the total catch. Mean fork length (± 1 s.e.) for each mesh size: 3.5" = 363.3 ± 28.5; 4.5" = 461.4 ± 10.7; 5.5" = 478.0 ± 21.1.

Scomber australasicus

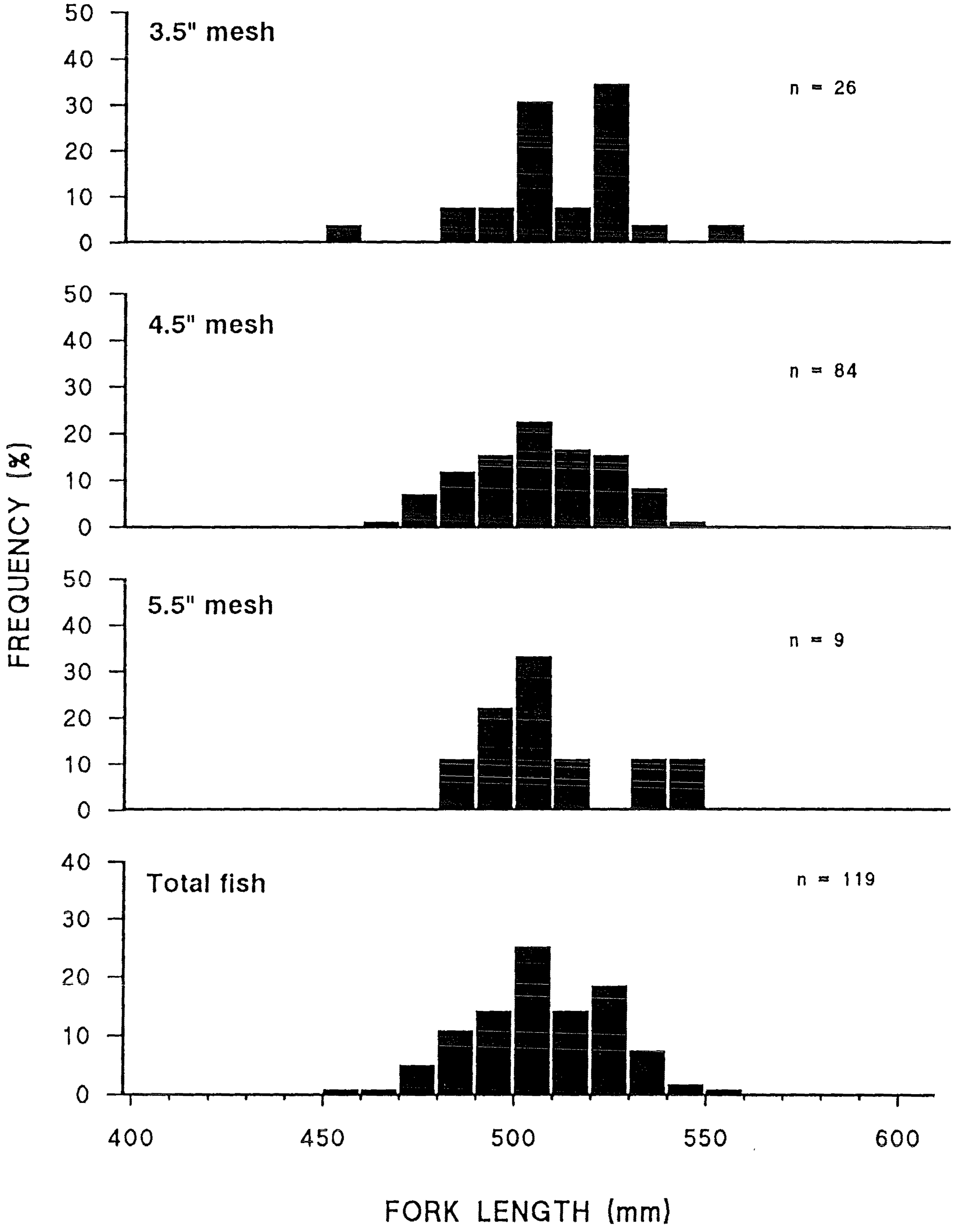


Figure 7.17 Size frequency distributions (%) of blue mackerel, *Scomber australasicus*, caught in three mesh sizes of gill-net and in the total catch. Mean fork length (± 1 s.e.) for each mesh size: 3.5" = 506.5 ± 3.8; 4.5" = 501.2 ± 2.0; 5.5" = 504.4 ± 6.5.

Scorpis lineolatus

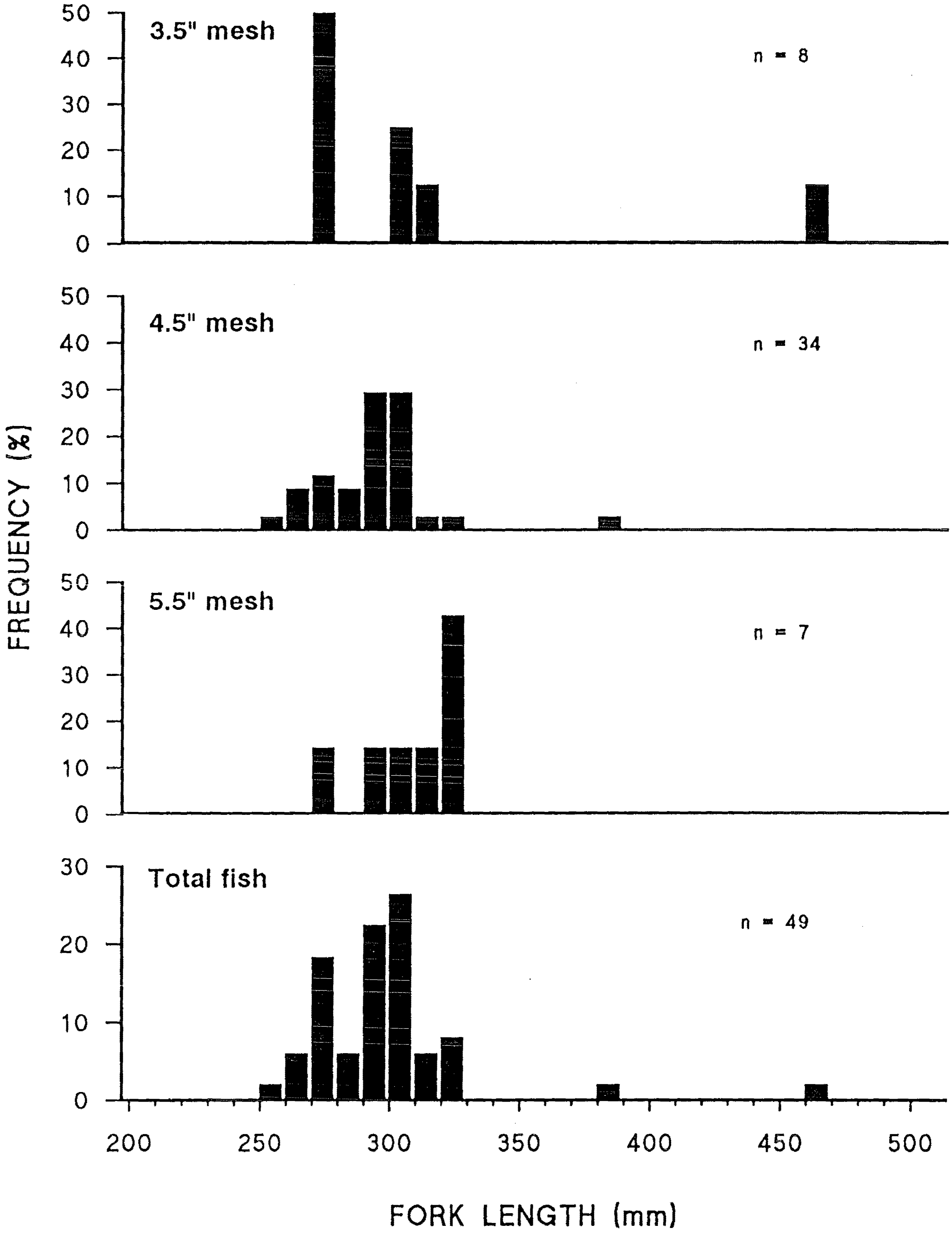


Figure 7.18 Size frequency distributions (%) of sweep, *Scorpis lineolatus*, caught in three mesh sizes of gill-net and in the total catch. Mean fork length (± 1 s.e.) for each mesh size: 3.5" = 306.3 ± 22.8; 4.5" = 290.0 ± 3.8; 5.5" = 304.3 ± 7.2.

Seriolella brama

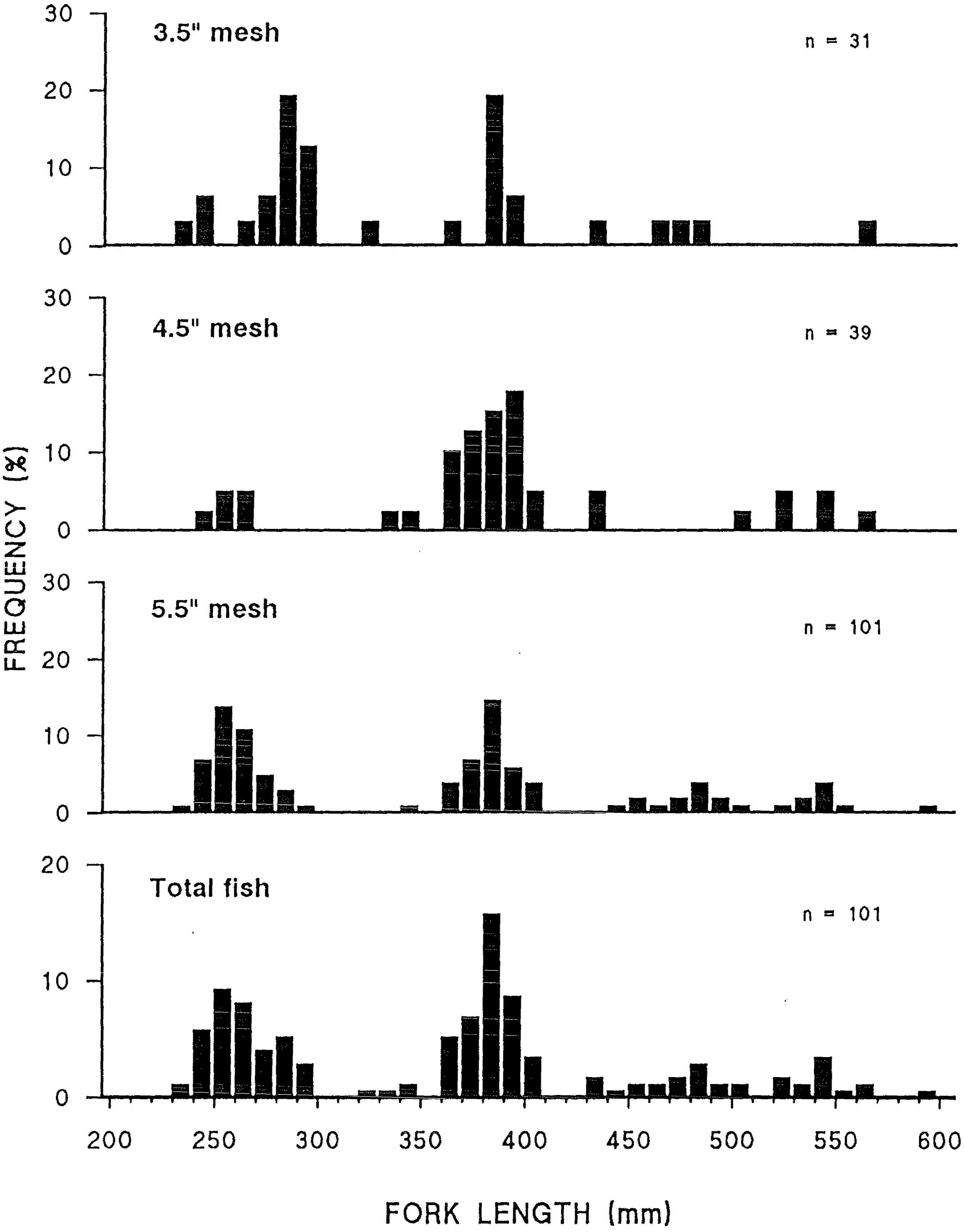


Figure 7.19 Size frequency distributions (%) of warehou, *Seriolella brama*, caught in three mesh sizes of gill-net and in the total catch. Mean fork length (± 1 s.e.) for each mesh size: 3.5" = 338.1 ± 14.8; 4.5" = 386.4 ± 12.5; 5.5" = 354.3 ± 9.7.

in the 3.5" mesh ($F_{2,38} = 14.51$, $p < 0.001$). The low number of fish caught in the 5.5" mesh prevented comparison with the other mesh sizes (Figure 7.20). The 3.5" mesh caught significantly more barracouta than the 4.5" and 5.5" mesh (Table 7.1).

There was no significant difference between the fork lengths of jack mackerel, *Trachurus declivis*, caught in the 4.5" and 5.5" mesh sizes ($F_{2,32} = 1.21$, $p = 0.280$). The low number of fish caught in the 5.5" mesh prevented comparison with the other mesh sizes (Figure 7.21). The 3.5" mesh caught significantly more jack mackerel than the 4.5" and 5.5" mesh (Table 7.1).

Tukey's pairwise comparisons showed the mean fork length of New Zealand Mackerel, *Trachurus novaezelandiae*, caught in the 3.5" mesh to be significantly larger than that of those caught in the 4.5" mesh ($F_{2,32} = 5.11$, $p < 0.05$). There was no significant difference between the fork length of mackerel caught in the 4.5" and 5.5" mesh sizes (Figure 7.22). There was no significant difference between the number of fish caught in each of the three mesh sizes (Table 7.1).

Tukey's pairwise comparisons showed the mean fork length of fish from all species caught in the 3.5" mesh to be significantly smaller than that of those caught in the 4.5" and 5.5" mesh ($F_{2,1916} = 51.60$, $p < 0.001$). There was no significant difference between the fork length of fish caught in the 4.5" and 5.5" mesh (Figure 7.23). The 5.5" mesh caught significantly less fish than the 3.5" and 4.5" mesh sizes (Table 7.1).

Thyrsites atun

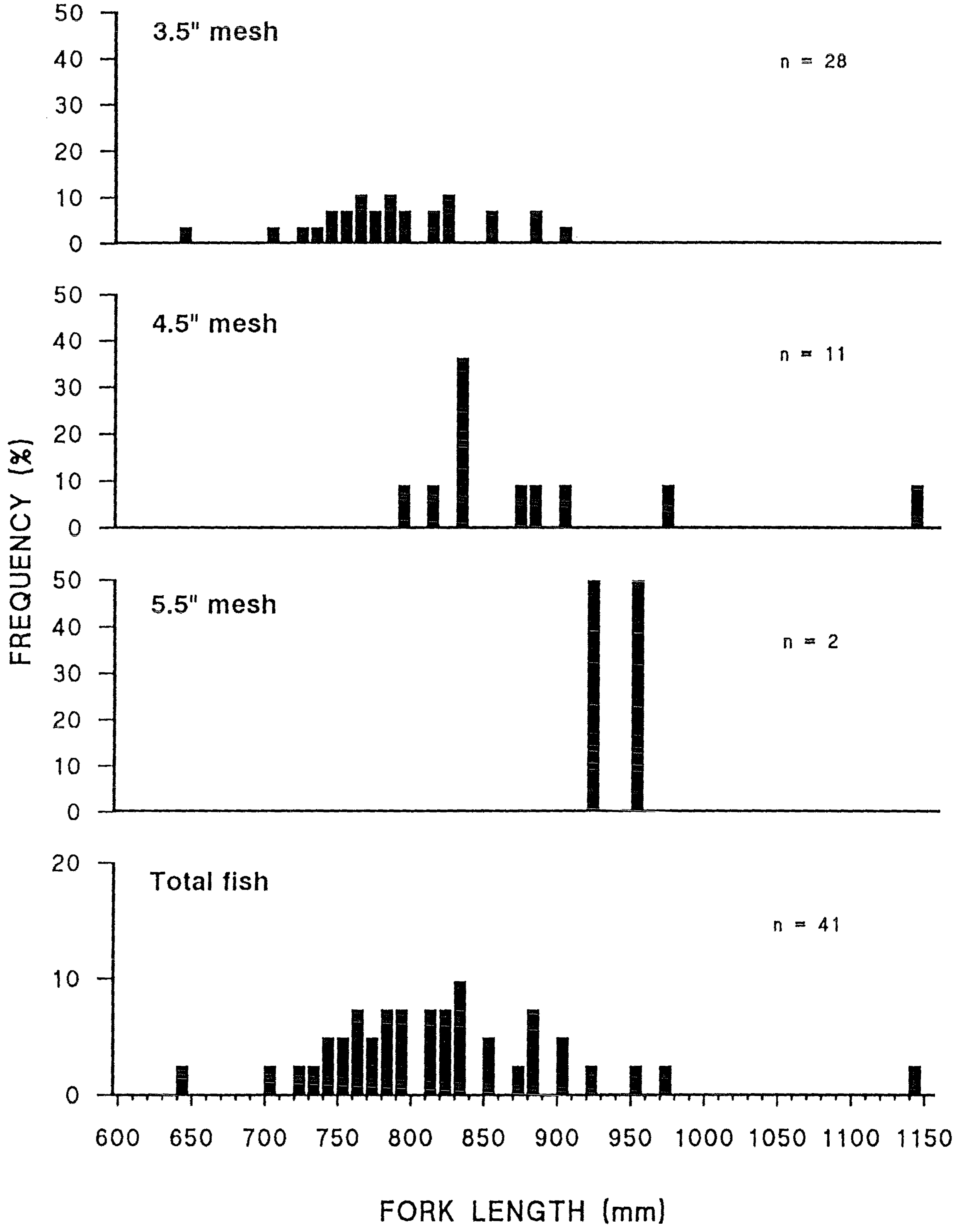


Figure 7.20 Size frequency distributions (%) of barracouta, *Thyrsites atun*, caught in three mesh sizes of gill-net and in the total catch. Mean fork length (± 1 s.e.) for each mesh size: 3.5" = 783.9 ± 10.9; 4.5" = 880.0 ± 30.0; 5.5" = 935.0 ± 15.0.

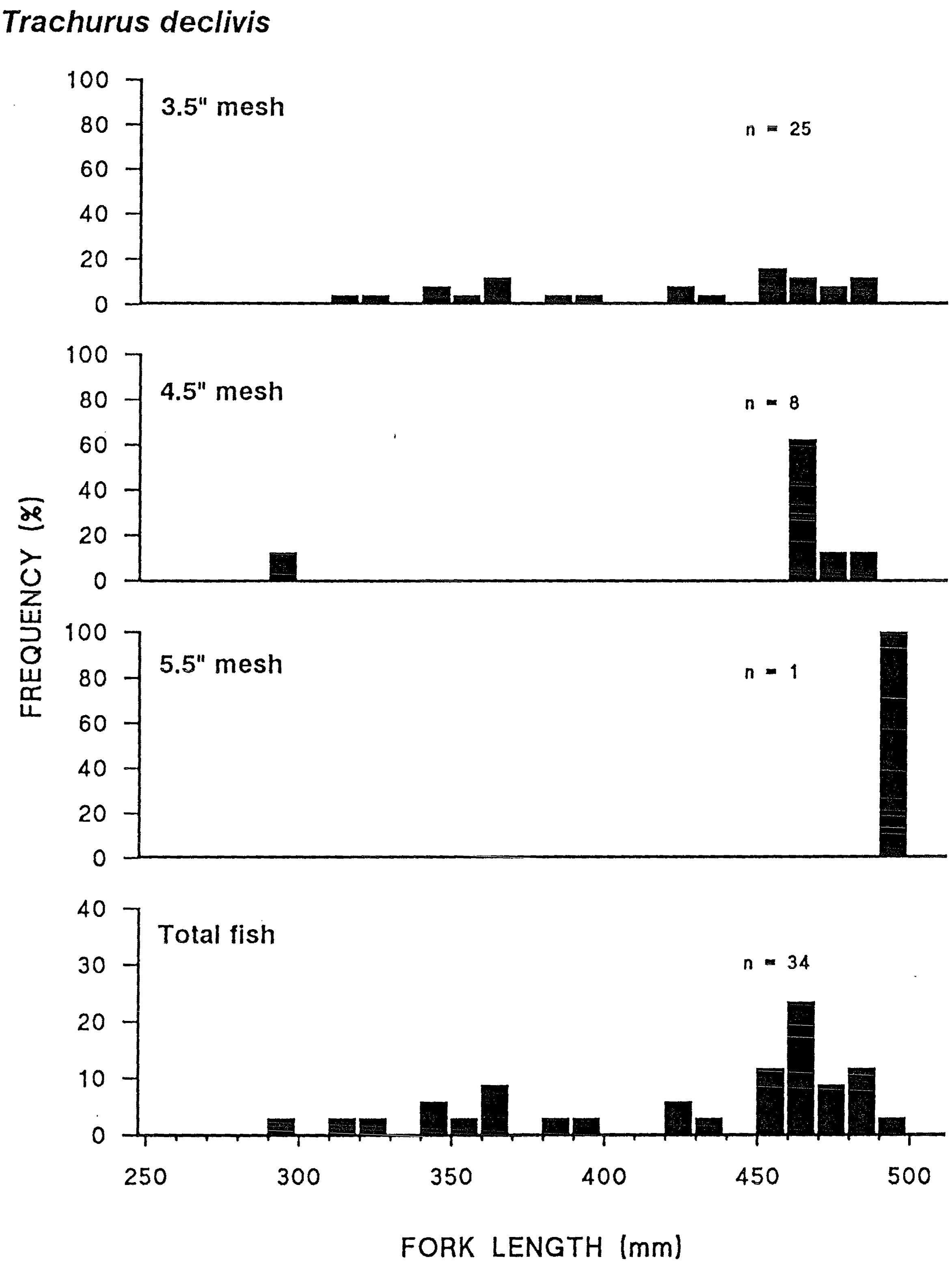


Figure 7.21 Size frequency distributions (%) of jack mackerel, *Trachurus declivis*, caught in three mesh sizes of gill-net and in the total catch. Mean fork length (± 1 s.e.) for each mesh size: 3.5" = 413.6 ± 11.3; 4.5" = 442.5 ± 21.9; 5.5" = 490.0.

Trachurus novaezelandiae

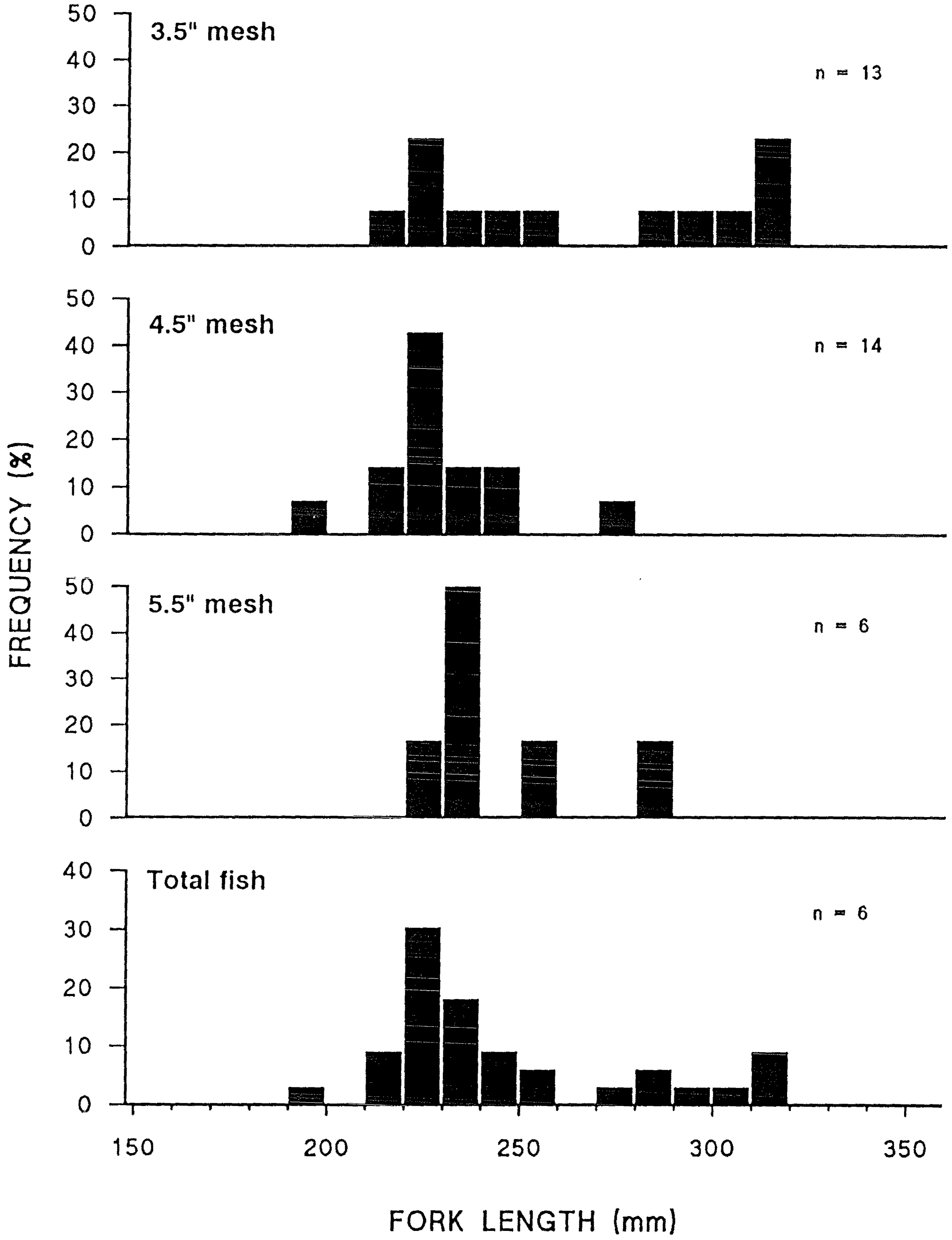


Figure 7.22 Size frequency distributions (%) of New Zealand mackerel, *Trachurus novaezelandiae*, caught in three mesh sizes of gill-net and in the total catch. Mean fork length (± 1 s.e.) for each mesh size: 3.5" = 260.8 ± 11.1; 4.5" = 224.3 ± 4.9; 5.5" = 240.0 ± 8.9.

All species

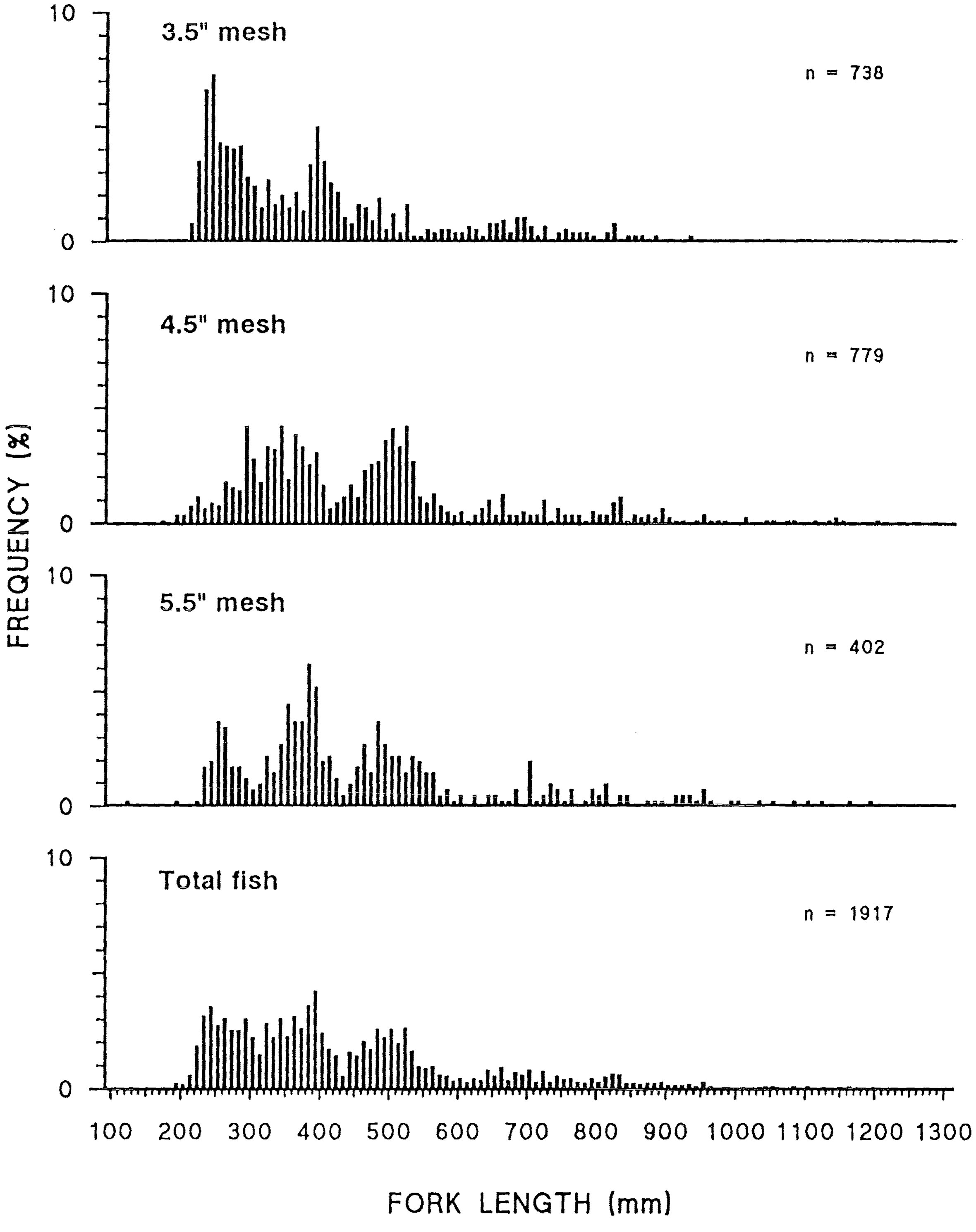


Figure 7.23 Size frequency distributions (%) of all species caught in three mesh sizes of gill-net and in the total catch. Mean fork length (± 1 s.e.) for each mesh size: 3.5" = 394.6 ± 6.3; 4.5" = 469.2 ± 6.8; 5.5" = 466.1 ± 9.6.

The fork lengths of several other species that were caught in moderate numbers but not subsequently measured could not be analysed by mesh size. However, the relative numbers of each species caught in each mesh size could be compared (Table 7.1). A significantly greater number of marblefish, *Aplodactylus arctidens*, were caught in the 5.5" mesh. A significantly greater number of blue maomao, *Scorpis violaceus*, were caught in the 3.5" mesh. Significantly less red mullet, *Upeneichthys lineatus*, were caught in the 5.5" mesh. A significantly lower number of spiny dogfish, *Squalus acanthias*, were caught in the 3.5" mesh.

The Ministry of Agriculture and Fisheries conducted a recreational fishing survey at fifty of the main boat ramps and surfcasting beaches in northern New Zealand during the summer - autumn period of 1990/91. The objective of the survey was to obtain baseline data on the recreation catch composition and catch per unit effort for finfish using line fishing methods. Recreational fishers were interviewed at the completion of their fishing trips. Questions concerning methods used, target species, hours spent fishing, location and numbers of fish (by species) caught were asked; around 90% (49,028) of the fish that were caught were measured.

9434 kahawai were caught by line fishing methods and 8192 were subsequently measured. The size frequency distribution of this catch was compared with the catch from the gill-nets (Figure 7.24). Little is currently known about the migration patterns of kahawai in the coastal waters of New Zealand, however, it is likely that these two surveys sampled similar populations, if not the same population. The gill-net catch distribution has two distinct modes at approximately 390 mm and 520 mm fork length. These distinct peaks are not as distinct in the line method catch distribution. The upper limit of the two distributions was approximately equal, but the lower size limit of kahawai caught by line methods was considerably lower than that of the gill-net distribution. The 3.5" gill-net appeared unable to catch kahawai that had a fork length less than 330 mm, or else these fish were absent during the gill-net sampling.

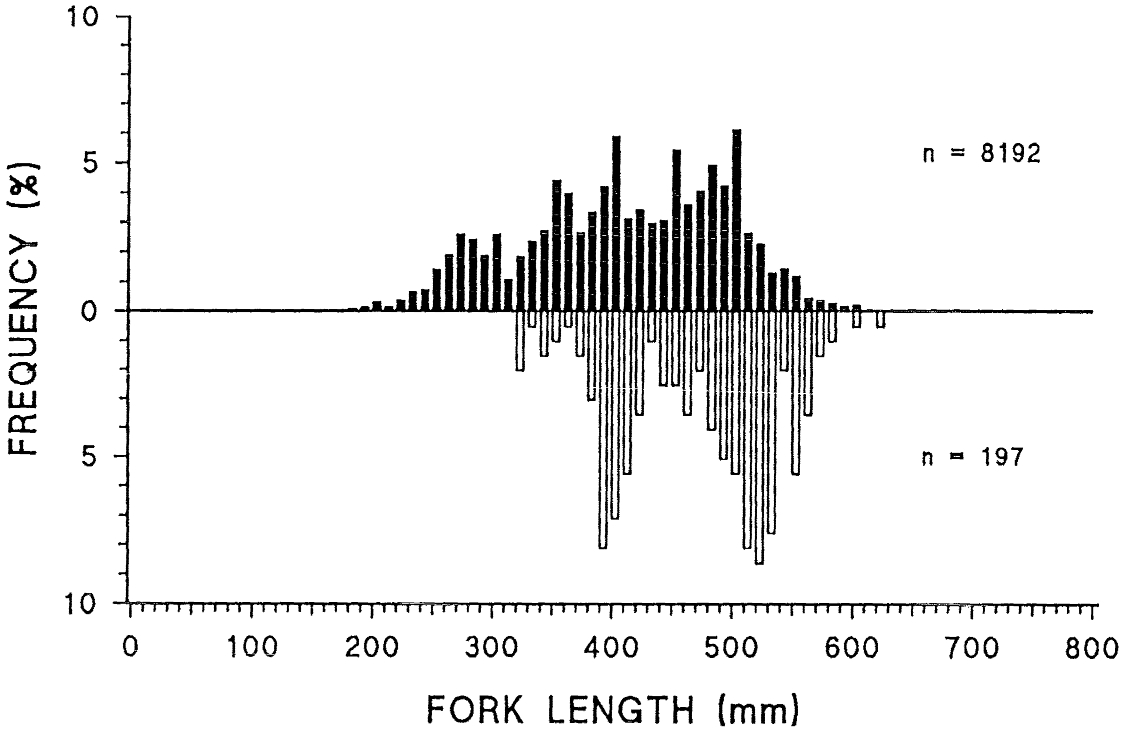


Figure 7.24 Size frequency distribution (%) of the fork lengths of kahawai, *Arripis trutta*, taken by line methods (solid) and gill-nets (open).

The fish from the line method distribution with fork lengths less than 330 mm were removed, and the percentage composition recalculated (Figure 7.25). The upper extreme of the line method's distribution falls away more abruptly than that of the gill-net distribution. The modal peaks at approximately 400 mm and 500 mm are more apparent in the line method distribution, but the associated peaks in the gill-net catch appear to occur at a larger fork length. The high proportion of fish caught by line methods in the 340 - 370 mm range do not appear in the gill-net catch. However, this may simply reflect seasonal or yearly differences in the size frequency distribution of the kahawai population, especially as the two sampling periods were separated by an interval of 5 years

The length frequency data from the catch of gill-nets used during my research was added to the gill-net catch distribution (Figure 7.26). This added the catch of

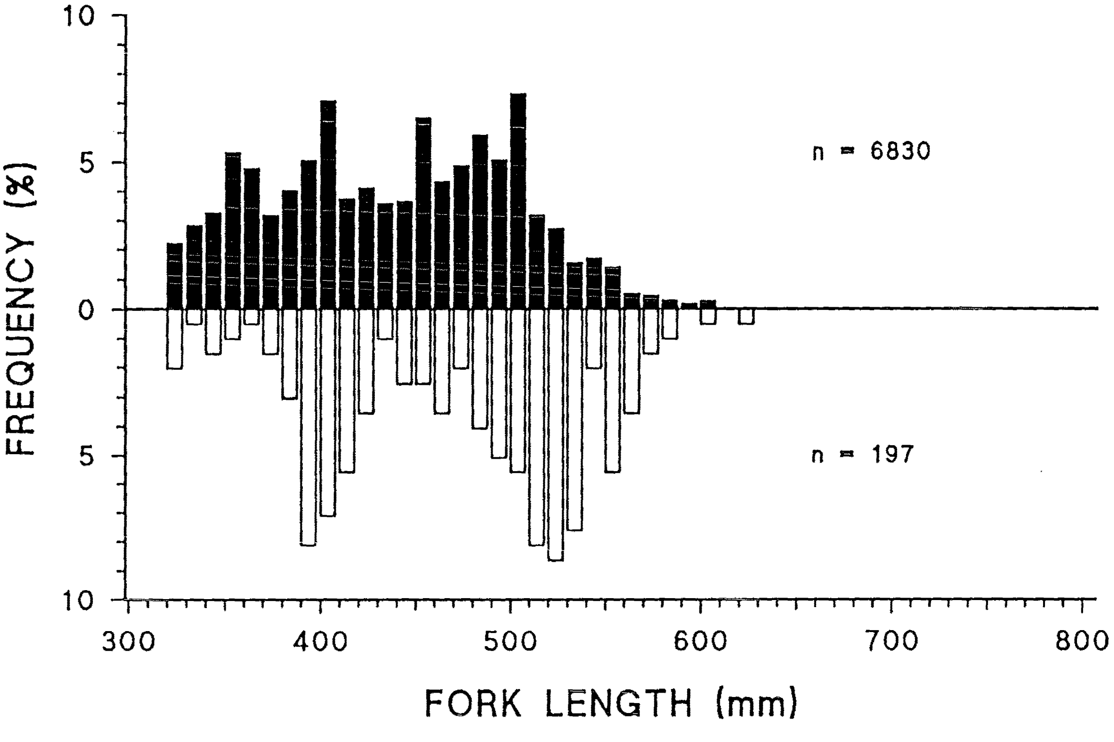


Figure 7.25 Size frequency distribution (%) of the fork lengths of kahawai, *Arripis trutta*, taken by line methods (solid) and gill-nets (open). Fish smaller than 330 mm fork length have been removed from the line methods catch data.

another mesh size (2.5" mesh) to the gill-net catch data. The large peak at 240 mm in the gill-net distribution (this is likely to be a 2+ year class from the von Bertalanffy growth curves described by M^c^Kenzie *et al.*, 1992) was not seen in the line method's distribution, although a smaller peak does occur at approximately 270 mm. The peak at approximately 330 mm fork length in the gill-net catch may be matched by the peak at 350 mm in the line method's distribution. The peaks at approximately 400 mm and 520 mm are not as sharply defined in the gill-net catch as those seen in the line method's distribution.

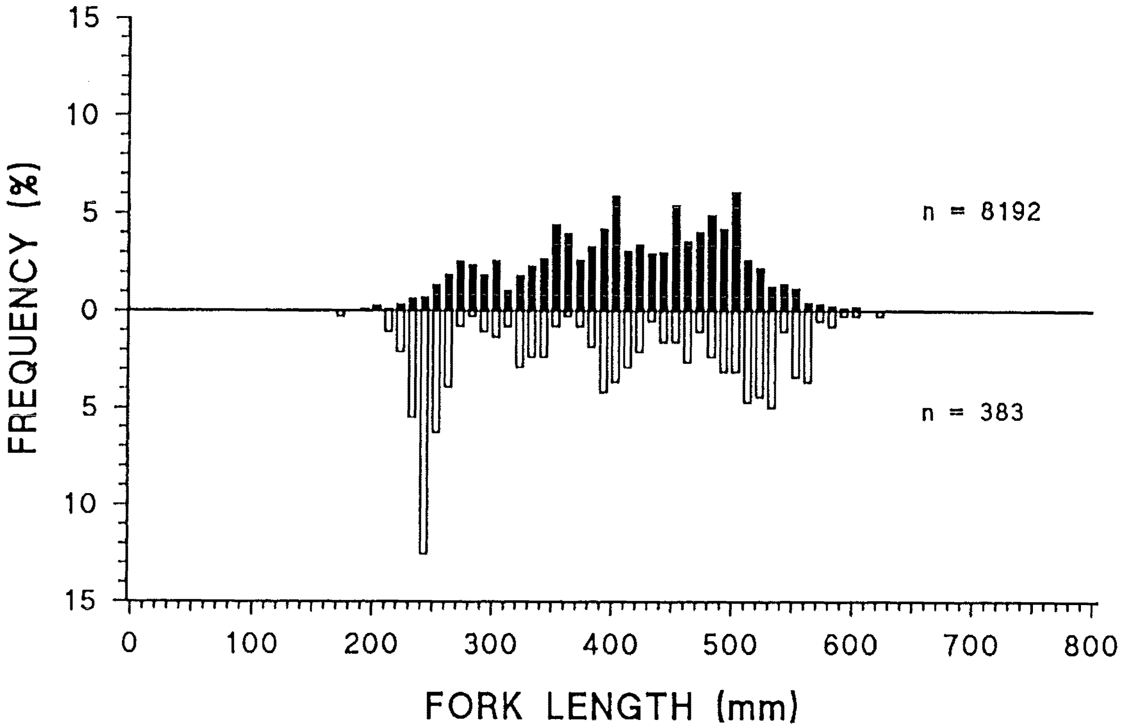


Figure 7.26 Size frequency distribution (%) of the fork lengths of kahawai, *Arripis trutta*, taken by line methods (solid) and gill-nets (open). Gill-net catch data from the smaller mesh sizes used during my study in central New Zealand have been pooled with the MAF gill-net catch data.

Correlation analyses were done on the number of fish from each species caught in each mesh size (Table 7.2). Species with less than five fish caught overall were excluded from this analysis. The number of fish from each species caught in each mesh size was positively correlated between mesh sizes for most species. However, for several species there appeared to be little relationship between the number of fish caught in each mesh size. There was no correlation between the number of barracouta caught in each of the mesh sizes.

The catch of several species was correlated between only two of the mesh sizes (Table 7.2). The number of butterfly perch, blue mackerel, sea perch, sweep and trevally caught in the 3.5" mesh was positively correlated with the catch of the same species in the 4.5" mesh. However, the catch of these same species in the 4.5" and 5.5" mesh, and 3.5" and 5.5" mesh was not related. The number of butterfish, kahawai, red moki and snapper caught in the 4.5" mesh was positively correlated with the catch of these species in the 5.5" mesh. However, there was no significant relation between the number of these species caught in the 3.5" and 4.5" mesh, and the 3.5" and 5.5" mesh.

There was no correlation between the total number of fish or the total number of species that were caught in the 3.5" and 5.5" mesh, or the 3.5" and 4.5" mesh. However, there was a positive correlation between the number of fish caught in the 4.5" and 5.5" mesh (Table 7.2).

A significantly greater number of arrow squid ($r_{15} = 0.540$, $p < 0.05$), northern bastard cod ($r_{15} = 0.553$, $p < 0.05$), carpet sharks ($r_{15} = 0.753$, $p < 0.001$), frostfish ($r_{15} = 0.685$, $p < 0.01$), hapuku ($r_{15} = 0.864$, $p < 0.001$), john dory ($r_{15} =$

Table 7.2 Pearson's correlation coefficients for the comparison of the number of 26 species of fish caught in three mesh sizes (e.g., the number of blue cod caught in the 3.5" mesh is positively correlated (0.606) with the number of blue cod caught in the 4.5" mesh). Significance levels are shown (* = 0.05, ** = 0.01, *** = 0.001 and ^{ns} = not significant).

SPECIES	3.5"	r_{15}	4.5"	r_{15}	5.5"	r_{15}	3.5"
ASQ		0.681^{**}		1.000^{***}		0.681^{**}	
BAR		0.302^{ns}		0.122^{ns}		-0.141^{ns}	
BCO		0.606^{**}		0.684^{**}		0.922^{***}	
BPE		0.999^{**}		-0.071^{ns}		-0.024^{ns}	
BRC		0.470^{ns}		0.764^{***}		0.767^{***}	
BSH		0.994^{***}		0.998^{***}		0.996^{***}	
BUT		-0.008^{ns}		0.609^{**}		-0.099^{ns}	
CAR		0.989^{***}		0.655^{**}		0.616^{**}	
EMA		0.982^{***}		0.374^{ns}		0.414^{ns}	
GUR		0.179^{ns}		0.721^{**}		0.105^{ns}	
HOK		0.835^{***}		0.888^{***}		0.778^{***}	
JMA		0.704^{**}		0.443^{ns}		0.757^{***}	
JMN		0.888^{***}		0.945^{***}		0.910^{***}	
KAH		0.316^{ns}		0.811^{***}		0.016^{ns}	
RAT		1.000^{***}		1.000^{***}		1.000^{***}	
RCO		0.964^{***}		0.910^{***}		0.861^{***}	
RMO		0.049^{ns}		0.699^{**}		0.110^{ns}	
RMU		0.119^{ns}		0.029^{ns}		0.996^{***}	
SNA		-0.098^{ns}		0.678^{**}		-0.154^{ns}	
SPD		0.877^{***}		0.946^{***}		0.928^{***}	
SPE		0.865^{***}		0.120^{ns}		-0.097^{ns}	
SPO		0.797^{***}		0.929^{***}		0.620^{**}	
SWE		0.962^{***}		0.203^{ns}		-0.071^{ns}	
TAR		0.892^{***}		0.782^{***}		0.513^{*}	
TRE		0.918^{***}		0.296^{ns}		0.147^{ns}	
WAR		0.815^{***}		0.878^{***}		0.618^{***}	
#FISH		0.355^{ns}		0.703^{**}		0.051^{ns}	
#SPECIES		0.654^{**}		0.354^{ns}		0.439^{ns}	

0.559, $p < 0.05$), jack mackerel ($r_{15} = 0.664$, $p < 0.01$), red cod ($r_{15} = 0.582$, $p < 0.05$), common roughy ($r_{15} = 0.685$, $p < 0.01$), school sharks ($r_{15} = 0.806$, $p < 0.001$), sea perch ($r_{15} = 0.499$, $p < 0.05$), tarakihi ($r_{15} = 0.762$, $p < 0.001$) and witch ($r_{15} = 0.497$, $p < 0.05$) were caught at greater depths.

Significantly fewer conger eels ($r_{15} = -0.681$, $p < 0.01$), marblefish ($r_{15} = -0.678$, $p < 0.01$) and moki ($r_{15} = -0.806$, $p < 0.001$) were caught at night. Significantly more blue cod ($r_{15} = 0.554$, $p < 0.05$) were caught with increasing set times, but the number of conger eels ($r_{15} = -0.576$, $p < 0.05$), blue moki ($r_{15} = -0.493$, $p < 0.05$) and sand flounders ($r_{15} = -0.508$, $p < 0.05$) caught decreased with increasing set times.

Significantly more sowfish ($r_{15} = 0.485$, $p < 0.05$), eagle rays ($r_{15} = 0.485$, $p < 0.05$), kingfish ($r_{15} = 0.485$, $p < 0.05$), leatherjackets ($r_{15} = 0.501$, $p < 0.05$), blue maomao ($r_{15} = 0.485$, $p < 0.05$), snapper ($r_{15} = 0.577$, $p < 0.05$), spotted stargazers ($r_{15} = 0.485$, $p < 0.05$) and trevally ($r_{15} = 0.619$, $p < 0.01$) were caught at the northern sites. More elephant fish ($r_{15} = 0.575$, $p < 0.05$), hoki ($r_{15} = 0.755$, $p < 0.001$), blue moki ($r_{15} = 0.567$, $p < 0.05$) and spiny dogfish ($r_{15} = 0.607$, $p < 0.01$) were caught at the southern site.

There was no correlation between the total number of species ($r_{15} = 0.445$), or the total number of fish ($r_{15} = 0.056$), caught and set time. There was also no difference in the number of species ($r_{15} = 0.360$) or fish ($r_{15} = -0.018$) caught during day and night sets.

7.4 DISCUSSION

Extensive analyses of gill-net selectivities are available in the published literature for a wide variety of species (Hamley, 1975). Most of these studies have relied heavily on the classical models of Baranov (1948) and Holt (1963). These models estimate gill-net selectivity indirectly, and require certain critical assumptions to be met. These include uniform catchability coefficients for nets of different mesh sizes and congruency in the shape of the selection curves. In practice, these assumptions are often violated (Pope *et al.*, 1975) due to a variety of factors such as behavioural effects (Hamley 1975; Rudstam *et al.*, 1984) or features of the net other than its mesh size (Riedel, 1963; Stewart, 1987).

Several aspects of a net's construction alter its ability to catch fish (Nomura, 1961; von Brandt, 1975). Loosely hung nets have been found to tangle more fish (Baranov, 1948; Riedel, 1963; Mohr, 1965; Ishida, 1969). Riedel's catches of tilapia (*Tilapia mossambica*) with 10 cm mesh gill-nets of varying hanging coefficients clearly demonstrate this:

Hanging coefficient	Average no. caught per day	Percentage tangled	Size range of 95% of catch
1:1	9.3	0	18-23 cm
1:2	29.5	24	13-23 cm
1:3	81.0	80	8-22 cm

Because tangling is not as selective as wedging or gilling (section 5.4.2), loosely hung nets catch *Tilapia* of a much wider size range. Net hanging is an important factor of captures by tangling, but has little effect on catches of species, such as butterfish, that are usually caught by being wedged or gilled (Mohr, 1965).

The selectivity of a gill-net also can be affected by the way in which it is set. As different sizes of fish may occupy different habitats, the sizes caught may depend on the location and depth of fishing (Parrish, 1963). Carlin and Lundin (1967) caught smaller Atlantic salmon, *Salmo salar*, nearer the surface and Coulter (1970) found larger Nile perch, *Lates mariae*, further from shore in deeper water.

Net handling techniques also may affect selectivity. Large herring are often held loosely by the mesh encircling their head, and fall out of the net easily during hauling. An increased proportion of these fish can be landed by hauling the net so that the side with the most herring is on top (Farran, 1936). Even the dimensions of the boat being used to retrieve the gill-nets may affect their selectivity. In low lying boats a shorter lift is required, and consequently fewer fish fall out (Burd, 1963).

The catch of a gill-net does not accumulate at a uniform rate. The efficiency of a net has been shown to decrease as fish accumulate in it (Van Oosten, 1935; Baranov, 1948; Kennedy, 1951; Beverton & Holt, 1957; Meth, 1970) or as it becomes fouled with algae or silt (Hewson, 1952; von Brandt, 1975). The number of fish caught in the net eventually reaches a saturation level and does not increase further (Figure 5.11). Even then, only a small percentage of the cells in the net are occupied by fish. Von Brandt (1955) found only 1.7% of the individual cells to be occupied in very good catches of herring by drift-nets. Because the distribution of captured fish in a net may be clustered (Maéda, 1953; Berst & M^{c}Combie, 1963), especially with schooling fishes, parts of the net may be saturated while others are not.

Saturation effects in gill-nets may affect their selectivity, but experimental evidence is lacking. Meth (1970) suggested that saturation will affect comparisons of different twine materials, because the more efficient nylon nets become saturated sooner than the cotton nets. Thus, any advantage nylon nets had over cotton nets would decrease the longer the nets are left in the water. Similarly, in gill-netting any particular fish population, the mesh sizes most efficient towards those fish should saturate first, and their advantage over the less efficient mesh sizes would decrease if the nets were set for a long period (Baranov, 1948).

The catch from experimental gill-nets designed to compare the selectivities of different mesh sizes may be biased if the mesh sizes are tied end-to-end in a single gang. Certain positions in the gang may be more favourable than others (von Brandt, 1955), the catch of one net may be reduced by competition with an adjacent, more efficient, mesh (Larkins, 1963, 1964), and large fish may 'lead' along a small-meshed net until they come to, and are captured by, a larger-meshed net (Anon, 1961). If nets are set in gangs, leading can be minimised by leaving gaps between the different mesh sizes. However, it is best to set different-meshed nets at separate, randomly chosen locations, far enough apart that they do not compete for capture of the same fish (Pope *et al.*, 1975).

This study did not aim to produce selectivity curves for the species caught, which could be used to predict catch rates and ideal mesh sizes. Instead, the catches of three mesh sizes of gill-net have been analysed, and the relative abundances of the size classes of each species caught in the nets have been compared between mesh sizes. The relative proportions of the size classes of each species caught in the different mesh sizes may be a direct result of morphological and behavioural differences. Therefore, interspecific and intraspecific differences in morphology and behaviour have been analysed for possible explanations.

The size frequency distributions of fish caught in the gill-nets varied significantly between mesh sizes and species. Generally, the mean fork length of fish caught in the 3.5" mesh was smaller than the mean fork length of fish caught in the 4.5" and 5.5" mesh sizes (e.g., kahawai, carpet sharks, hoki, rig, tarakihi, butterfish, trevally). This follows the general premise that the length of fish likely to be captured by a gill-net increases with increasing mesh size (Kitahara, 1971). However, for most species there was no significant difference between the fork length of fish caught in the 4.5" and 5.5" mesh sizes. Furthermore, in several species (e.g., red gurnard, sea perch, red cod, northern bastard cod, blue mackerel, sweep and jack mackerel) there was no significant difference between the fork lengths of fish caught in any of the three mesh sizes.

Fish with smooth fusiform shapes, such as kahawai and butterfish, appear to be selected predominately by size in the gill-nets. These fish enter the mesh of a net, and if their maximum girth is smaller than the perimeter of the mesh then they are able to swim through the net. If their opercular girth is greater than the mesh perimeter, then they are unable to escape from the net and are caught. If the species does not have projections or large appendages, then few fish are tangled and the fork length of fish caught in each mesh size increases in proportion to increasing mesh size.

Fish with projections on their body (fins, spines and barbs) likely to snag on the mesh often become tangled in gill-nets. Tangling in gill-nets is less size selective than wedging or gilling. Therefore, the size range of fish from these species caugh in gill-nets will be greater than of smooth fusiform species.

There was no significant difference in the mean fork length of red gurnard and sea perch caught in the three mesh sizes. Red gurnard have large wedge shaped heads with several spines along the hind margin of the operculum (Figure 7.27A). If a gurnard entered a mesh that was too small to allow forward progress, these spines would be likely to snag on the mesh and hold the fish in the gill-net. The large pectoral fins of this species are also likely to become tangled in the mesh. Sea perch also have spines on their operculum, pre-opercular ridge and above their eyes (Figure 7.27B) and large dorsal fin spines. Like the red gurnard, this species is likely to become tangled in the gill-net. Consequently, the size distribution of fish from these species caught in gill-net would be expected to be relatively independent of mesh size, as was observed.

Morphological differences also may account for the observed differences in the number of each species caught in each of the mesh sizes. Approximately half the species caught in the gill-nets showed significant differences in the number of fish caught in each of the mesh sizes. Several species were caught in significantly greater numbers in the 3.5" mesh size (e.g., barracouta, butterfly perch, jack mackerel, blue maomao and sea perch). This may be the result of large fish being tangled in the small mesh size and increasing the species' catch disproportionately. Large fish from species such as jack mackerel and sea perch, which have large maxillae and spines respectively, are likely to become tangled in small mesh sizes.

Differences in the number of fish from each species caught in each of the mesh sizes may be indicative of the relative abundances of the various size classes present in each species. The average length of butterfly perch is 15-25 cm fork length, and they rarely reach any larger than 30 cm (Ayling & Cox, 1987). It is unlikely that the 4.5" and 5.5" mesh gill-nets can prevent butterfly perch of this size escaping, unless they become tangled. Wedging and gilling are more effective than

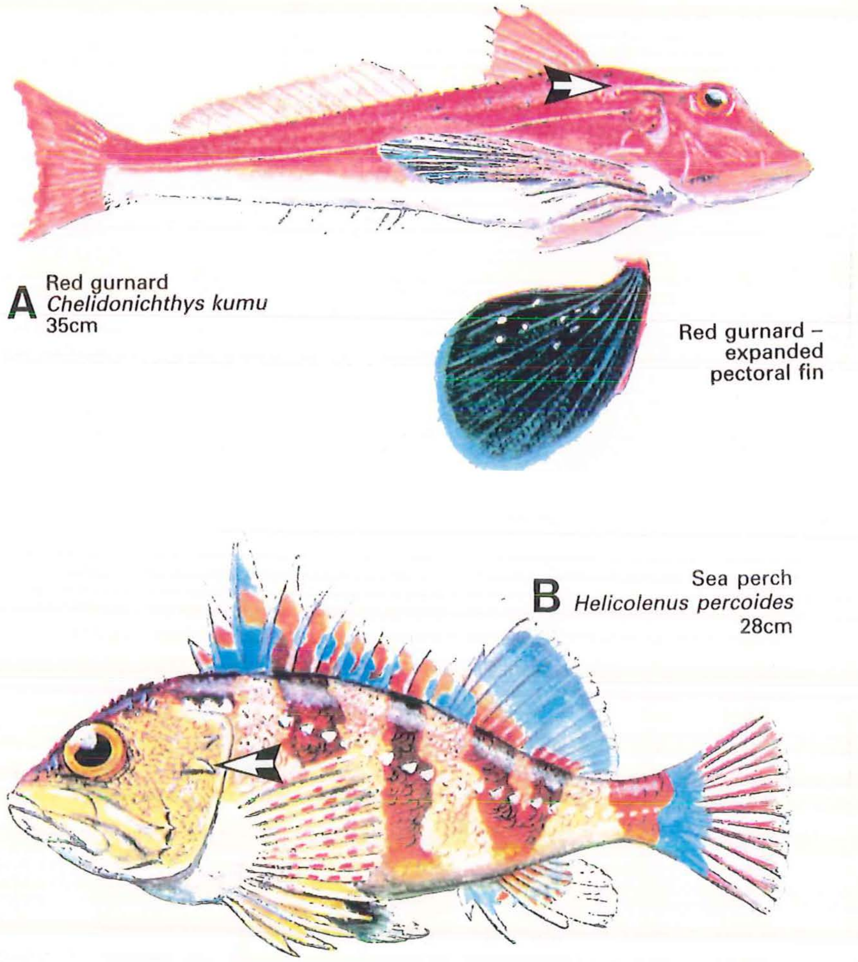


Figure 7.27 **A.** Red gurnard, *Chelidonichthys kumu*, showing the spines on the posterior edge of the operculum (arrow). **B.** Sea perch, *Helicolenus percoides*, showing the spines on the operculum (arrow), the pre-opercular ridge and between the eyes. Reproduced from Ayling & Cox (1987), Plate 14 and 15.

tangling (Winters & Wheeler, 1990), therefore it would be expected that more butterfly perch would be caught in the 3.5" mesh.

Blue maomao are a moderately deep-bodied laterally compressed fish that rarely reach > 30 cm in fork length around the mainland coast of New Zealand (Ayling & Cox, 1987). The 4.5" and 5.5" mesh sizes are unlikely to be able to wedge or gill blue maomao < 30 cm in fork length. The low dorsal and anal fins, and small pectoral fins of blue maomao (Ayling & Cox, 1987) will not cause this species to become tangled. Consequently, very few blue maomao would be expected to be caught in the two larger mesh sizes.

The maximum girth of a 100 cm (fork length) barracouta appears to be similar to that of a 30 cm blue maomao. Therefore, few of this species would be expected to be caught in the 4.5" and 5.5" mesh sizes. However, the large operculum and teeth of this species may cause fish to become tangled in the gill-nets.

Several species were caught predominantly in the larger two mesh sizes (e.g., black sharks, marblefish and warehou). This may be indicative of the relative abundance of the size classes capable of being caught by these mesh sizes. However, without a known population sampled by non-selective fishing gear with which to compare this catch, no conclusion can be drawn.

The unusual size frequency distribution of warehou may be a result of the schooling behaviour of this species. Warehou form schools with other warehou of similar sizes. Each individual peak in the catch of each mesh size may be a single school of warehou, all with similar fork lengths. This behaviour has also been observed in kahawai (Jones, pers. comm.).

The size distribution of kahawai caught in the gill-nets could be compared with that of kahawai caught by the less selective method of line fishing. Line fishing is less selective than gill-nets in terms of the size of fish caught (Elliot & Beamesderfer, 1990), but has the potential for behavioural differences to influence the catch. However, line fishing methods have been found to produce catches that are more representative of the length frequency of the fished population than gill-nets (Elliot & Beamesderfer, 1990).

The catch of kahawai from the gill-nets showed several differences when compared with the catch from the line methods. The first two modes of the gill-net catch occurred at smaller fork lengths than the corresponding modes in the line method catch. These modes also differed significantly in their amplitude, with the gill-nets implying that a considerably larger proportion of the 210 - 280 mm size class was present. Elliot & Beamesderfer (1990) observed gill-nets to underestimate the mode of white sturgeon, *Acipenser transmontanus*, seen in the catch of setlines and those caught by angling. The subsequent two modes in the gill-net catch are at similar fork lengths to those seen in the line method's catch, but are more defined in the gill-net catch. The modes in the gill-net catch do not appear to be an artifact of mesh selectivity. The 5.5" mesh should be capable of catching kahawai from 300 mm to 490 mm fork length by gilling and wedging (from the observed girth/perimeter ratio in Chapter Five and the morphological data in Appendix 3). However, no single peak spans this range, suggesting that the modes are a characteristic of the kahawai population being sampled.

The correlation between the number of each species caught by each mesh size may provide further evidence of the selectivity of gill-nets. Only a few species showed a significant correlation between mesh sizes and the number of fish caught, indicating that a given mesh size will not necessarily catch fish from a certain species simply because another mesh size nearby does. Rather than being a result of size selectivity, however, this may simply be a result of the aggregation patterns of different species. There was little correlation between the catch of barracouta, butterfly perch, blue mackerel, kahawai, snapper, sweep and trevally in each of the mesh sizes, all of which are schooling fish. Berst & M^{c}Combie (1963) found that the spatial distribution of fish in a gill-net corresponds to their distribution when approaching the net. Therefore, a schooling species would have a clustered distribution in the net and could feasibly be restricted to a single mesh size. It could appear that this mesh size was the only one capable of catching this species, when it may actually have been the only mesh with which the fish came into contact.

The number of fish from solitary species (blue cod, black sharks, carpet sharks, hoki and red cod) that were caught in each of the mesh sizes was positively correlated. The widespread distribution of these species is likely to result in a uniform catch across different mesh sizes.

The catch of several species was positively correlated with depth. Frostfish, red cod, sea perch and witch are deep-water fish and would be expected to be caught in higher numbers at greater depths. Hapuku, common roughy, arrow squid and northern bastard cod are commonly found in deeper water, and were caught in greater numbers in gill-nets set in deep water.

Marblefish and blue moki were caught in lower numbers in overnight sets. Both these species are inactive during darkness, and therefore there would be little chance that they would be caught in a gill-net during the night. Conger eels were also caught in lower numbers during overnight sets. This result is unusual because, like most other eels, they are more active at night, swimming actively near the bottom in search of prey (Ayling & Cox, 1987). They would be expected to be caught in higher numbers during these periods of higher activity. However, the number of daytime gill-net sets may have been too low to allow accurate comparison.

The correlations between latitude and species abundance in the gill-nets are generally in agreement with the recognised distributions of the species caught. Eagle rays, kingfish, blue maomao, snapper and trevally are more common in the warmer waters surrounding Northern New Zealand. Elephant fish, hoki, blue moki and spiny dogfish are more common south of Cook Strait.

The lack of correlation between the total number of species/fish caught and time may be a direct result of saturation effects in the gill-nets. The low number of very short set times in this study may have meant that all the nets had become saturated before they were lifted. Thus, no relationship between time and catch would have been observed. Because sets of longer duration are also night sets, saturation effects also may account for the lack of correlation between the number of species/fish caught and the time of day of the set.

Clearly gill-nets are size selective with respect to the fish they catch from some species. However for other species, morphological characteristics appear to override the selectivity of the nets. The selectivity of gill-nets may result in different mesh sizes catching varying numbers of each species, but these varying numbers also may be a direct result of the aggregation behaviour of individual species. The size-frequency of kahawai caught by gill-nets is comparable to the distribution caught with line fishing methods. However for other species, behavioural traits may make the two distributions very different. The catch from the gill-nets used in this study appears to be indicative of the geographical location and physical attributes of the fishing site. This suggests that the use of gill-nets to compare the abundances of individual species at different locations is valid.

CHAPTER EIGHT

General Discussion

There is considerable debate about the effects of gill-netting on reef fish populations. Statements such as "set netting has a severe impact on reef fish" (Royal Forest and Bird Protection Society, 1991) and "the destructive effects that setnets have already had on...reef fish...will take many years to correct" (Feldman, 1991) indicate a widespread belief that the effects of gill-netting are severe and long-lasting. Such statements are often made with little supporting evidence. An extensive literature search was done during this project. Very few studies were found that investigated the effects of gill-netting on fish populations and none of these was on the temperate reef fish populations of New Zealand. The reef fish populations of New Zealand and of the South Island in particular are still relatively undescribed, which has made it difficult to assess the effects of gill-nets on these populations.

The major conclusion from my study is that gill-nets do not fish representatively in terms of numbers or species from reef fish populations. This appears to relate to the habitat structure, the suite of fish species present, fish morphology and behaviour, and the mesh size of the nets being used.

8.1 Habitat structure and its association with fishes

As for most temperate inshore reefs (Choat & Schiel, 1982; Schiel, 1990) the near-shore habitats around Kaikoura are diverse biologically and topographically. Dense beds of large brown algae are common to depths of 20 m, but the physical structure is mostly composed of large boulders, compacted together or else with large interstices between them. These gaps of sea floor are usually covered with cobble and smaller rocks, with few large brown algae. These types of areas represent distinct habitats with respect to fishes (Choat & Ayling, 1987). By comparison to North Island habitats, where most ecological studies on fishes in New Zealand have been done, the habitats around Kaikoura are often closely spaced over tens of metres. When a gill-net of even 30 m length is set along a reef, therefore, it has a high probability of crossing more than one of these habitats.

As for most areas of New Zealand (Ayling, 1978; Kingett & Choat, 1981; M^{c}Cormick, 1986), the resident reef fish species around Kaikoura are highly associated with habitat types. Labrids, especially spotties, *Notolabrus celidotus*, are most abundant in algal covered areas, and are far less common over coralline algae-dominated areas or other habitats where large brown algae are sparse or absent. Butterfish, *Odax pullus*, are exclusively associated with algae, particularly the southern fucoid species *Marginariella boryana*. The large cheilodactylid species *Nemadactylus macropterus* and the latridid species *Latridopsis ciliaris* are more common in areas where large brown algae are sparse. These species are bottom feeders that require a soft substrate to feed. Blue cod, *Parapercis colias*, are another large carnivore that feeds predominantly in open areas.

These same associations between habitat type and species abundance have been observed in studies in the North Island (Jones, 1981a; Jones 1984b; Kingett & Choat, 1981). However, the large urchin-dominated areas typically seen on North Island coasts do not occur in the South Island (Schiel, 1990), so the spatial array of habitats is often compressed.

In terms of gill-netting, the closely spaced distribution and proximity of distinct habitats around Kaikoura can have a major effect on catches in terms of the species caught. Nets set across habitats will sample a greater diversity of inshore species as well as transient pelagic species.

8.2 Fish morphology

Morphological differences between species affect the susceptibility of individual fish to gill-nets. The primary factor that determines how a fish is caught in a gill-net is the body shape of the fish (M^{c}Combie & Berst, 1969). Fusiform fish (e.g., kahawai and butterfish) are commonly caught by becoming wedged, whereas laterally compressed fish (e.g., blue moki and tarakihi) are more commonly tangled or gilled. The fusiform body shape of butterfish allows this species to enter a considerable distance into the mesh of a gill-net before being held. The sinusoidal swimming motion of butterfish prevents them from backing out of gill-nets, and consequently most fish become gilled or wedged as they try to force their way through the mesh.

The swimming motion of fish alters their susceptibility to gill-nets. The 'sculling' swimming motion of spotties helps in avoiding capture because fish can swim backwards out of the mesh. Carangiform swimmers, such as kahawai, cannot swim backwards and subsequently have little ability to escape from a gill-net. Large laterally compressed fish (tarakihi and blue moki) are weak swimmers that do not appear to be able to break free from the mesh of a net, especially after becoming tangled by their spines, which is the commonest form of capture for them.

Species with protruding fins or spines, such as marblefish and blue moki, often become tangled in gill-nets. Tangling is the least selective form of entrapment in a gill-net and, therefore, these species can be equally vulnerable to all mesh sizes.

8.3 Fish behaviour

The behavioural characteristics of a species can significantly alter its susceptibility to gill-nets. Wide ranging, fast swimming species such as kahawai and butterfish are more likely to encounter a gill-net (Rudstam *et al.*, 1984) because of the greater distance they travel in a given time. Resident fish such as labrids have relatively small and often loose territories, usually comprising about 400 m^2 (Thompson, 1981). They are also acute visual predators, picking small invertebrates from algal fronds and the benthos. These species behave around nets as if they see them, often swimming over the net or even through it at larger mesh sizes. Other kelp-oriented species, especially butterfish, are wider ranging on reefs. These fish usually hit the nets just below the algal canopy and, because of their swimming motion, have little chance of escape. Latrid and Cheilodactylid fish frequently seem to blunder into nets, often barely touching these before becoming tangled. The visual acuity of 'pickers' (spotties) and visual predators (blue cod) may allow these fish to see the mesh of a gill-net and avoid capture. Bottom gleaners (tarakihi and blue moki) may not be able to detect the gill-nets presence.

8.4 Targeting

Targeting with gill-nets is in practice a relative term. The passive fishing action of gill-nets prevents precise targeting of individual species. A fisher targeting tarakihi on a reef using a 4" mesh, for example, is likely to catch butterfish. These butterfish are likely to be below legal size because they were caught in the smaller mesh size, and legally must be returned to the water. However, butterfish die quickly in gill-nets, and in my study very few of this species were landed while still alive. Consequently the absurd situation probably arises where fishers throw back dead undersized fish.

A gill-net set among dense kelp may catch large numbers of butterfish, but there is also a large by-catch of unwanted and unused species. Of the 1868 fish caught during this study, over 20% were species which are unwanted and unusable (marblefish, banded wrasse, spotties, yellow eyed mullet and rock cod). These by-catch species may not be sought after, but are often very important on reefs. Mesh sizes below 3.5" are more likely to catch spotties. The inappropriate use of a small mesh size net on a reef will remove smaller individuals from the reef fish population. Jones (1984c) noted a high correlation between juvenile spotty numbers and subsequent densities. Removing juvenile spotties from a reef may, therefore, have large consequent effects of changing the number of adult spotties on the reef and alter density dependent behaviour(Jones, 1984c).

High numbers of juvenile butterfish were caught in 2.5" and 3.5" mesh gill-nets. This species has little ability to escape from gill-nets. Therefore, successfully recruited juveniles are removed form the population and do not grow to adulthood. Little is known about the population structure of butterfish, but it is unlikely that any population could sustain high mortality of juveniles and remain unchanged.

8.5 Conclusions

Gill-nets do not representatively sample the fish population at reef sites. Behavioural traits, such as the wide ranging nature of butterfish, and morphological characteristics, such as the spines of sea perch, act to make some species more vulnerable to the fishing action of gill-nets than others. The mesh size of the gill-net also plays a major role in the susceptibility of fish to capture. Spotties appear to only be susceptible to mesh sizes smaller than 3.5". Consequently, most gill-nets may have little effect on this species. However, inappropriately sized gill-nets may have a severe impact on resident reef fish populations.

Gill-nets are commonly used by amateurs around the coast of New Zealand. Despite this, the regulations as to the targeting of species with particular mesh sizes are unclear. The legislation outlines the minimum mesh size that may be used to target a species, but does not regulate which species may be targeted in which areas. 2.5" gill-nets are readily available to amateur fishers in New Zealand. This mesh size catches a significantly greater number of fish and species than the 3.5" or 4.5" gill-nets over a six hour period (n = 21):

Mesh size	Number of fish	Number of species
2.5"	25.0 ± 0.5	4.5 ± 0.1
3.5"	9.1 ± 0.3	3.1 ± 1.3
4.5"	2.3 ± 0.1	1.5 ± 0.1

Clearly the 2.5" mesh size poses a much greater risk to reef fish populations. It is not known how often inappropriate nets such as the 2.5" mesh are used to fish on inshore reefs. However, my study shows that the use of a small mesh size greatly endangers a broader suite of juvenile and resident reef fish. These mesh sizes are clearly inappropriate for use in the near-shore reef environment.

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APPENDIX ONE

Species Codes

Code	Species	Common Name
ASQ	*Nototodarus sloanii*	Arrow Squid
BAR	*Thyrsites atun*	Barracouta
BCO	*Parapercis colias*	Blue Cod
BFL	*Rhombosolea retiaria*	Black Flounder
BNS	*Hyperoglyphe antarctica*	Bluenose
BOA	*Paristiopterus labiosus*	Sowfish
BPE	*Caesioperca lepidoptera*	Butterfly Perch
BPF	*Notolabrus fucicola*	Banded Wrasse
BRC	*Pseudophycis breviuscula*	Northern Bastard Cod
BRI	*Colistium guntheri*	Brill
BSH	*Scymnorhinus licha*	Black Shark
BSK	*Cetorhinus maximus*	Basking Shark
BUT	*Odax pullus*	Butterfish
CAR	*Cephaloscyllium isabellum*	Carpet Shark
CMO	*Latridopsis forsteri*	Copper Moki
CON	*Conger verreauxi*	Conger Eel
EGR	*Myliobatis tenuicaudatus*	Eagle Ray
ELE	*Callorhinchus milii*	Elephant Fish
EMA	*Scomber australasicus*	Blue Mackerel
ESO	*Peltorhamphus novaezeelandiae*	New Zealand Sole
FLA	Unspecified flatfish species	Mixed Flatfish
FRO	*Lepidopus caudatus*	Frostfish
GFL	*Rhombosolea tapirina*	Greenback Flounder
GMU	*Mugil cephalus*	Grey Mullet
GPF	*Notolabrus cinctus*	Girdled Wrasse
GTR	*Aplodactylus arctidens*	Marblefish
GUR	*Chelidonichthys kumu*	Red Gurnard
HAK	*Merluccius australis*	Hake

Code	Species	Common Name
HAP	*Polyprion oxygeneios*	Hapuku
HOK	*Macruronus novaezelandiae*	Hoki
HPB	Composite code	Hapuku and Bass
JDO	*Zeus faber*	John Dory
JMA	*Trachurus declivis*	Jack Mackerel
JMN	*Trachurus novaezelandiae*	New Zealand Mackerel
KAH	*Arripis trutta*	Kahawai
KIN	*Seriola lalandi*	Kingfish
LEA	*Parika scaber*	Leatherjacket
LIN	*Genypterus blacodes*	Ling
LSO	*Pelotretis flavilatus*	Lemon Sole
MAO	*Scorpis violaceus*	Blue Maomao
MOK	*Latridopsis ciliaris*	Blue Moki
OCT	*Octopus maorum*	Octopus
OSD	Unspecified sharks & dogfish	Other Sharks and Dogfish
PAR	*Girella tricuspidata*	Parore
POR	*Nemadactylus douglasi*	Porae
RAT	Family Macrouridae	Rattails
RBY	*Plagiogeneion rubiginosus*	Rubyfish
RCO	*Pseudophycis bachus*	Red Cod
RHY	*Paratrachichthys trailli*	Common Roughy
RIB	*Mora moro*	Ribaldo
RMO	*Cheilodactylus spectabilis*	Red Moki
RMU	*Upeneichthys lineatus*	Red Mullet
ROC	*Lotella rhacinus*	Rock Cod
RSC	*Scorpaena cardinalis*	Scorpion Fish
RSK	*Raja nasuta*	Rough Skate
RSN	*Centroberyx affinis*	Red Snapper

Code	Species	Common Name
SCH	*Galeorhinus galeus*	School Shark
SFE	*Anguilla australis*	Short-finned Eel
SFL	*Rhombosolea plebeia*	Sand Flounder
SKI	*Rexea solandri*	Gemfish
SNA	*Chrysophrys auratus*	Snapper
SPD	*Squalus acanthias*	Spiny Dogfish
SPE	*Helicolenus percoides*	Sea Perch
SPF	*Pseudolabrus miles*	Scarlet Wrasse
SPO	*Mustelus lenticulatus*	Rig
SPZ	*Genyagnus monopterygius*	Spotted Stargazer
SSK	*Raja innominata*	Smooth Skate
STA	*Kathetostoma giganteum*	Giant Stargazer
STY	*Notolabrus celidotus*	Spotty
SWA	*Seriolella punctata*	Silver Warehou
TAR	*Nemadactylus macropterus*	Tarakihi
TEL	*Mendosoma lineatum*	Telescope Fish
TRE	*Pseudocaranx dentex*	Trevally
TRU	*Latris lineata*	Trumpeter
WAR	*Seriolella brama*	Warehou
WIT	*Arnoglossus scapha*	Witch
WWA	*Seriolella caerulea*	White Warehou
YBF	*Rhombosolea leporina*	Yellow-belly Flounder
YEM	*Aldrichetta forsteri*	Yellow-eyed Mullet

APPENDIX TWO

Glossary of Terms

Drift Net : A kind of gill-net which is released to float freely on the surface or just below it. Usually considerably longer than bottom set gill-nets.

Float-line : The head line of a net which usually has floats encasing it to keep the net vertical in the water column.

Gilled : Mode of entanglement of fish in a gill-net whereby the fish has entered the mesh far enough for a mesh filament to become snagged behind one or both gill covers.

Gill-net : A vertical wall of netting designed to trap fish within its meshes. Can be either anchored or free floating.

Hanging Ratio/Coefficient : The percentage by which the unslung mesh is shortened when a net in attached to its lead-line and float line.

Lead-line : The bottom rope of a net which usually has lead weights encasing it to keep the net tight.

Mesh Cell : Two loops of nylon, which are joined together with knots to form a diamond shape.

Mesh Perimeter : The total length of the four sides of each mesh cell.

Mesh Selectivity : The selectivity of a given mesh size for a particular fish - usually related to size of fish.

Mesh Size : The dimension of the mesh from the centre of one knot to the centre of the next diagonally opposite knot when the mesh is stretched.

Set-net : A kind of gill-net which is temporarily secured to the sea bed, usually with anchors or weights, so that it will not move.

Tangled : Mode of entanglement of fish in a gill-net whereby the fish is trapped in the net by the mesh snagging its fins, teeth, maxillae or spines.

Trammel Net : A net made with three sheets of netting which are joined so they lay together in one wall. The two outer layers are of a larger mesh than the loosely hung inner piece. When a fish strikes the net, it becomes tangled in a pocket as the force carries the smaller mesh through the larger net.

Wedged : Mode of entanglement of fish in a gill-net whereby the fish has passed through the mesh beyond its gills but the mesh has become wedged around the fish's gut.

APPENDIX THREE

Morphometric Relationships

A.3.1 INTRODUCTION

Morphology is a term derived from the Greek word morphè for 'form'. In its strictest sense it means a branch of bioscience concerned with the study of shape in biological objects (Meeuse, 1986). Linear measurements of the dimensions of animals tend to compound size and shape. Examining shape rather than size involves the use of two or more linear measurements to obtain a ratio or some more complex combined measurement. This measurement may be easier to handle statistically, particularly when whole populations are being considered (Arthur, 1984).

Little work has been done on the morphology of New Zealand reef fish. The morphometric relationships (especially length-weight) of commercially important species such as blue moki, *Latridopsis ciliaris*, tarakihi, *Nemadactylus macropterus*, and blue cod, *Parapercis colias*, have been described by various authors (Annala, 1993), but other common species such as spotties, *Notolabrus celidotus*, banded wrasse, *Notolabrus fucicola*, and butterfish, *Odax pullus*, are relatively undescribed. This study analyses the combined catch of the 2.5", 3.5" and 4.5" gill-nets during this project, and describes the morphological relationships of the species that were commonly caught.

A.3.2 MATERIALS AND METHODS

Over 1900 fish were caught during this study from 33 different species. All fish that were caught were weighed, and both the fork length and standard length was measured. The opercular girth (at the posterior edge of the operculum) and maximum girth was measured (Figure 5.1). The sex was recorded if it could be identified visually. Opercular girth, maximum girth and weight were plotted against fork length, and regression lines were fitted (Minitab, release 8.2). Comparisons between regression lines obtained for each sex were performed in species where the sexes could be distinguished visually. Before comparisons, tests for homogeneity of variances between regression lines were done.

The test for homogeneous variances used the ratio of the Mean Square values to provide an *F* value. If no difference existed, tests for equal slopes of regression lines between treatments (sexes) were carried out. The slopes of the regressions were tested by dividing the mean squares of difference between the single regressions and the pooled result (from an ANCOVA) from the mean squares of the single regressions. Differences in the adjusted means can be tested by dividing the Treatment Mean Square (Sex) by the Residual Mean Square (Snedecor & Cochran, 1967). This was tested by the Minitab ANCOVA function.

If the individual sexes regression lines were not significantly different the data was pooled for the entire species. Severely and majorly damaged fish (section 5.2.3) were excluded from the length/girth analysis, and only undamaged fish were used for length/weight analysis.

A.3.3 RESULTS

29 yellow-eyed mullet, *Aldrichetta forsteri*, were caught in the gill-nets. This species could not be sexed externally, so the data was pooled across sexes. The

morphometric relationships for yellow-eyed mullet are shown in Figures A.3.1 - A.3.4.

172 marblefish, *Aplodactylus arctidens*, were caught in the gill-nets. This species could not be sexed externally, so the data was pooled across sexes. The morphometric relationships for marblefish are shown in Figures A.3.5 - A.3.8.

189 kahawai, *Arripis trutta*, were caught in the gill-nets. This species could not be sexed externally, so the data was pooled across sexes. The morphometric relationships for kahawai are shown in Figures A.3.9 - A.3.12.

12 red moki, *Cheilodactylus spectabilis*, were caught in the gill-nets. This species could not be sexed externally, so the data was pooled across sexes. The morphometric relationships for red moki are shown in Figures A.3.13 - A.3.16.

257 blue moki, *Latridopsis ciliaris*, were caught in the gill-nets. This species could not be sexed externally, so the data was pooled across sexes. The morphometric relationships for blue moki are shown in Figures A.3.17 - A.3.20.

10 copper moki, *Latridopsis forsteri*, were caught in gill-nets. This species could not be sexed externally, so the data was pooled across sexes. The morphometric relationships for copper moki are shown in Figures A.3.21 - A.3.24.

70 spotties, *Notolabrus celidotus*, were caught in gill-nets. The sex of this species could be determined visually. The data was grouped according to sex, and regression lines were fitted and compared. No significant difference was found

between the variances ($p > 0.05$), slopes ($p > 0.05$) or adjusted means of the regression lines fitted for each sex for standard length v. fork length ($F_{1,57} = 1.35$, $p = 0.250$), opercular girth v. fork length ($F_{1,5} = 0.79$, $p = 0.415$) or maximum girth v. fork length ($F_{1,5} = 0.17$, $p = 0.700$). The data for each sex was pooled for these relationships and regression lines were fitted again (Figures A.3.25 - A.3.27). The adjusted means differed significantly between sexes for weight v. fork length ($F_{1,51}$ $= 4.37$, $p < 0.05$), so this relationship was plotted separately for each sex (Figures (A.3.28 & A.3.29).

71 banded wrasse, *Notolabrus fucicola*, were caught in gill-nets. The sex of this species could be determined visually. The data was grouped according to sex, and regression lines were fitted and compared. No significant difference was found between the variances ($p > 0.05$), slopes ($p > 0.05$) or adjusted means of the regression lines fitted for each sex for standard length v. fork length ($F_{1,49} = 0.97$, $p = 0.330$), opercular girth v. fork length ($F_{1,47} = 1.10$, $p = 0.299$), maximum girth v. fork length ($F_{1,47} = 1.03$, $p = 0.316$) or weight v. fork length ($F_{1,49} = 3.50$, $p =$ 0.067). The data for each sex was pooled for these relationships, and regression lines were fitted again (Figures A.3.30 - A.3.33).

773 butterfish, *Odax pullus*, were caught in gill-nets. The sex of this species could be determined visually. The data was grouped according to sex, and regression lines were fitted and compared. No significant difference was found between the variances ($p > 0.05$), slopes ($p > 0.05$) or adjusted means of the regression lines fitted for each sex for standard length v. fork length ($F_{1,203} = 1.81$, $p = 0.180$). The data for each sex was pooled for this relationship, and a regression line was fitted (Figure A.3.34). The variance of the regression lines for each sex were unequal for

opercular girth v. fork length ($F_{73,73} = 1.63$, $p < 0.01$), maximum girth v. fork lengt ($F_{73,73} = 3.55$, $p < 0.001$) and weight v. fork length ($F_{102,102} = 1.80$, $p < 0.001$) These relationships were plotted separately for each sex (Figure A.3.35 - A.3.40).

35 blue cod, *Parapercis colias*, were caught in the gill-nets. This species could not be sexed externally, so the data was pooled across sexes. The morphometric relationships for blue cod are shown in Figures A.3.41 - A.3.44.

17 red cod, *Pseudophycis bachus*, were caught in the gill-nets. This species could not be sexed externally, so the data was pooled across sexes. The morphometric relationships for red cod are shown in Figures A.3.45 - A.3.48.

127 warehou, *Seriolella brama*, were caught in the gill-nets. This species could not be sexed externally, so the data was pooled across sexes. The morphometric relationships for warehou are shown in Figures A.3.49 - A.3.52.

21 jack mackerel, *Trachurus declivis*, were caught in the gill-nets. This species could not be sexed externally, so the data was pooled across sexes. The morphometric relationships for jack mackerel are shown in Figures A.3.53 - A.3.56.

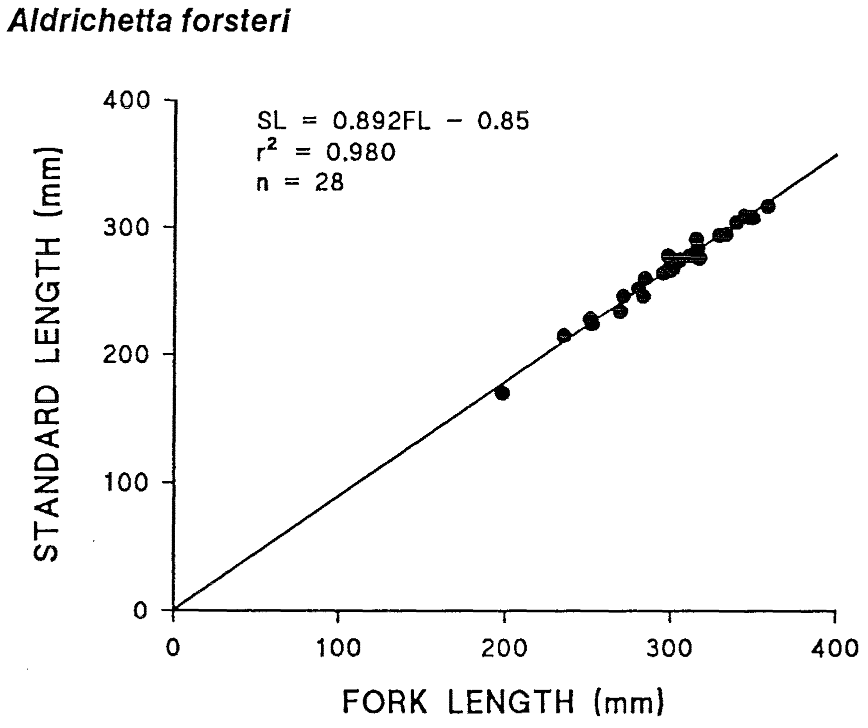


Figure A.3.1 Plot of standard length against fork length for yellow-eyed mullet, *Aldrichetta forsteri*, caught in gill-nets. Linear regression equation is shown.

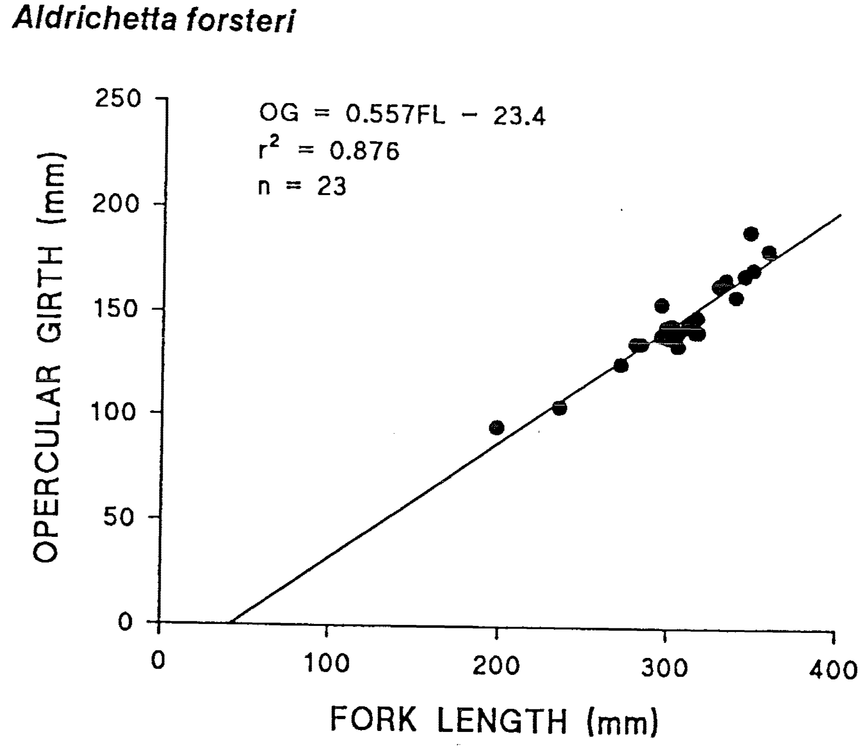
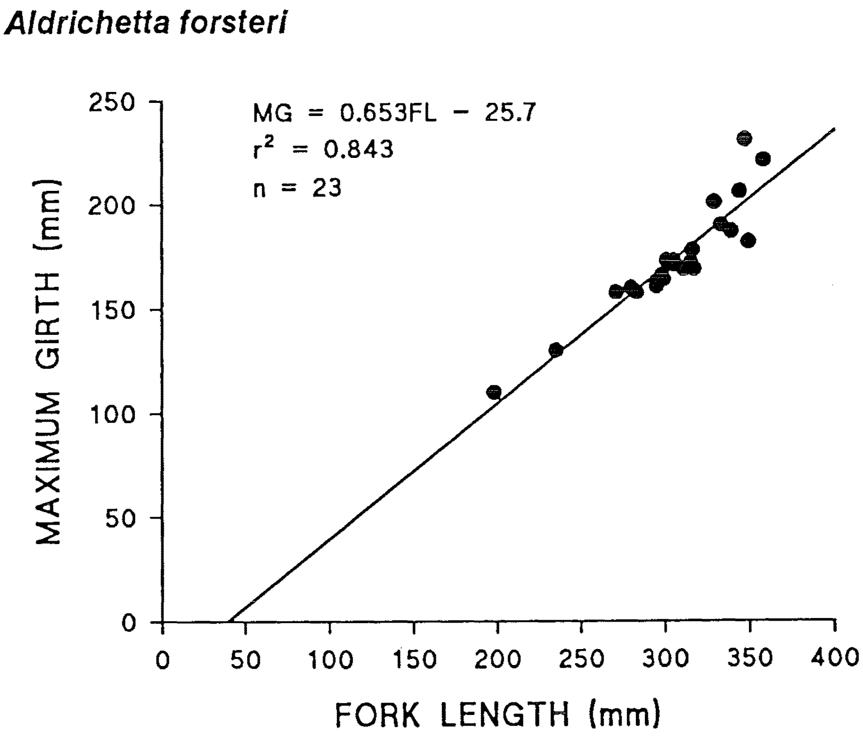
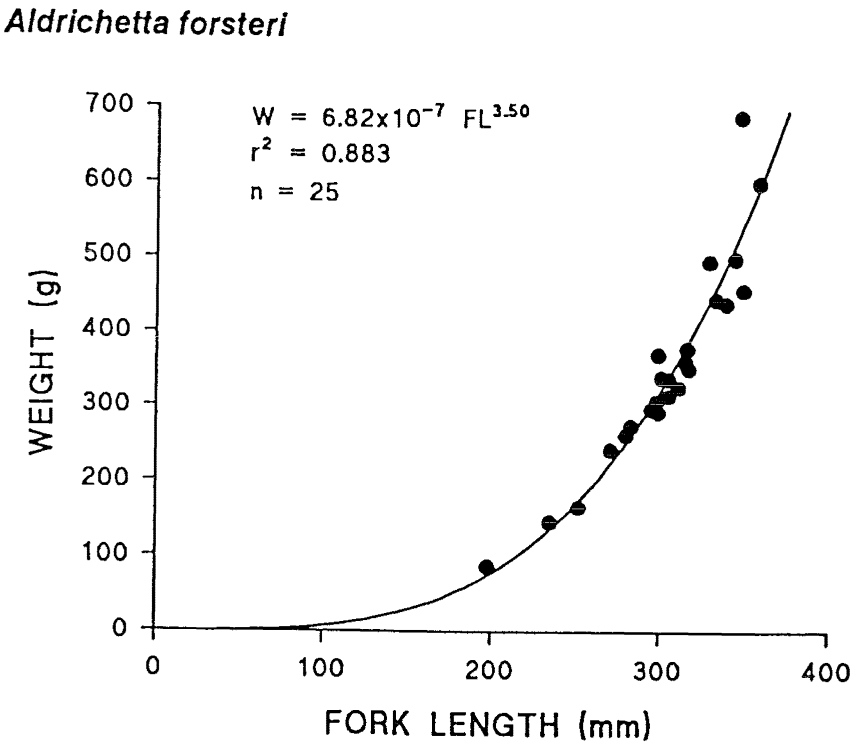


Figure A.3.2 Plot of opercular girth against fork length for yellow-eyed mullet, *Aldrichetta forsteri*, caught in gill-nets. Linear regression equation is shown.



Aldrichetta forsteri

Figure A.3.3 Plot of maximum girth against fork length for yellow-eyed mullet, *Aldrichetta forsteri*, caught in gill-nets. Linear regression equation is shown.



Aldrichetta forsteri

Figure A.3.4 Plot of weight against fork length for yellow-eyed mullet, *Aldrichetta forsteri*, caught in gill-nets. Linear regression equation is shown.

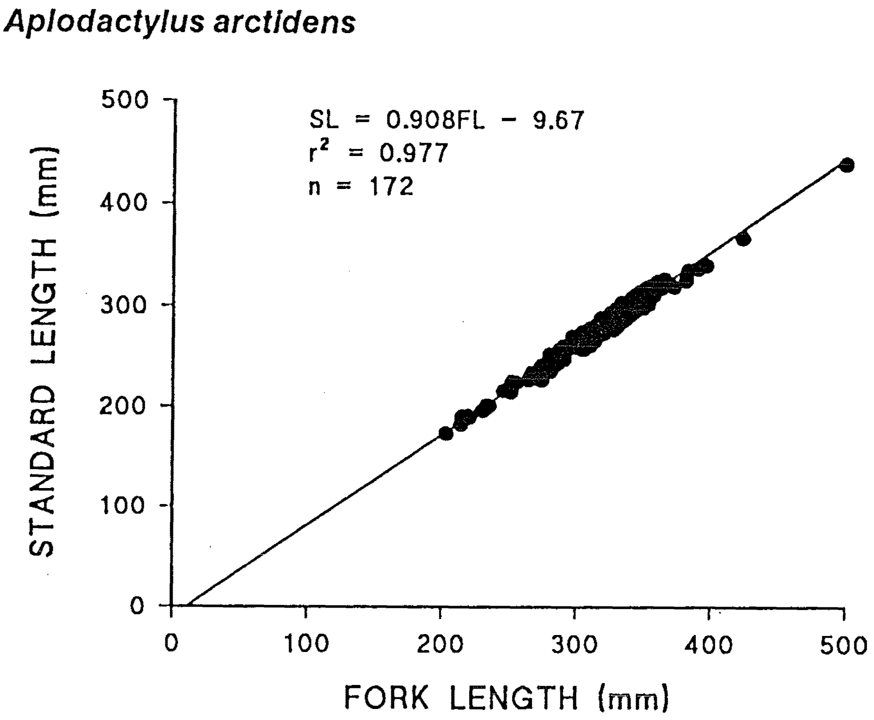


Figure A.3.5 Plot of standard length against fork length for marblefish, *Aplodactylus arctidens*, caught in gill-nets. Linear regression equation is shown.

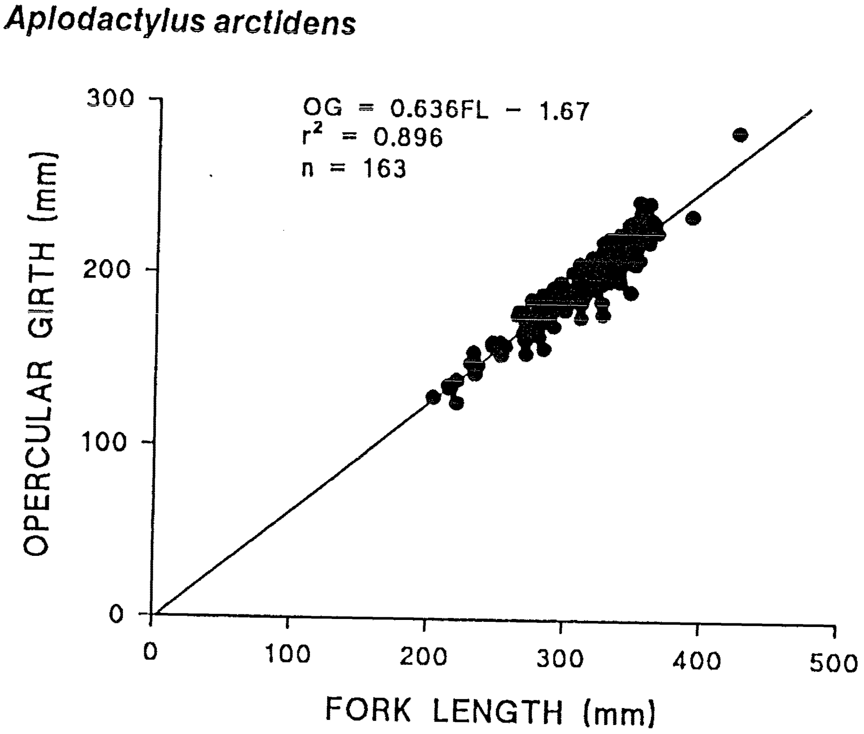


Figure A.3.6 Plot of opercular girth against fork length for marblefish, *Aplodactylus arctidens*, caught in gill-nets. Linear regression equation is shown.

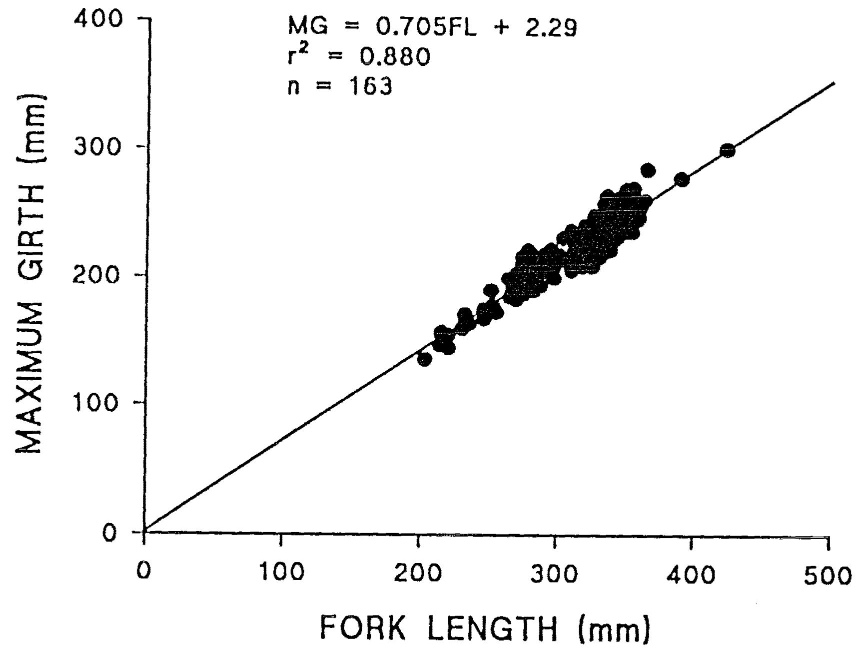


Figure A.3.7 Plot of maximum girth against fork length for marblefish, *Aplodactylus arctidens*, caught in gill-nets. Linear regression equation is shown.

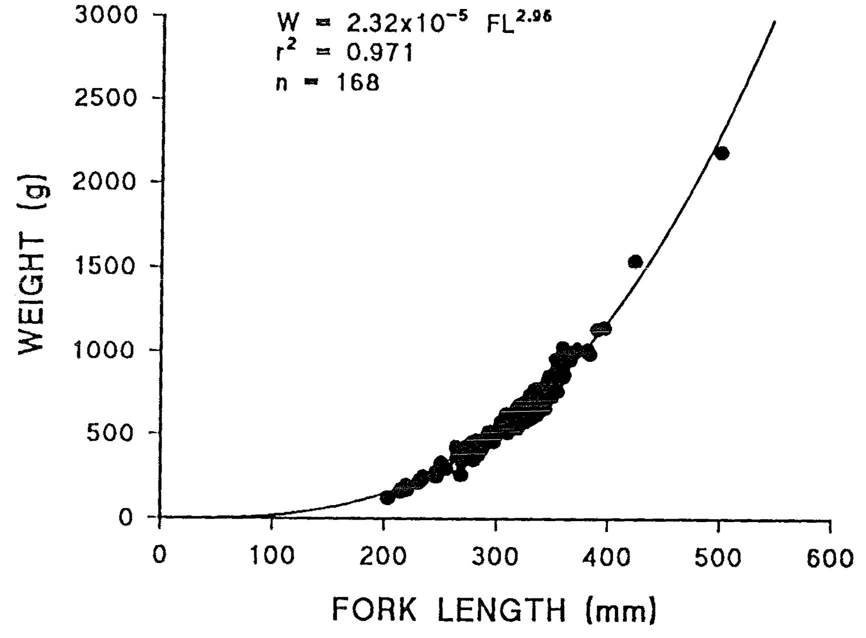


Figure A.3.8 Plot of weight against fork length for marblefish, *Aplodactylus arctidens*, caught in gill-nets. Linear regression equation is shown.

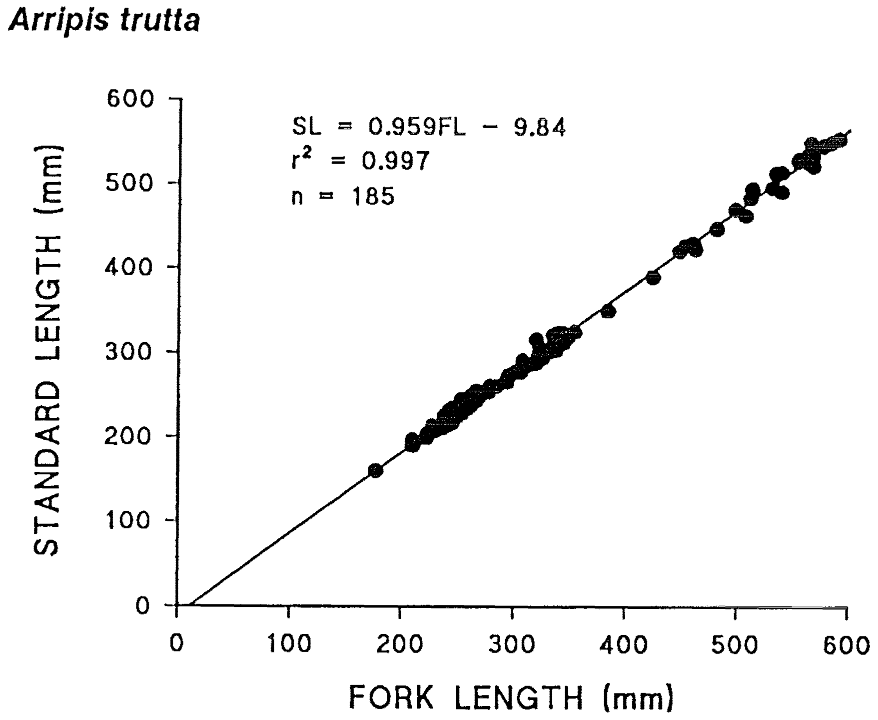


Figure A.3.9 Plot of standard length against fork length for kahawai, *Arripis trutta*, caught in gill-nets. Linear regression equation is shown.

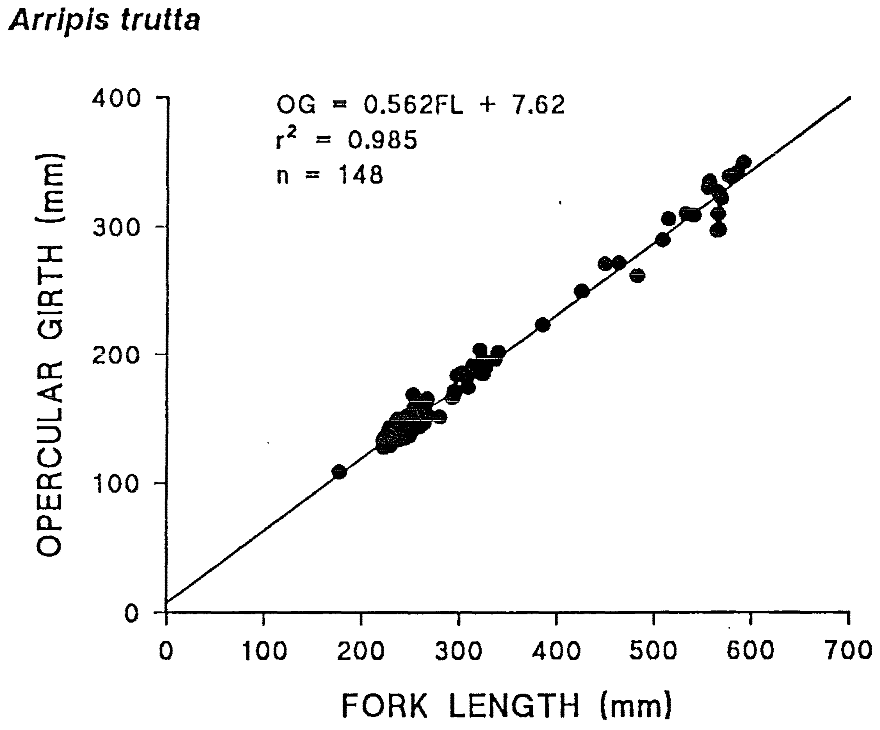
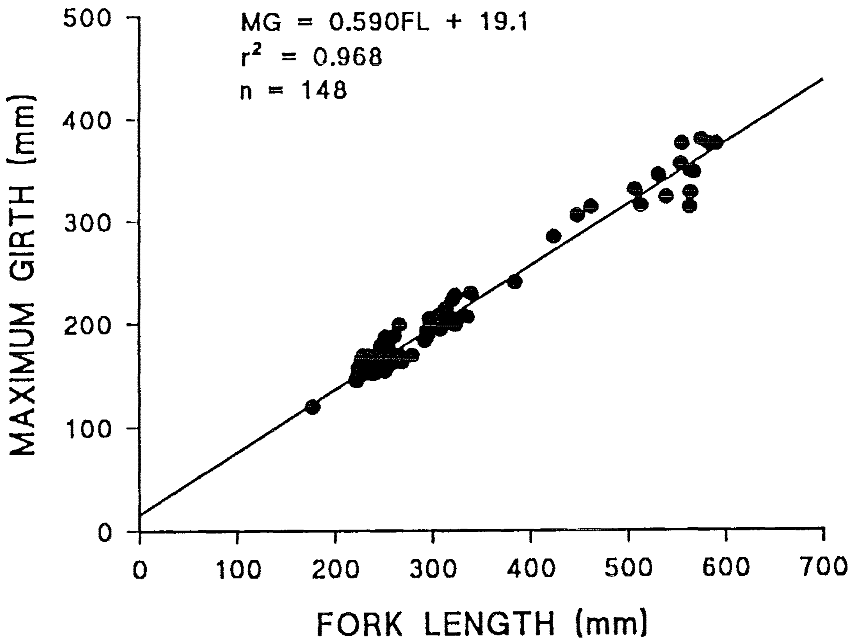
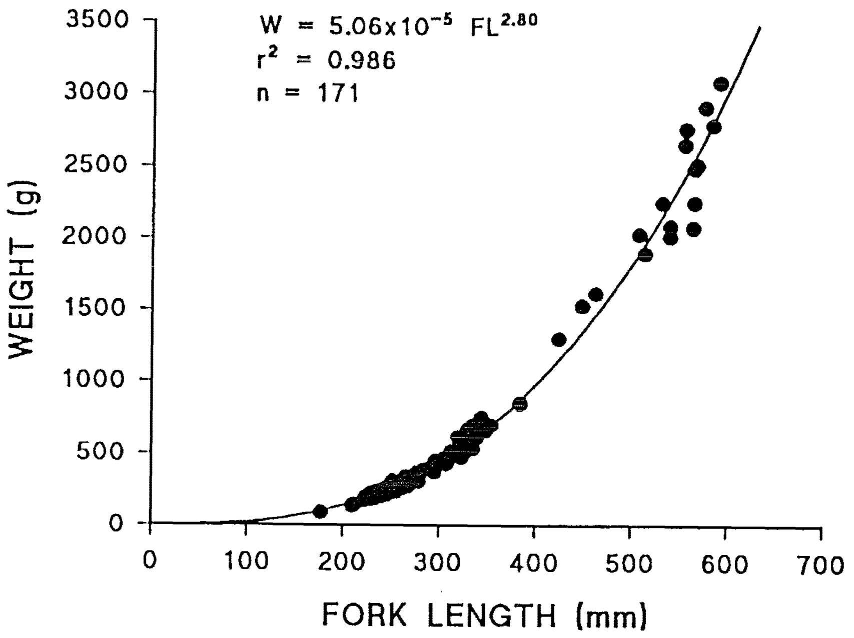


Figure A.3.10 Plot of opercular girth against fork length for kahawai, *Arripis trutta*, caught in gill-nets. Linear regression equation is shown.



Arripis trutta

Figure A.3.11 Plot of maximum girth against fork length for kahawai, *Arripis trutta*, caught in gill-nets. Linear regression equation is shown.



Arripis trutta

Figure A.3.12 Plot of weight against fork length for kahawai, *Arripis trutta*, caught in gill-nets. Linear regression equation is shown.

Cheilodactylus spectabilis

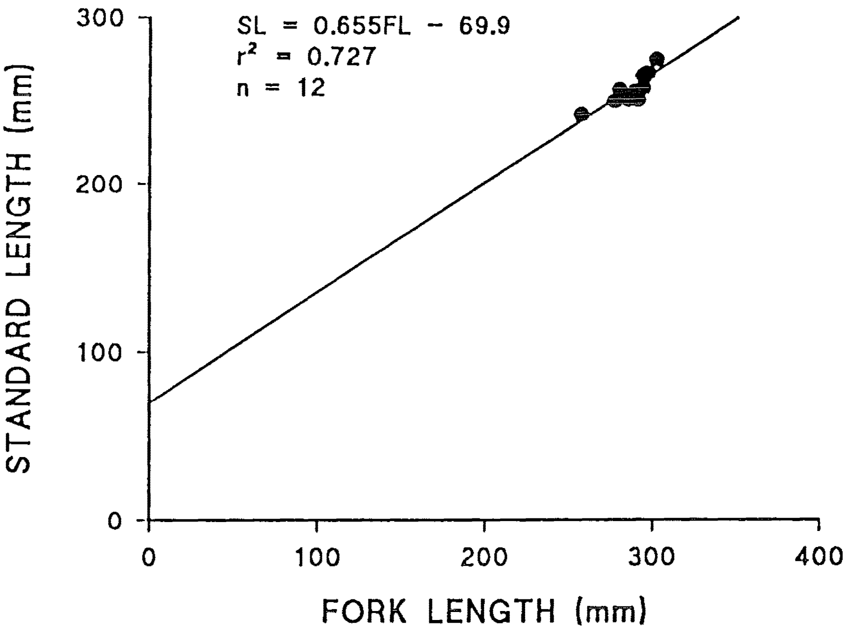


Figure A.3.13 Plot of standard length against fork length for red moki, *Cheilodactylus spectabilis*, caught in gill-nets. Linear regression equation is shown.

Cheilodactylus spectabilis

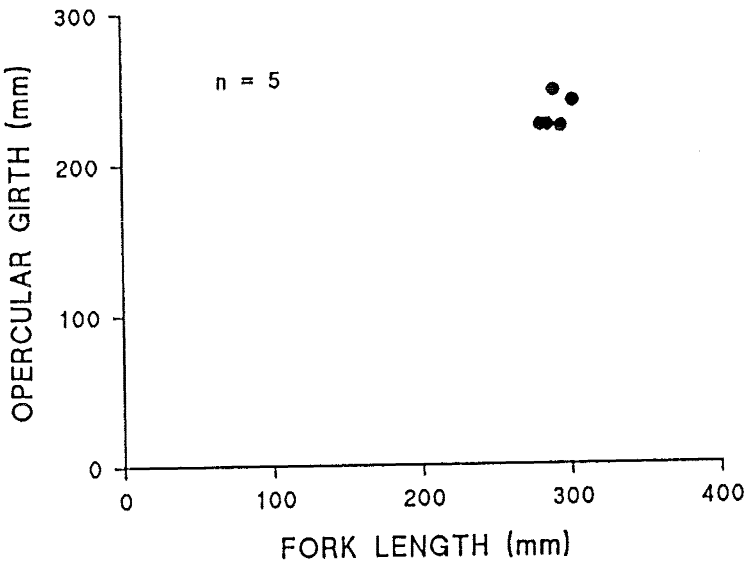


Figure A.3.14 Plot of opercular girth against fork length for red moki, *Cheilodactylus spectabilis*, caught in gill-nets.

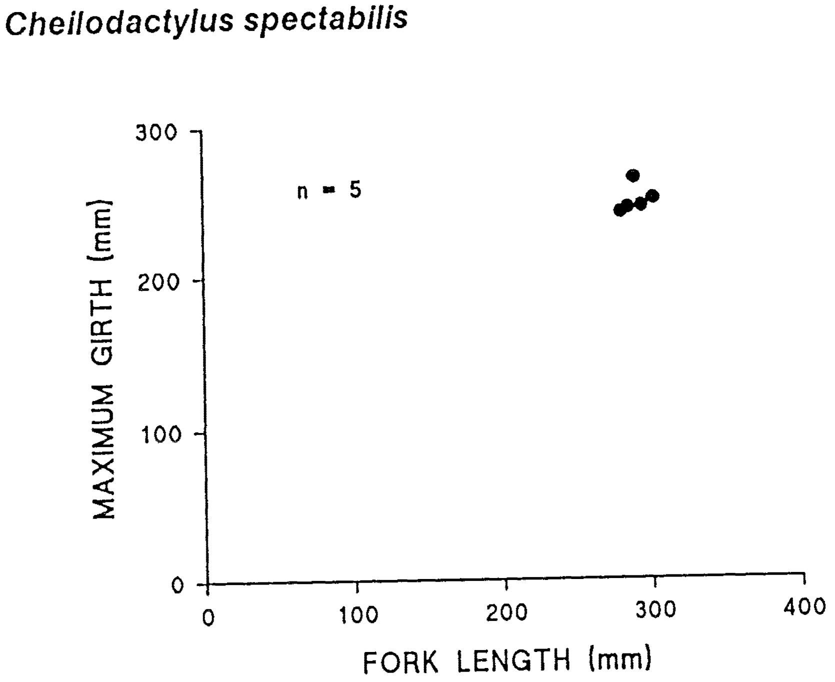


Figure A.3.15 Plot of maximum girth against fork length for red moki, *Cheilodactylus spectabilis*, caught in gill-nets.

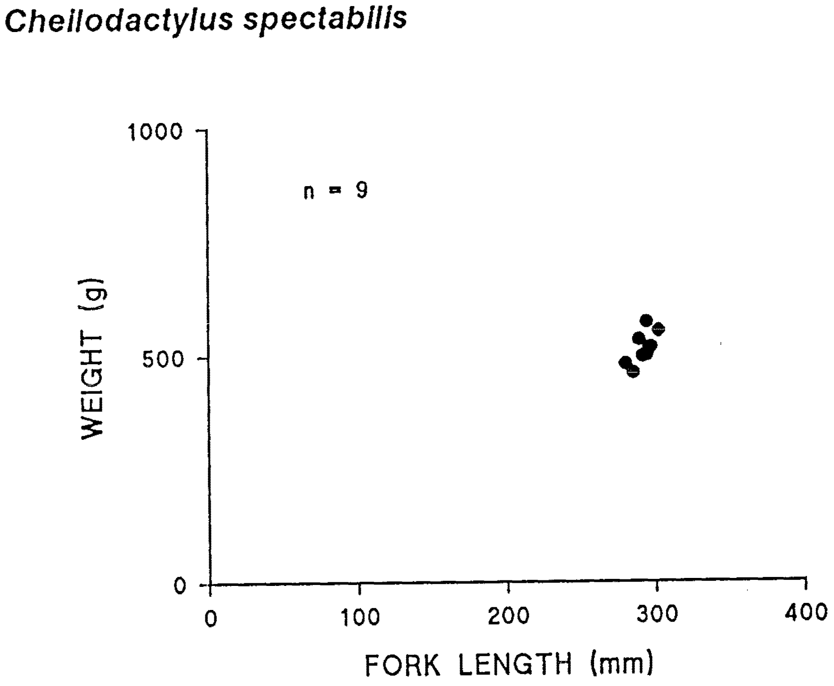


Figure A.3.16 Plot of weight against fork length for red moki, *Cheilodactylus spectabilis*, caught in gill-nets.

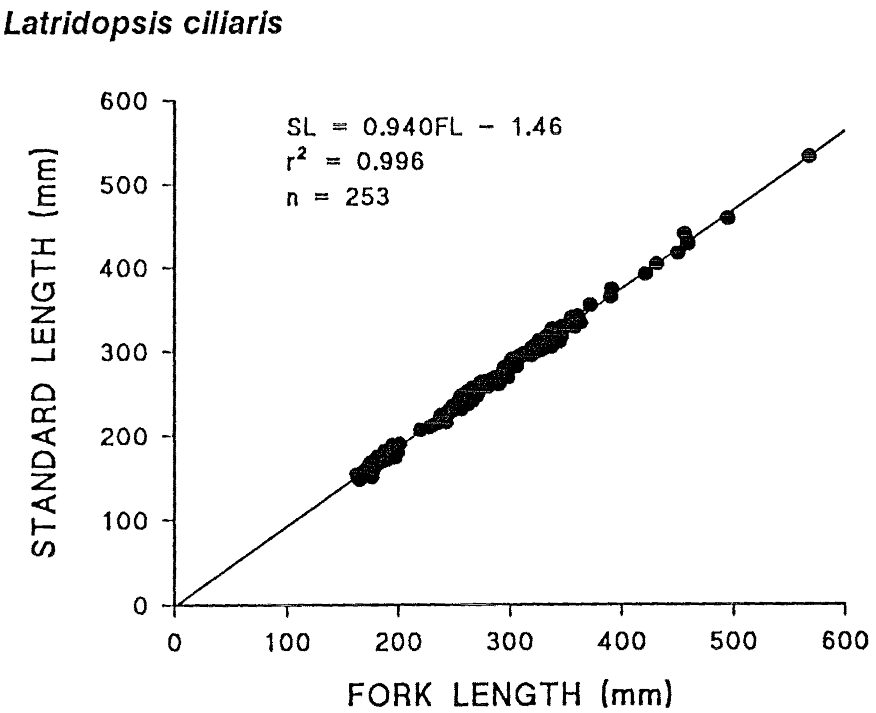


Figure A.3.17 Plot of standard length against fork length for blue moki, *Latridopsis ciliaris*, caught in gill-nets. Linear regression equation is shown.

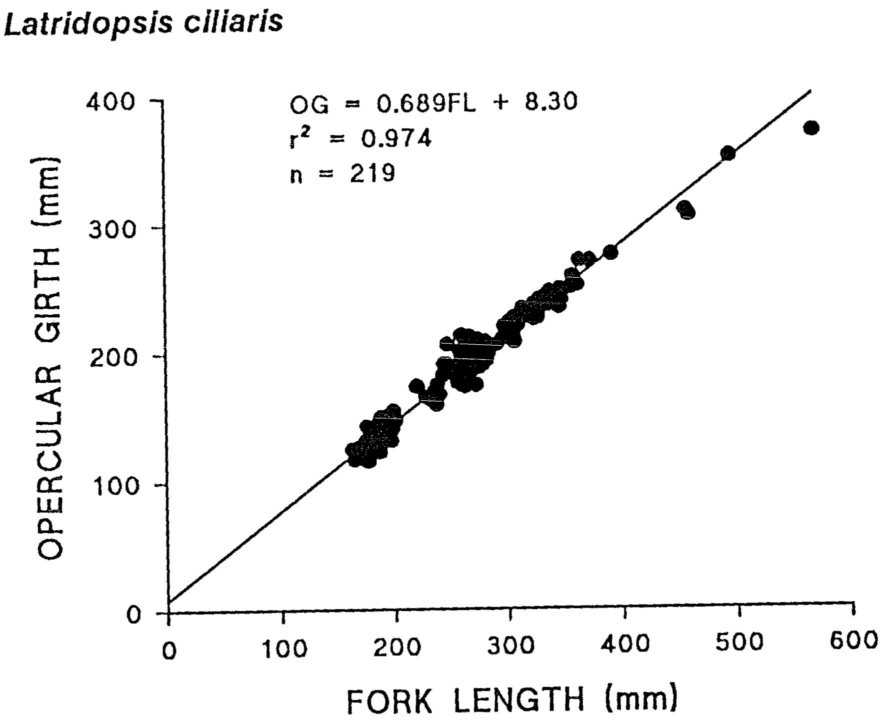


Figure A.3.18 Plot of opercular girth against fork length for blue moki, *Latridopsis ciliaris*, caught in gill-nets. Linear regression equation is shown.

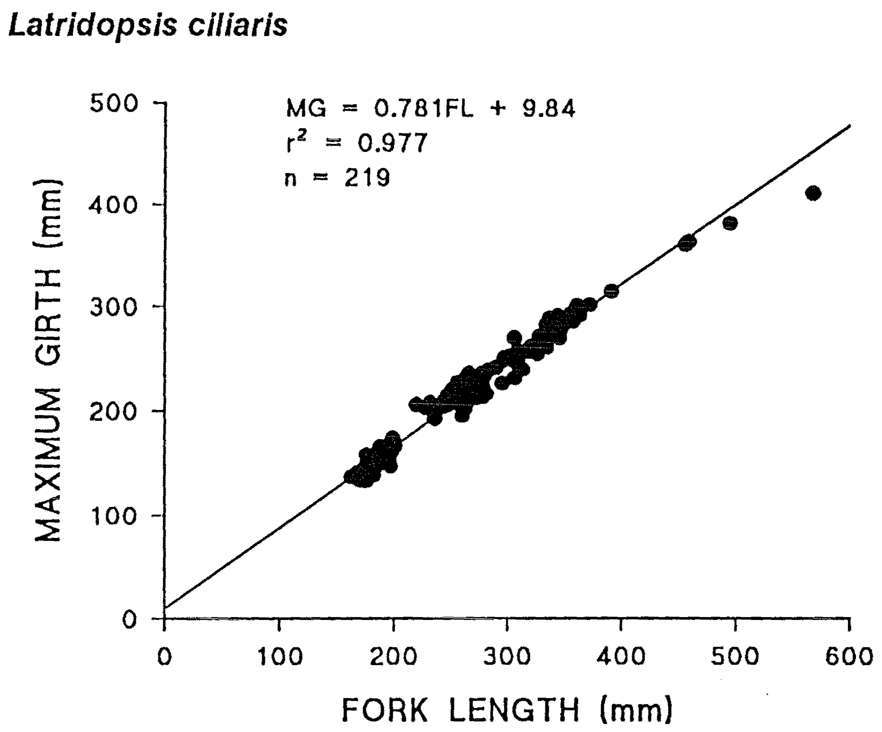


Figure A.3.19 Plot of maximum girth against fork length for blue moki, *Latridopsis ciliaris*, caught in gill-nets. Linear regression equation is shown.

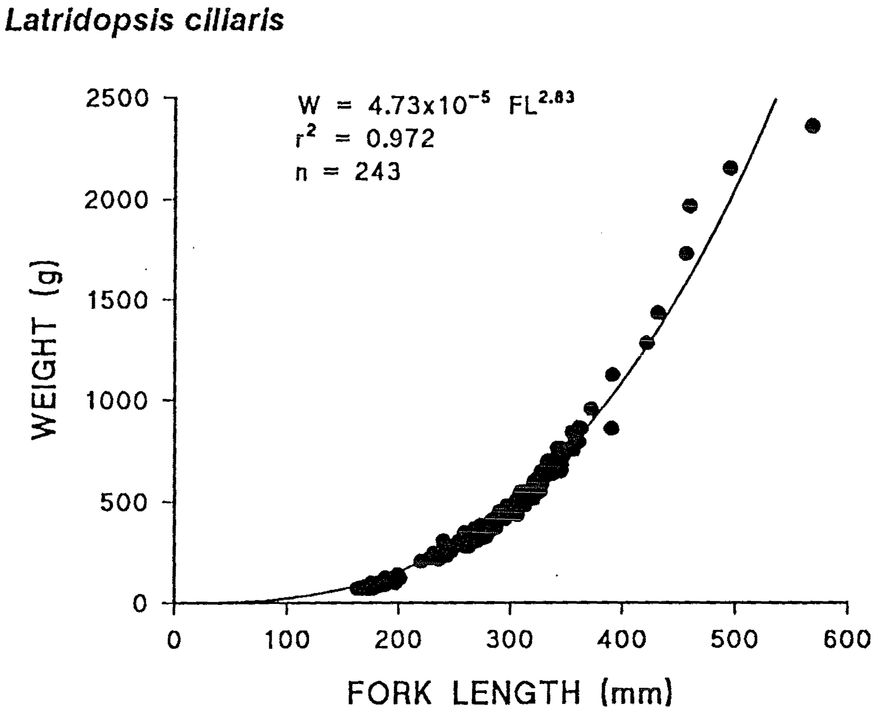


Figure A.3.20 Plot of weight against fork length for blue moki, *Latridopsis ciliaris*, caught in gill-nets. Linear regression equation is shown.

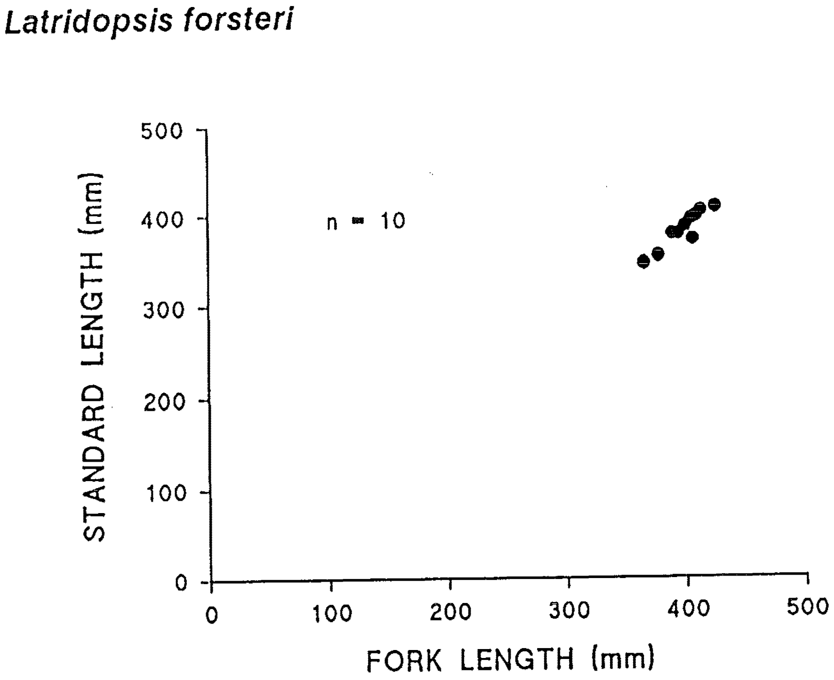


Figure A.3.21 Plot of standard length against fork length for copper moki, *Latridopsis forsteri*, caught in gill-nets.

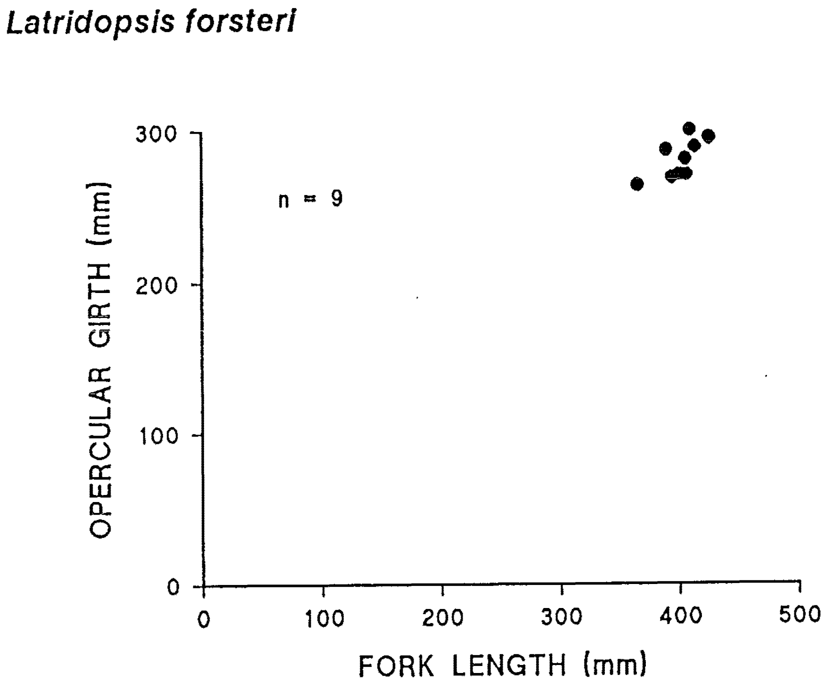


Figure A.3.22 Plot of opercular girth against fork length for copper moki, *Latridopsis forsteri*, caught in gill-nets.

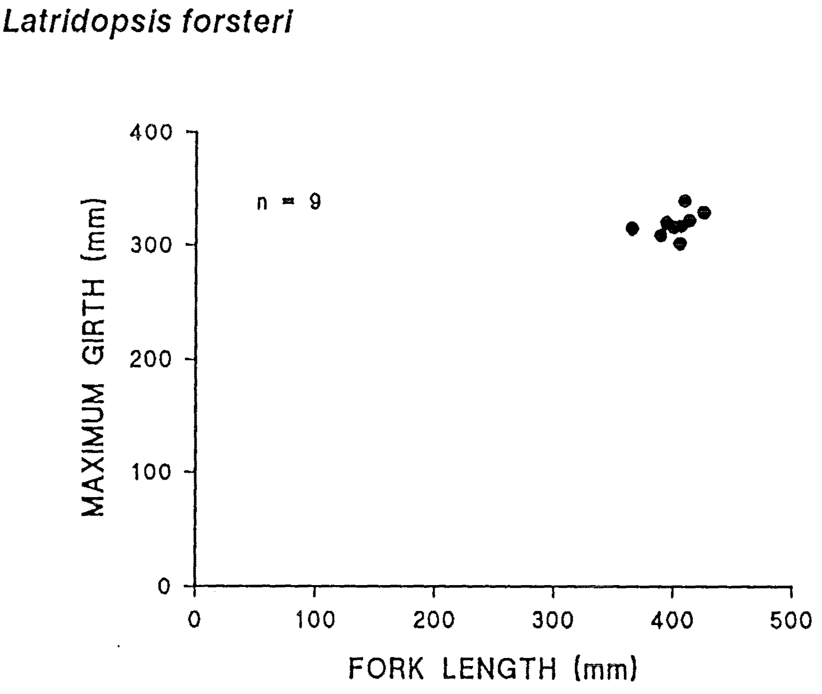


Figure A.3.23 Plot of maximum girth against fork length for copper moki, *Latridopsis forsteri*, caught in gill-nets.

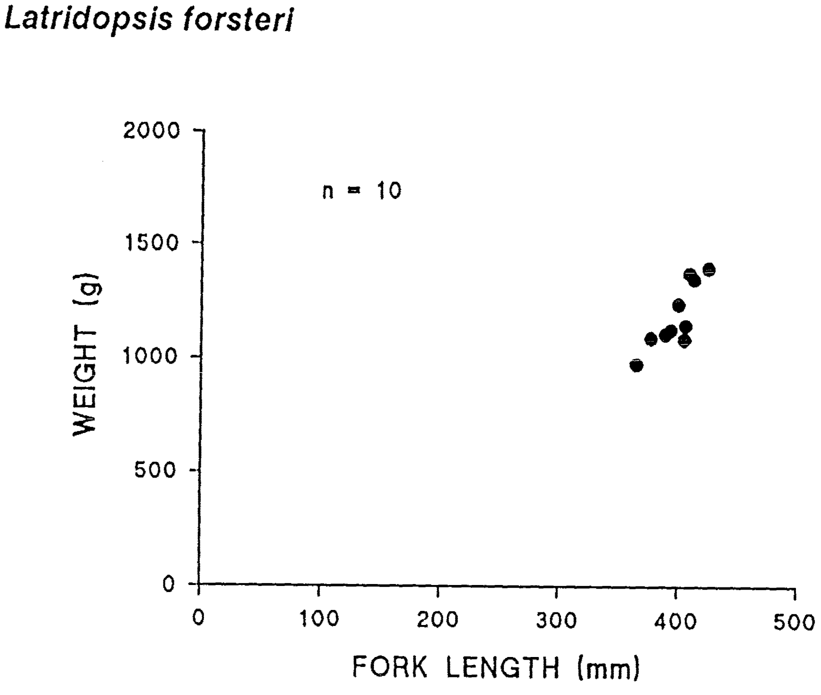


Figure A.3.24 Plot of weight against fork length for copper moki, *Latridopsis forsteri*, caught in gill-nets.

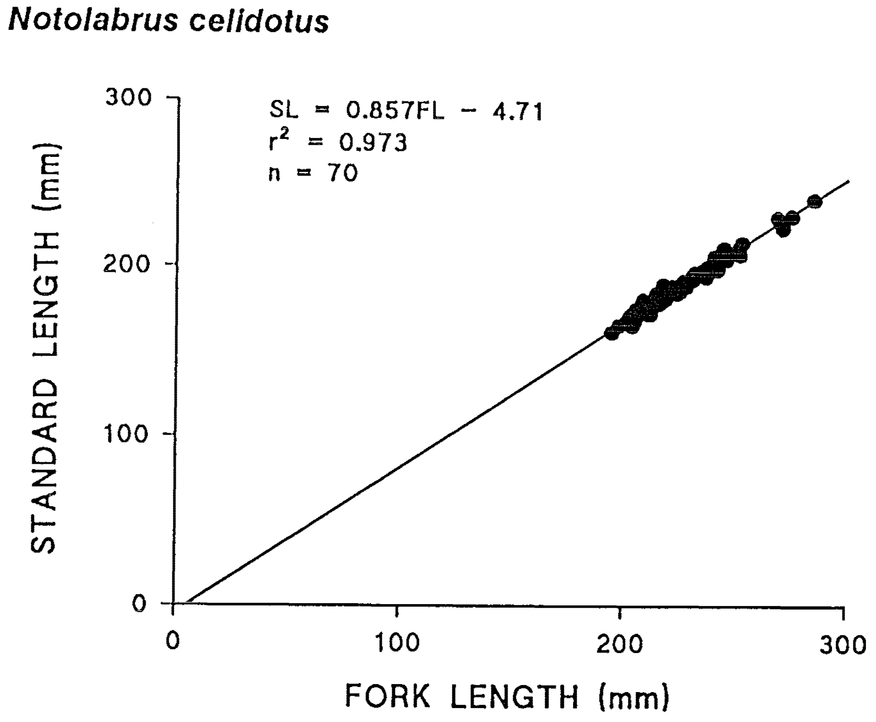


Figure A.3.25 Plot of standard length against fork length for spotties, *Notolabrus celidotus*, caught in gill-nets. Linear regression equation is shown.

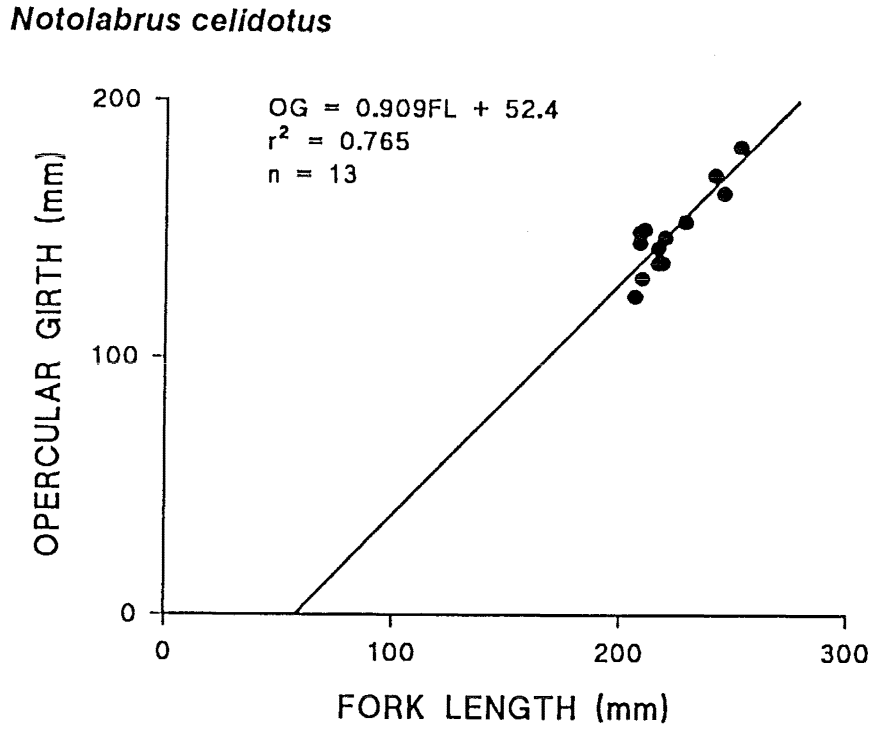


Figure A.3.26 Plot of opercular girth against fork length for spotties, *Notolabrus celidotus*, caught in gill-nets. Linear regression equation is shown.

Notolabrus celidotus

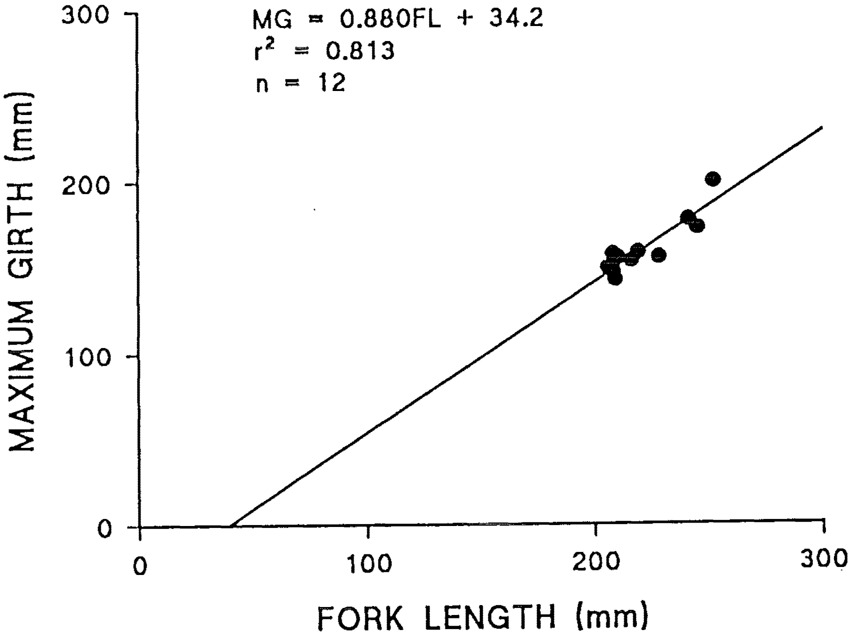


Figure A.3.27 Plot of maximum girth against fork length for spotties, *Notolabrus celidotus*, caught in gill-nets. Linear regression equation is shown.

Notolabrus celidotus - Females

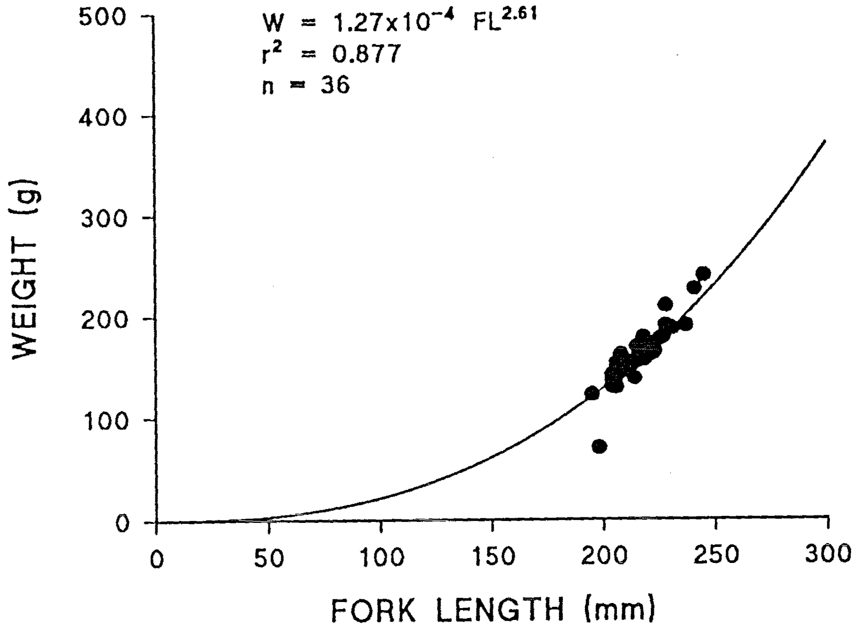


Figure A.3.28 Plot of weight against fork length for female spotties, *Notolabrus celidotus*, caught in gill-nets. Linear regression equation is shown.

Notolabrus celidotus - Males

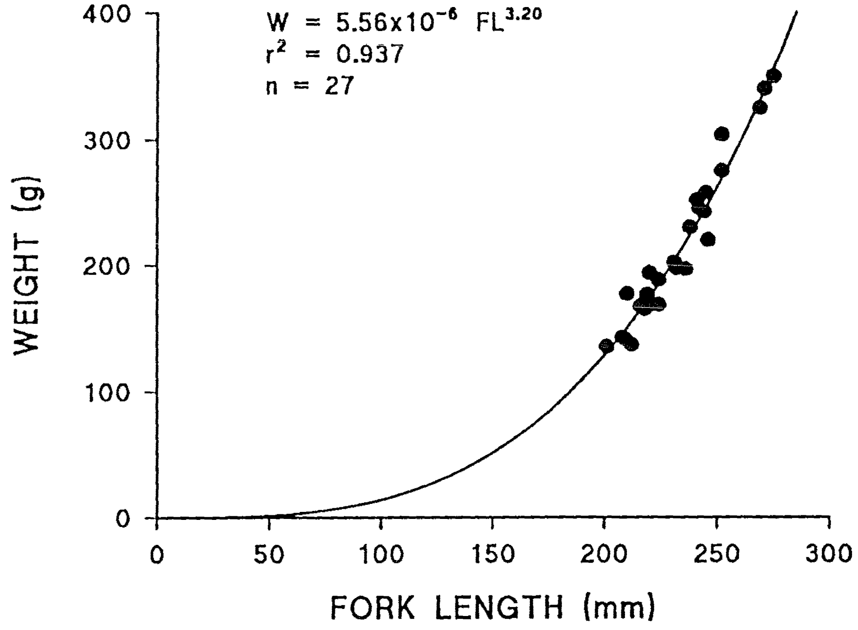


Figure A.3.29 Plot of weight against fork length for male spotties, *Notolabrus celidotus*, caught in gill-nets. Linear regression equation is shown.

Notolabrus fucicola

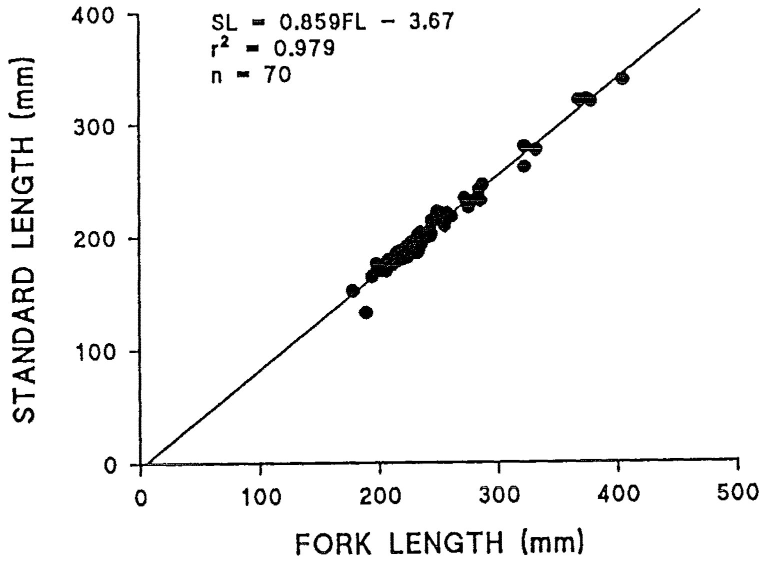


Figure A.3.30 Plot of standard length against fork length for banded wrasse, *Notolabrus fucicola*, caught in gill-nets. Linear regression equation is shown.

Notolabrus fucicola

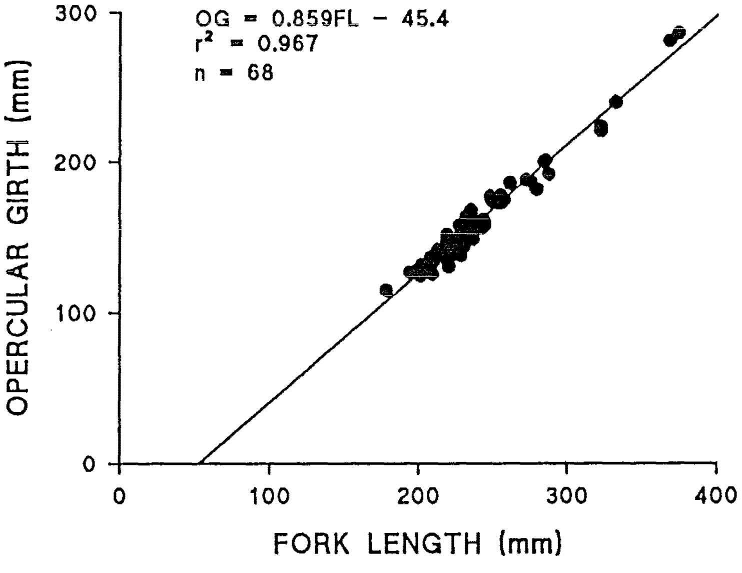


Figure A.3.31 Plot of opercular girth against fork length for banded wrasse, *Notolabrus fucicola*, caught in gill-nets. Linear regression equation is shown.

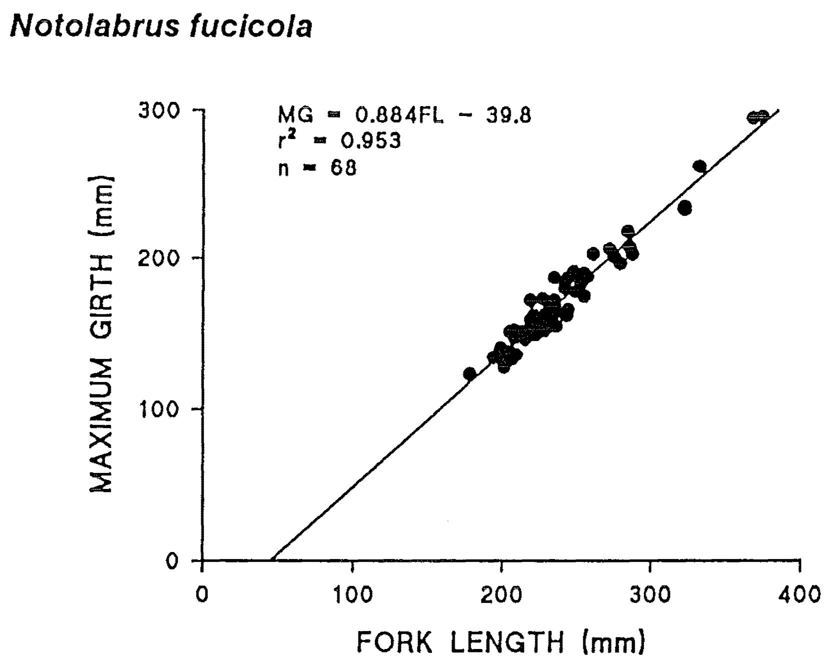


Figure A.3.32 Plot of maximum girth against fork length for banded wrasse, *Notolabrus fucicola*, caught in gill-nets. Linear regression equation is shown.

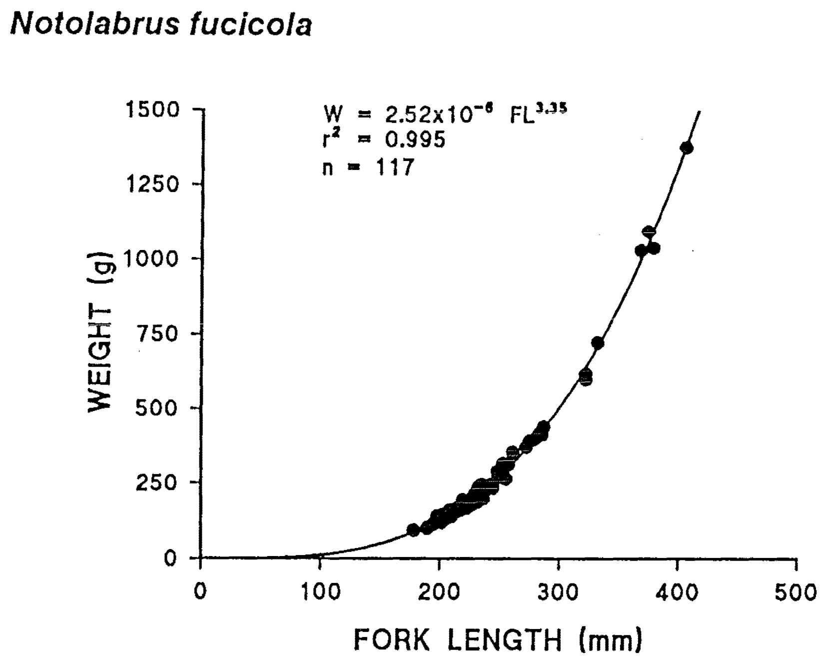


Figure A.3.33 Plot of weight against fork length for banded wrasse, *Notolabrus fucicola*, caught in gill-nets. Linear regression equation is shown.

Odax pullus

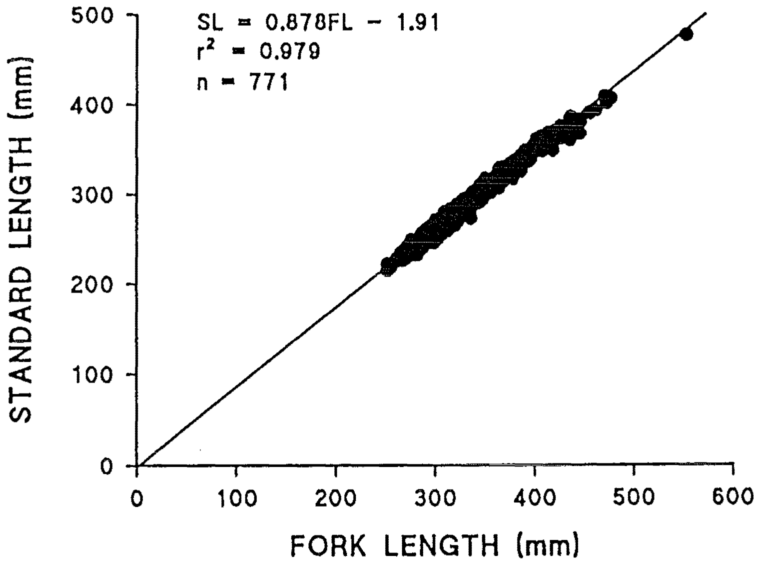


Figure A.3.34 Plot of standard length against fork length for butterfish, *Odax pullus*, caught in gill-nets. Linear regression equation is shown.

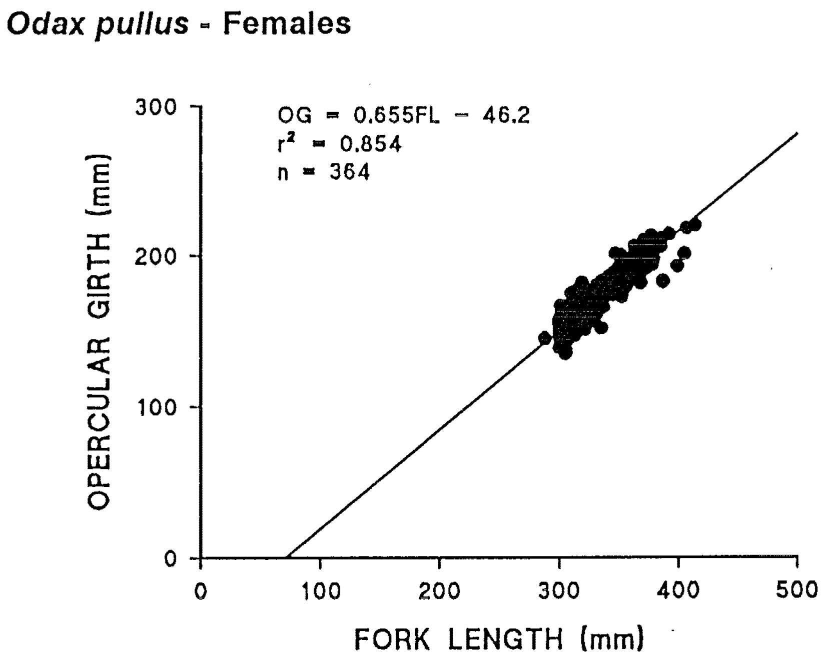


Figure A.3.35 Plot of opercular girth against fork length for female butterfish, *Odax pullus*, caught in gill-nets. Linear regression equation is shown.

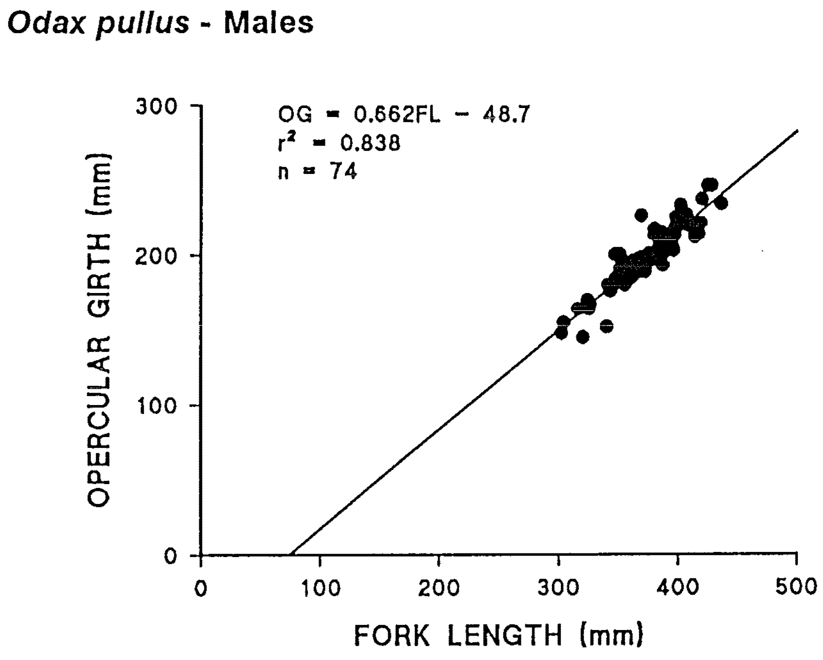


Figure A.3.36 Plot of opercular girth against fork length for male butterfish, *Odax pullus*, caught in gill-nets. Linear regression equation is shown.

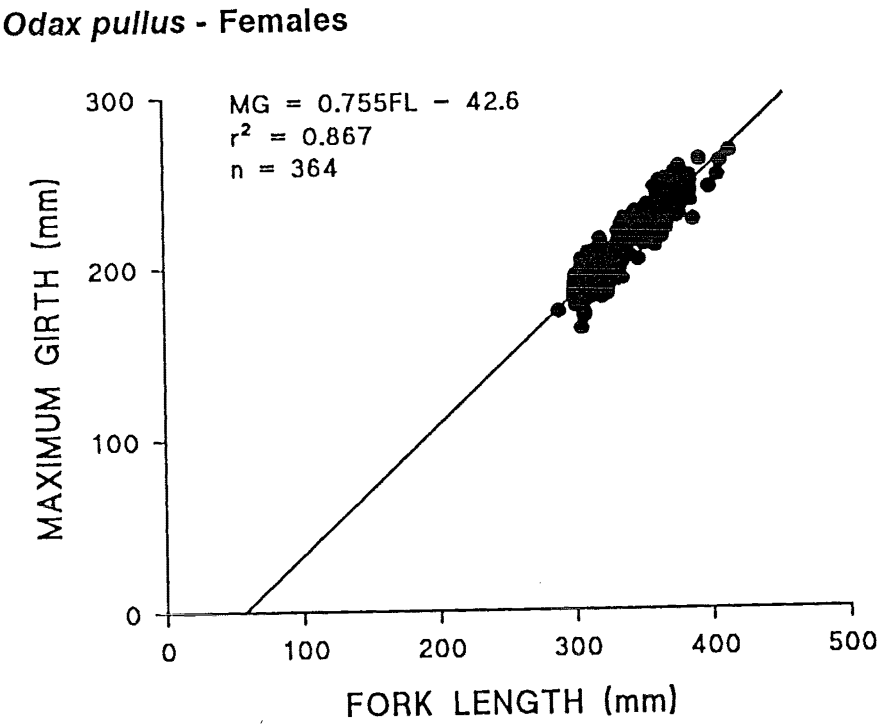


Figure A.3.37 Plot of maximum girth against fork length for female butterfish, *Odax pullus*, caught in gill-nets. Linear regression equation is shown.

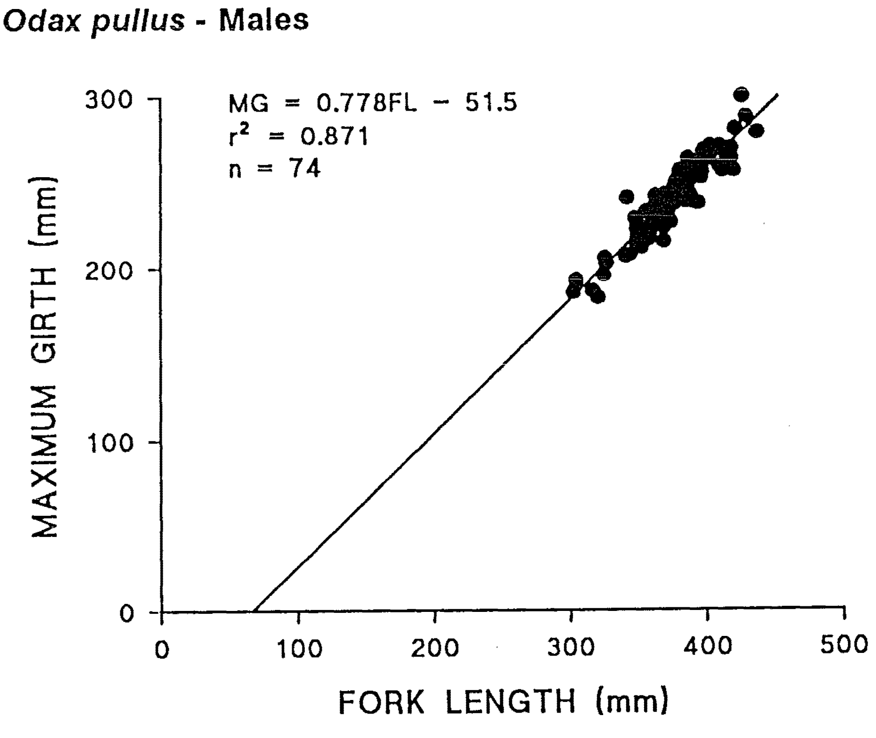


Figure A.3.38 Plot of maximum girth against fork length for male butterfish, *Odax pullus*, caught in gill-nets. Linear regression equation is shown.

Odax pullus **- Females**

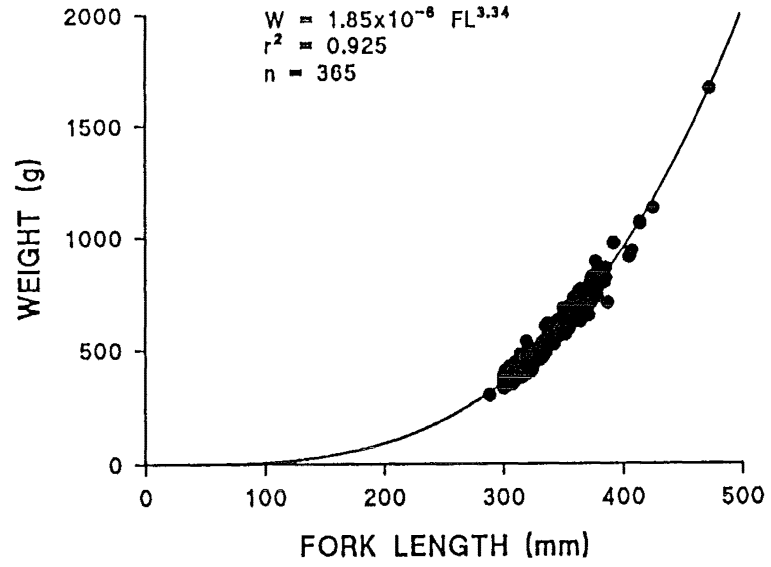


Figure A.3.39 Plot of weight against fork length for female butterfish, *Odax pullus*, caught in gill-nets. Linear regression equation is shown.

Odax pullus **- Males**

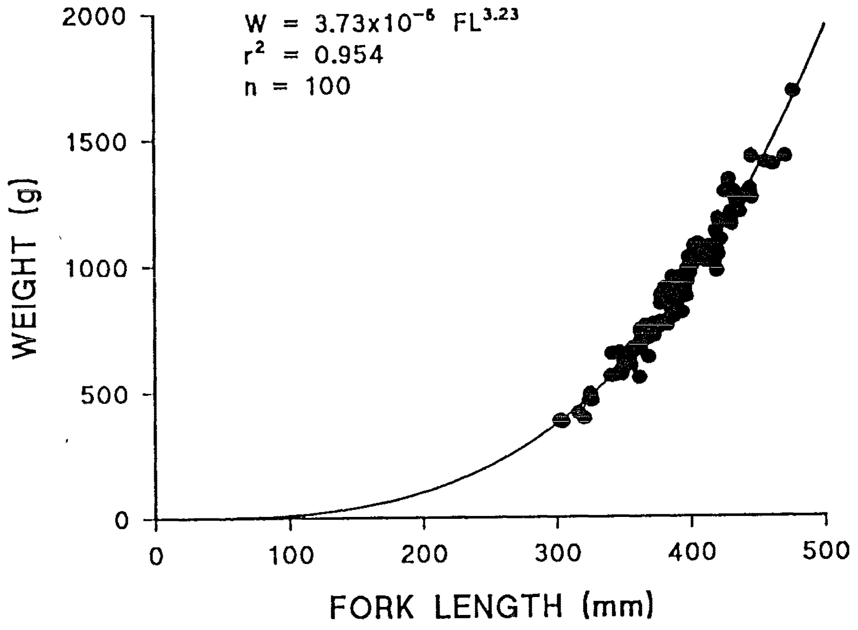


Figure A.3.40 Plot of weight against fork length for male butterfish, *Odax pullus*, caught in gill-nets. Linear regression equation is shown.

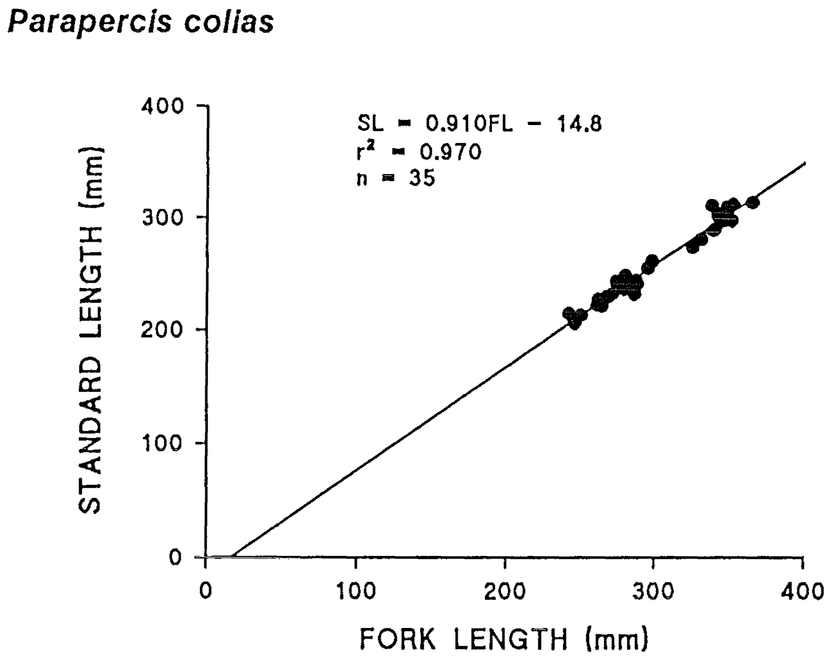


Figure A.3.41 Plot of standard length against fork length for blue cod, *Parapercis colias*, caught in gill-nets. Linear regression equation is shown.

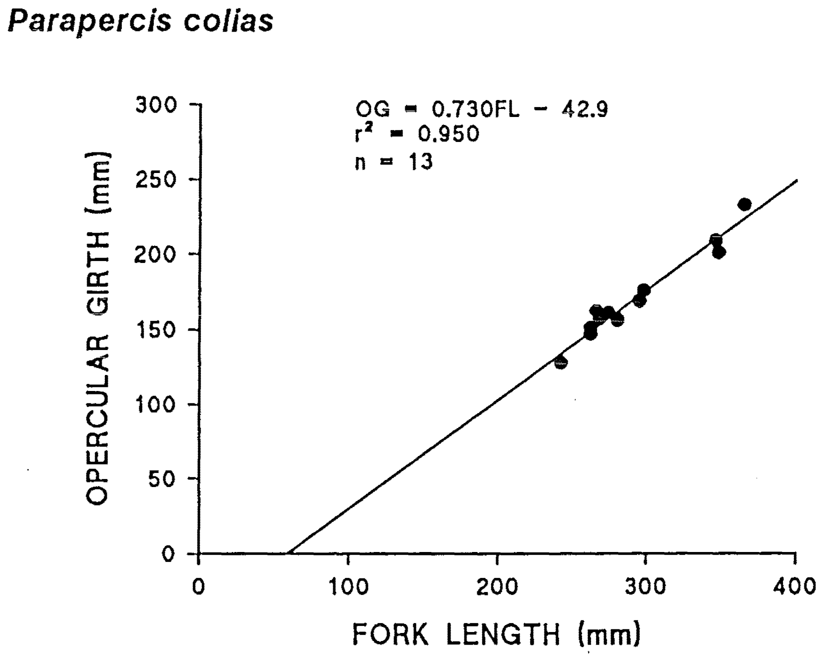


Figure A.3.42 Plot of opercular girth against fork length for blue cod, *Parapercis colias*, caught in gill-nets. Linear regression equation is shown.

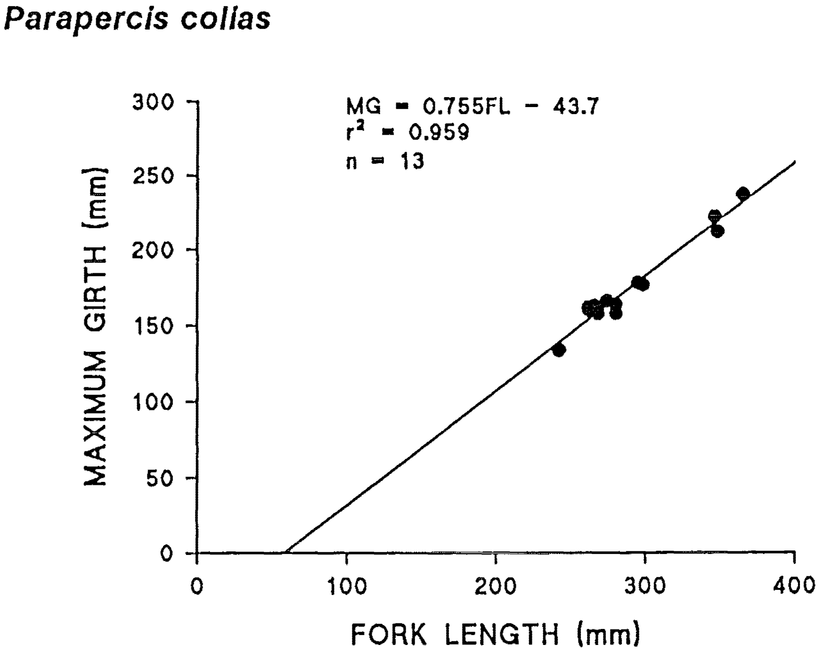


Figure A.3.43 Plot of maximum girth against fork length for blue cod, *Parapercis colias*, caught in gill-nets. Linear regression equation is shown.

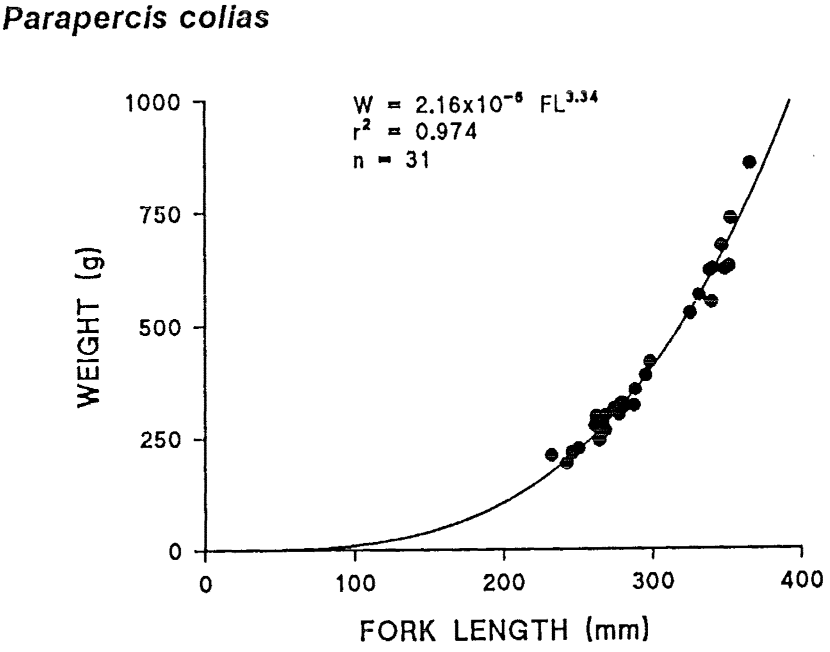


Figure A.3.44 Plot of weight against fork length for blue cod, *Parapercis colias*, caught in gill-nets. Linear regression equation is shown.

Pseudophycis bachus

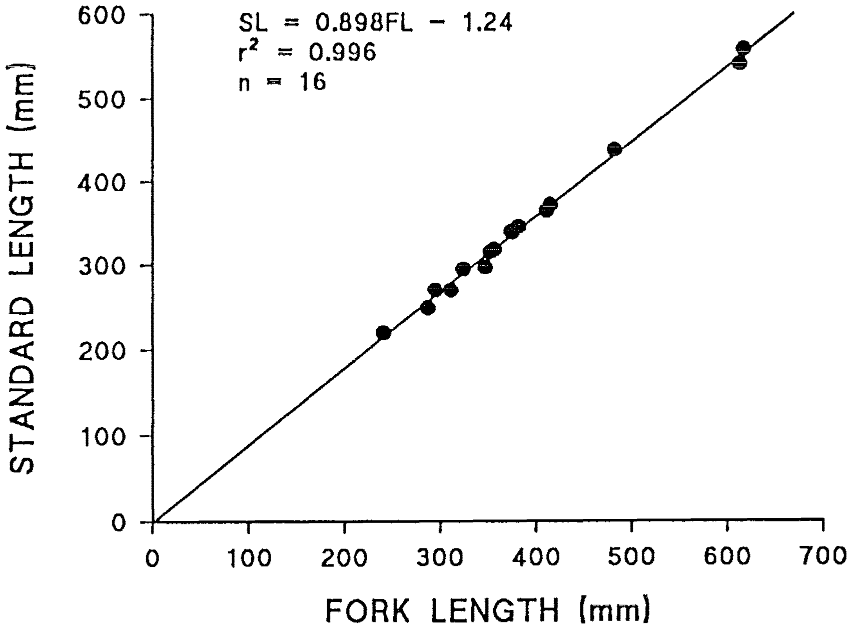


Figure A.3.45 Plot of standard length against fork length for red cod, *Pseudophycis bachus*, caught in gill-nets. Linear regression equation is shown.

Pseudophycis bachus

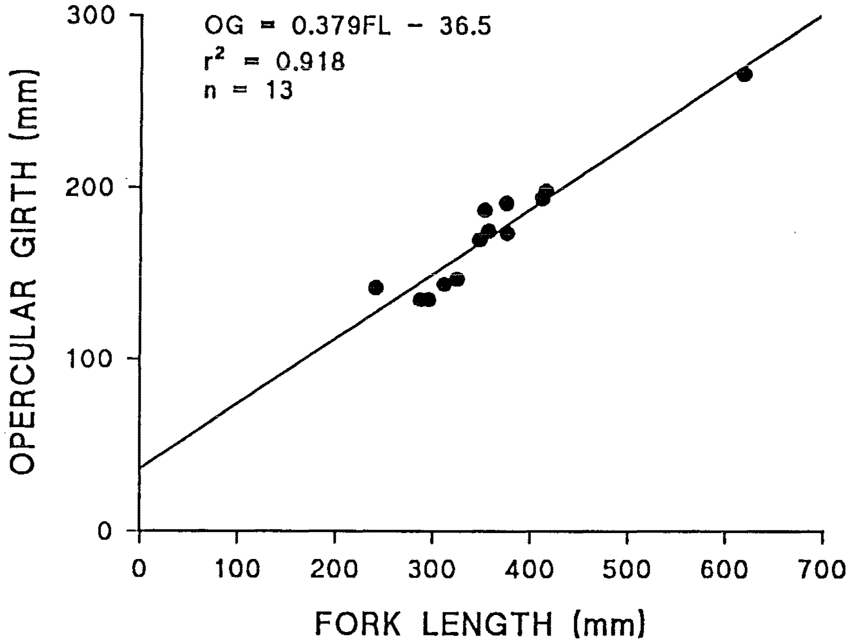


Figure A.3.46 Plot of opercular girth against fork length for red cod, *Pseudophycis bachus*, caught in gill-nets. Linear regression equation is shown.

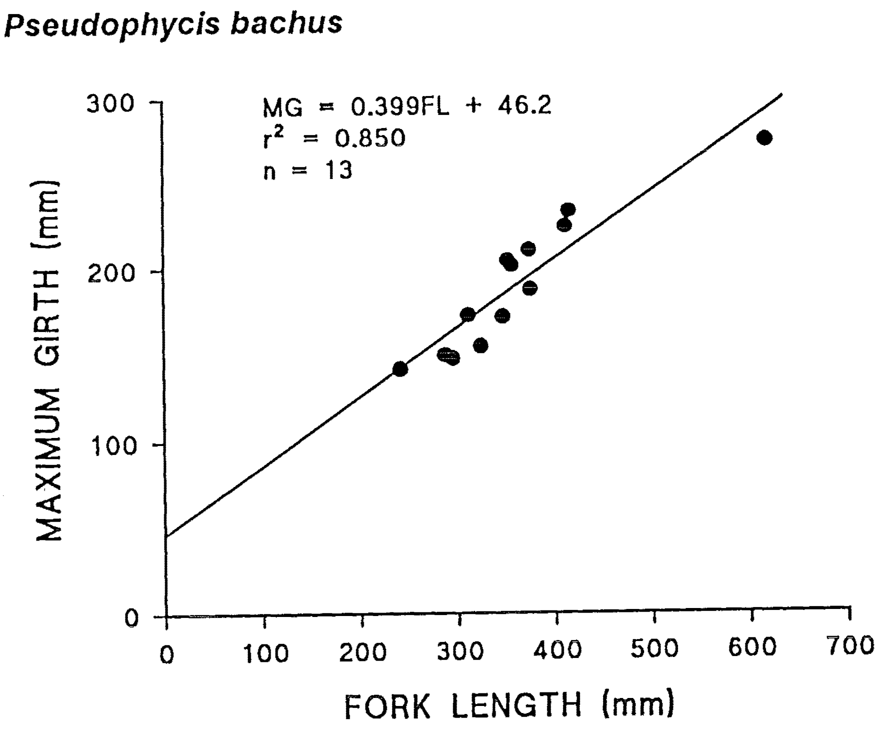


Figure A.3.47 Plot of maximum girth against fork length for red cod, *Pseudophycis bachus*, caught in gill-nets. Linear regression equation is shown.

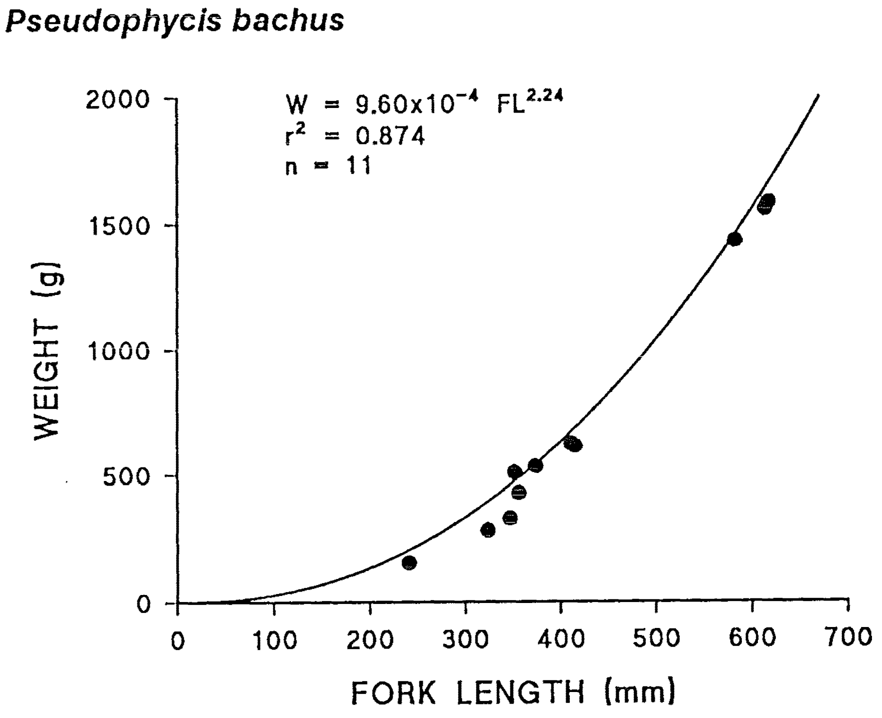


Figure A.3.48 Plot of weight against fork length for red cod, *Pseudophycis bachus*, caught in gill-nets. Linear regression equation is shown.

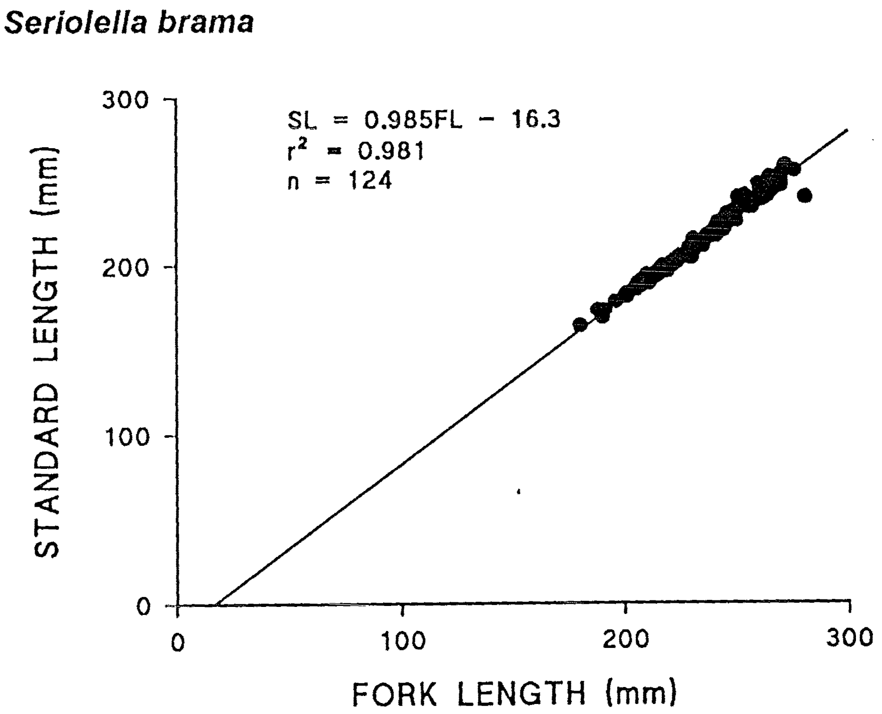


Figure A.3.49 Plot of standard length against fork length for warehou, *Seriolella brama*, caught in gill-nets. Linear regression equation is shown.

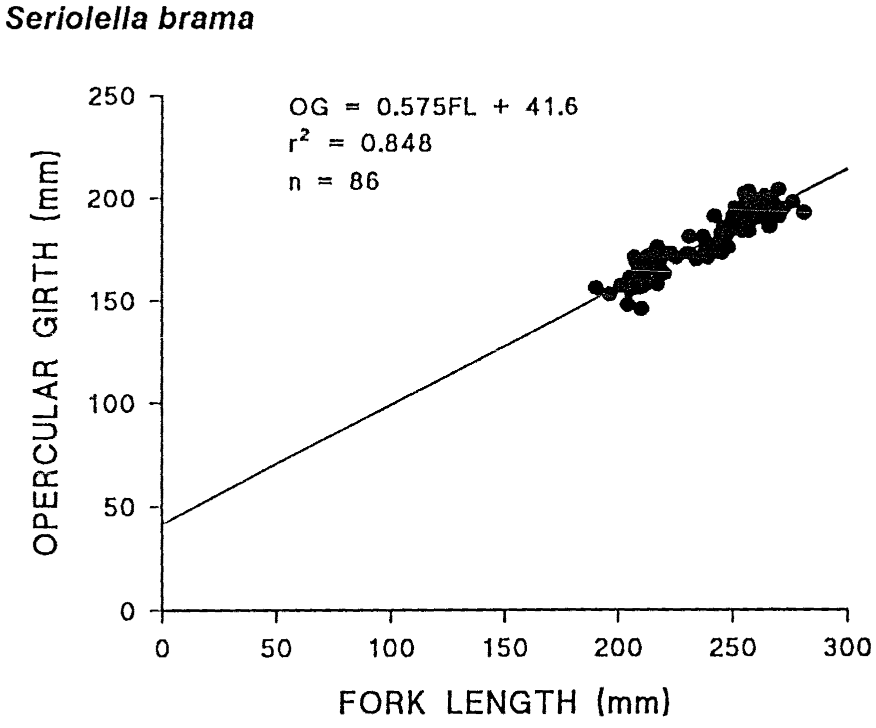


Figure A.3.50 Plot of opercular girth against fork length for warehou, *Seriolella brama*, caught in gill-nets. Linear regression equation is shown.

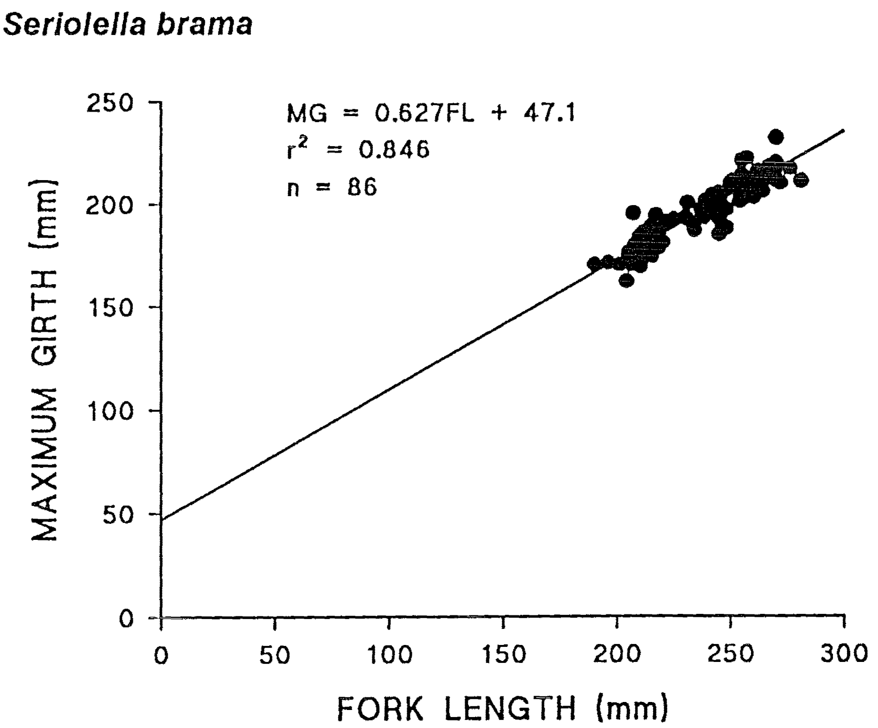


Figure A.3.51 Plot of maximum girth against fork length for warehou, *Seriolella brama*, caught in gill-nets. Linear regression equation is shown.

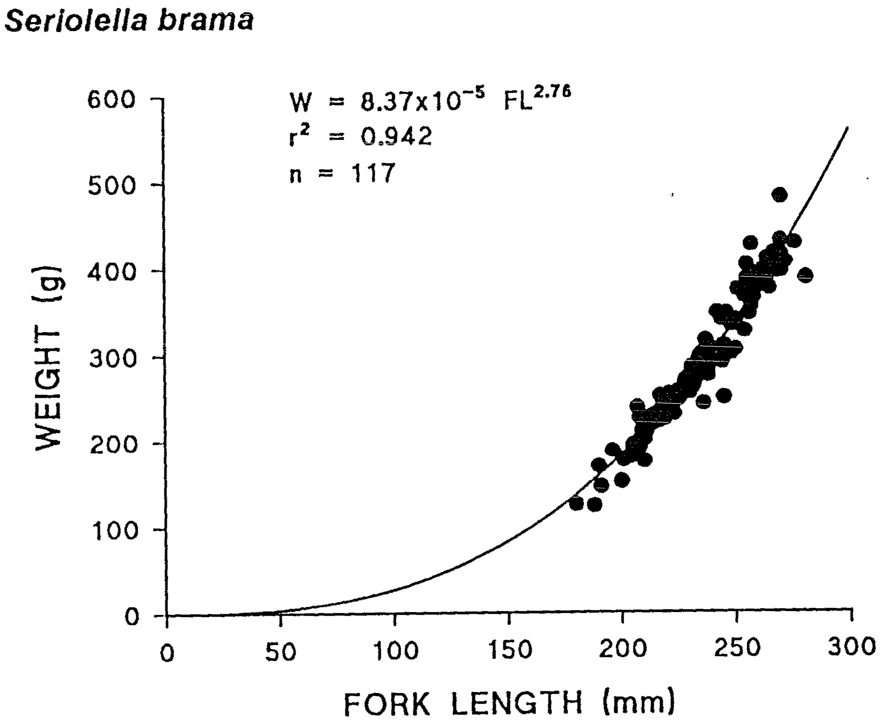


Figure A.3.52 Plot of weight against fork length for warehou, *Seriolella brama*, caught in gill-nets. Linear regression equation is shown.

Trachurus declivis

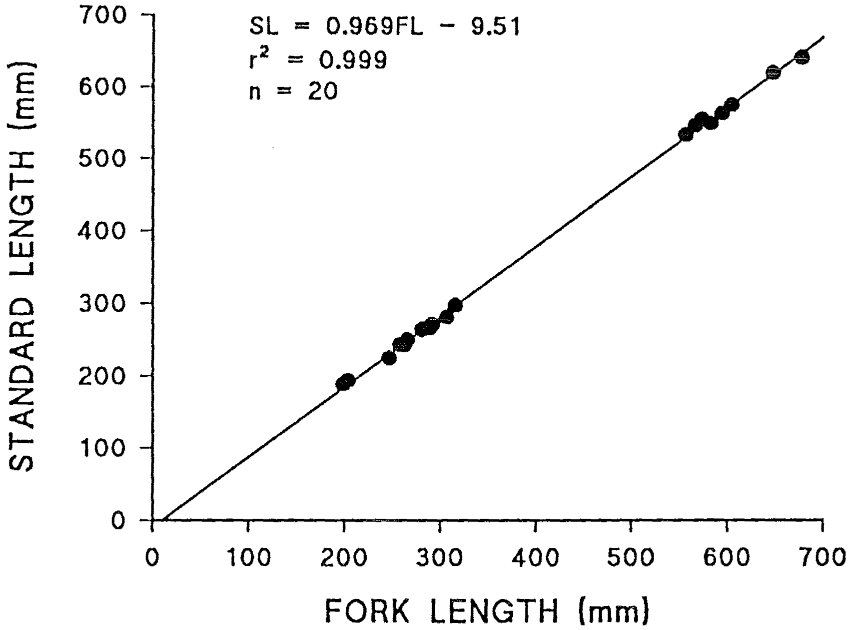


Figure A.3.53 Plot of standard length against fork length for jack mackerel, *Trachurus declivis*, caught in gill-nets. Linear regression equation is shown.

Trachurus declivis

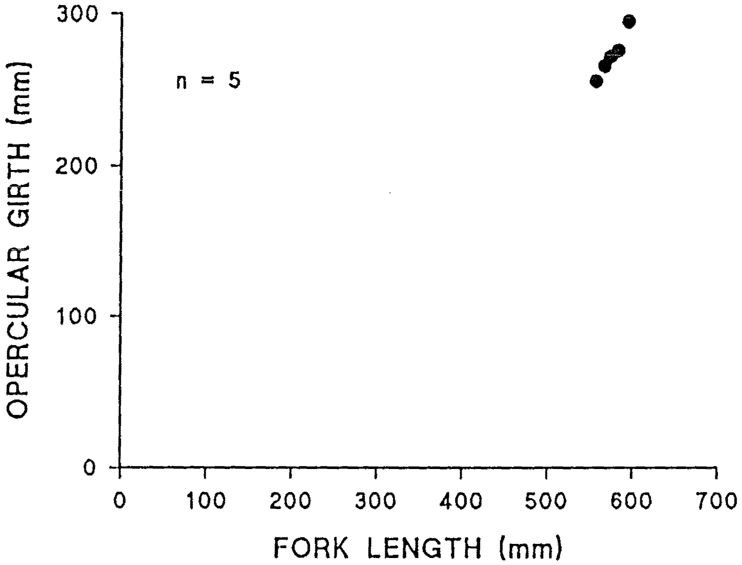


Figure A.3.54 Plot of opercular girth against fork length for jack mackerel, *Trachurus declivis*, caught in gill-nets.

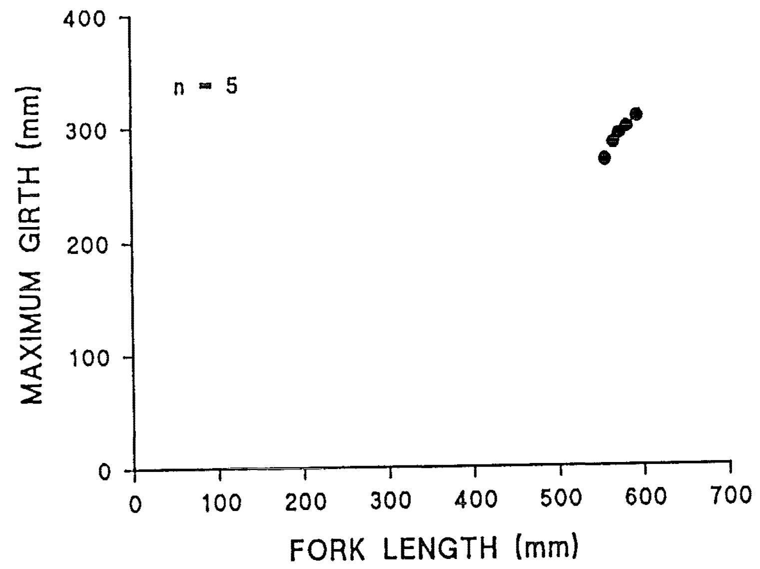

Trachurus declivis

Figure A.3.55 Plot of maximum girth against fork length for jack mackerel, *Trachurus declivis*, caught in gill-nets.

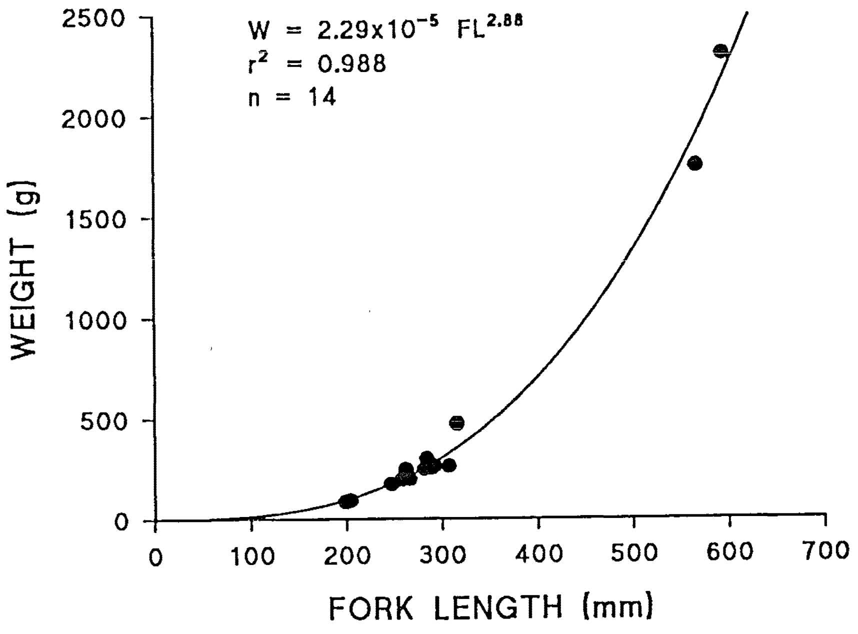

Trachurus declivis

Figure A.3.56 Plot of weight against fork length for jack mackerel, *Trachurus declivis*, caught in gill-nets. Linear regression equation is shown.

A.3.4 DISCUSSION

The regression equations fitted to the morphometric relationships of the eleven species for which more than 10 fish measurements had been made were all significant, and their r^2 values were greater than 0.80 in all cases. Over the range of fish sizes encountered, the relationship between standard length and fork length, maximum girth and fork length, and opercular girth and fork length could be described by a linear regression. Weight and fork length were related by a power function.

The increased variability in girth at larger fork lengths observed in kahawai is likely to be a result of sexual dimorphism in larger mature fish. The relationship between weight and fork length for kahawai has been estimated previously by Jones *et al.*, (1992). Sampling the kahawai stock from the northern South Island, they found that weight was related to fork length by the equation $W = 0.03(FL)^{2.80}$ (weight in g, fork length in cm). The regression equation for weight against fork length derived from this project estimates a weight at a given length slightly less than that estimated by the equation derived by Jones *et al.* (1992).

The relationship between weight and fork length in blue moki has been described previously by Francis (1979). He found the weight of blue moki to obey the equation $W = 0.055(FL)^{2.713}$ (weight in g, fork length in cm). This equation describes a blue moki population that appears to be considerably heavier at a given length than those caught during this study.

M^c^Gregor (1988) described the relationship between length and weight for both male and female blue cod in the south of the South Island. He found that the relationship in female blue cod was described by the equation $W = 0.02(FL)^{2.95}$ and for males $W = 0.01(FL)^{3.10}$ (weight in g, fork length in cm). Because the sample o blue cod caught during this project was not separated by sex, the results are not directly comparable. However, the relationships appear to be similar.

Jack mackerel have been described by Horn (1991), who found the relationship between length and weight to be described by the equation $W = 0.023(FL)^{2.84}$ (weight in g, fork length in cm). The relationship determined in this study, although derived from a small sample size, appears to be very similar to this result.

The size selectivity of gill-nets resulted in relatively narrow size ranges of each species being caught in the nets. Although not ideal for determining widely applicable morphometric relationships, the analysis of this catch provides some insight into several species that have not previously been described morphologically.

APPENDIX FOUR

Gill-nets and Non-Fish Species

During this study, several non-fish species were observed in the vicinity of gill-nets. Like most information on the interactions of non-fish species with gill-nets, these observations are purely anecdotal. However, they may contribute some unbiased information to an often emotive topic.

A.4.1 Sea-birds

Sea-birds which feed by diving are vulnerable to becoming caught in gill-nets that are set near the surface or in shallow water. Lalas (1991) suggested that wing-propelled divers (e.g., penguins and shearwaters) were more vulnerable to gill-net entanglement than foot propelled divers (e.g., shags) because they present a larger body profile, reach higher speeds and often feed in groups. It is generally assumed that sea-birds become entangled and drown in nets that they unexpectedly encounter during a dive. However, DeGange & Newby (1980) described the apparent attraction of albatross, fulmar and petrels to organisms entangled in a lost pelagic gill-net. "Whether sea-birds are similarly attracted to actively fishing gill-nets, where levels of decomposing and encrusting organisms are low, is unknown" (Taylor, 1992).

During this study two black shags, *Phalacrocorax carbo*, were observed actively feeding on live kahawai, *Arripis trutta*, caught in a gill-net. Three gill-nets had been set in 7 m of water and were c. 60 m from shore on the northern side of the Kaikoura Peninsula. There were several exposed rocks near the nets, and solitary shags were observed to be sunning themselves on these. The gill-nets were being used for the study of fish behaviour in the vicinity of nets, and two divers were swimming along the nets observing fish. The first shag was observed to dive and swim along the 3.5" net until it reached a fish that it pecked at, and then surfaced. The second shag was observed by a diver to dive repeatedly and feed on a single fish caught in the upper region of the 3.5" gill-net (c. 5 m below the surface).

These observations suggest that certain species of sea-birds may be attracted to gill-nets by the presence of fish caught in the nets. If this is the case, these species may be more vulnerable to entanglement in gill-nets. It seems unlikely that this behaviour would occur with bottom set gill-nets in deeper water, particularly in murky conditions, where the sea-birds would have little chance of seeing the fish or of being capable of diving to a sufficient depth to become caught.

A.4.2 Cetaceans

The possibility of marine mammals actively feeding on the catch of gill-nets has been suggested by Dawson (1990). He stated that "in some cases marine mammals appear to feed directly on fish caught in gill-nets or on the scavengers of trapped fish". Marine mammals that feed on fish caught in gill-nets are likely to be more vulnerable to capture in gill-nets.

During this study, a solitary bottlenose dolphin, *Tursiops truncatus*, took up residence in the inshore water around the Kaikoura Peninsula. The dolphin was injured when first observed, and was thought to have been separated or ejected from its pod. The dolphin was attracted to the boat traffic around the Peninsula and closely followed fishing boats as they left the slipways (a second injury was thought to be caused by the dolphin being hit by a propeller).

The bottlenose dolphin often accompanied our research boat while gill-nets were being set and retrieved. It was particularly attracted to the buoy ropes, which it would follow down from the surface. Often the dolphin was observed to take bites from fish as they were brought to the surface (Plate A.4.1), and to chase fish that fell from the net during hauling. The dolphin always appeared to be aware of the nets' presence, and at no stage was it observed to be in danger of becoming tangled. Even with nine 30 metre gill-nets set in an area less than 100 m x 100 m, the dolphin managed to negotiate, and apparently feed among, the nets.

The dolphin was also observed by divers twice during the behaviour study around the gill-nets. On both occasions the nets were in 12 m of water on a heavily convoluted, algal dominated broken reef. The dolphin was observed to keep at

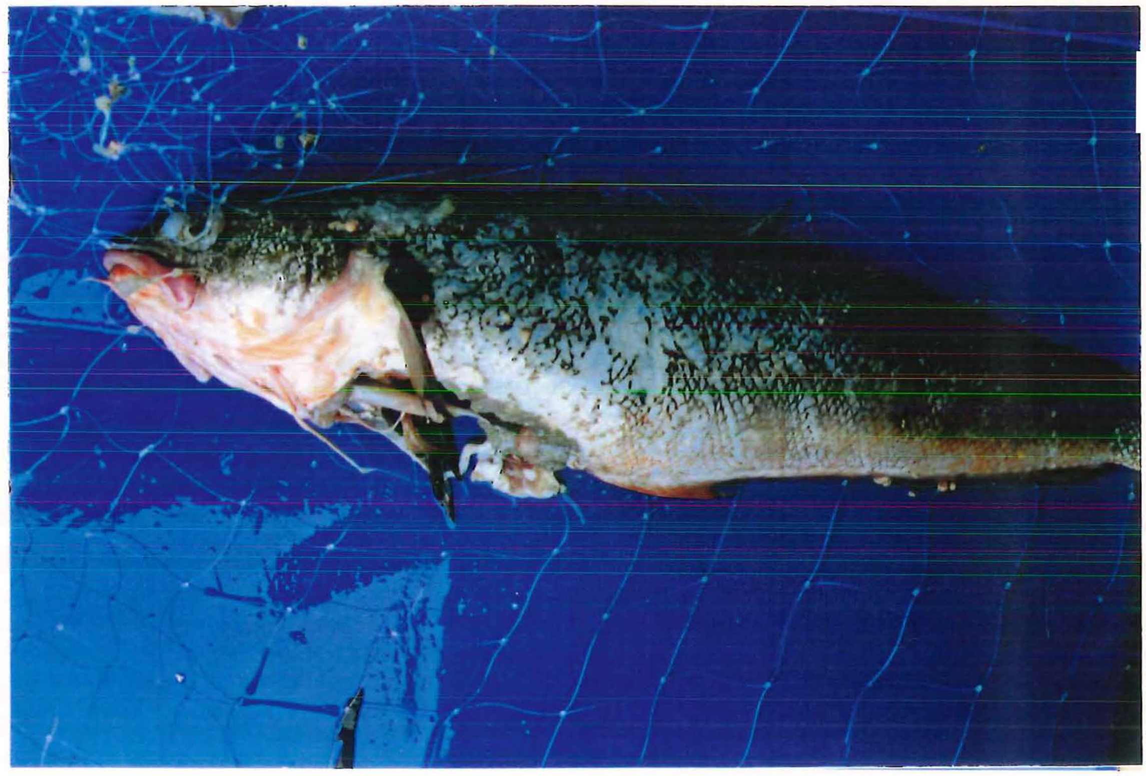


Plate A.4.1 A red cod, *Pseudophycis bachus*, which was observed to be bitten by the bottlenose dolphin, *Tursiops truncatus*, while the gill-net was being hauled.

least two metres away from any part of the net at all times, and on these occasions did not appear interested in the fish caught in the net.

Although this dolphin's behaviour around gill-nets suggested it was relatively invulnerable to becoming tangled, her reactions to gill-nets may have been atypical, as indeed was most of her behaviour (Dawson, pers. comm.). Its behaviour of closely following fishers before and after setting their nets suggests she would have been very familiar with gill-nets. Unfamiliarity with nets and failing to perceive them as dangerous obstacles are thought to be important factors in entanglement (Au & Jones, 1991; Dawson, in press). Various studies have shown that young age-classes of cetaceans are over-represented in entanglement data, suggesting inexperience is likely to be a contributing factor to entanglement.

A.4.3 Crustacea

Gill-nets appear to be very effective at entangling crustaceans. Numerous crayfish, *Jasus edwardsii*, were caught in the gill-nets during overnight sets around the Kaikoura Peninsula. These animals were often tangled close to a badly damaged fish, suggesting that they may have been feeding on fish caught in the gill-nets. Mostly undersize, the crayfish were usually still alive when removed from the nets and could be returned to the sea relatively undamaged. Crayfish are nocturnal feeders (Gunson, 1983) and were usually caught during night sets; however several were also caught during the day. The red rock crab, *Plagusia chabrus*, was frequently tangled in the gill-nets. This species occupies much the same habitat as the crayfish (Heath & Dell, 1971), and is more active towards dusk. The red rock crab feeds mainly on worms and amphipods (Morton & Miller, 1968). Therefore, it is unlikely to be caught while feeding on fish in the net and may simply become tangled while foraging on the sea floor.

A.4.4 Ghost fishing

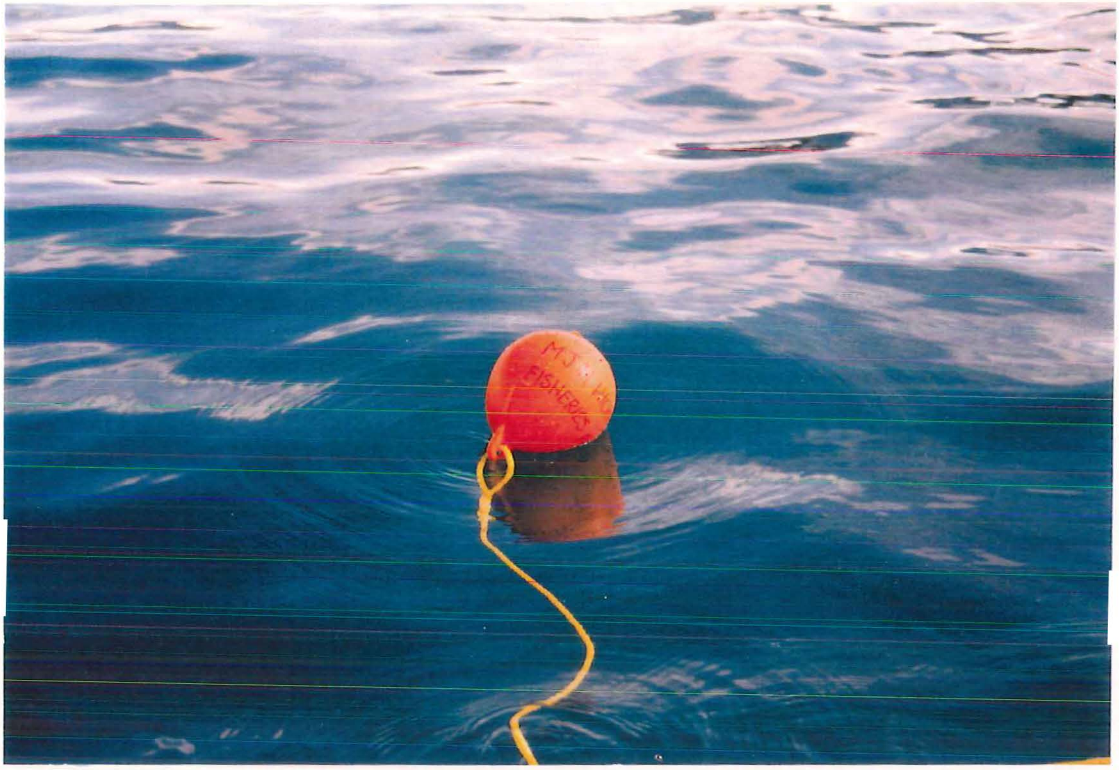
The gill-nets used during this study were set 251 times over the space of twelve months. Because these nets were well anchored, well maintained and not left out during storms, no nets were lost during the study. However, the loss of commercial and especially amateur gill-nets is a common occurrence around the coast of New Zealand. Gill-nets are usually made from synthetic materials that can last for long periods of time. High (1985) observed that lost salmon gill-nets continued to kill birds and fish for 3 years, and estimated that crabs may be killed for at least 6 years. Walshe (1980) observed high fish catches in ghost nets initially, but after 100 days of fishing the catch dropped to a low plateau level, with less than 10 fish being caught every two week period. A decline in the area of net fishing caused the observed decline in the catch rate of the net. This decrease in fishing area was caused by the entanglement of fish and algae in the mesh. The fishing area of the net also will decrease if the anchors drag.

During this study an environmental group in Kaikoura organised a clean up of beaches and the subtidal region. The clean up was designed to remove several known nets from around the Peninsula (previously observed by divers), and to remove debris from local beaches. Several nets were located and recovered. Three nets were found on beaches around the peninsula. These nets were badly tangled and contained no algae or fish. Two nets were retrieved from the subtidal zone. These nets were both badly tangled when found, and were both wedged under rock ledges. Neither net was found to contain fish remains or large crustaceans when cut open. Both nets were heavily tangled with algae (Plate A.4.2), but only one still had its anchors attached. The coralline algae growth on the floats of the nets suggested each had been lost for a considerable period (Plate A.4.3). When the interior of one net was examined, it was found to contain numerous polychaete worms. The net also provided refuge for several juvenile sea urchins, *Evechinus chloroticus*, and spider crabs, *Elamena producta* (Plate A.4.3).

It is unlikely that ghost nets would fish for any length of time along the Kaikoura coast. The heavy wave action and frequent storms would soon act to tangle the net, and either wash it up on a beach or wedge it into a crevasse. The large quantities of drift algae that result from the heavy wave action around Kaikoura would quickly become entangled in a net and pull it to the sea bed, where it would soon become tangled and inefficient. Experiences from this study have shown that well maintained nets that are heavily anchored and carefully used stand very little chance of becoming lost, even in rough sea conditions.

Plate A.4.2 One of the two ghost nets retrieved from the sub-tidal zone around the Kaikoura Peninsula. The net is heavily tangled with *Carpophyllum maschalocarpum* and red algae.

Plate A.4.3 The interior of one of the lost nets that was retrieved by divers. The crustose coralline algae on the float suggests the net may have been lost for a considerable period of time. A juvenile sea urchin, *Evechinus chloroticus*, and a spider crab, *Elamena producta*, found within the net are shown.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