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Catch vs count: Effects of gill-netting on reef fish populations in southern New Zealand

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Abstract

This study investigated the relationships between visual counts of fishes and the catch from gill-nets on rocky reefs in southern New Zealand. Visual censuses were done and then gill-nets of three mesh sizes (2.5″, 3.5″ and 4.5″) were set in the surveyed areas. There were significant differences among habitats in the assemblages of reef fishes. The number and species of fishes caught by the gill-nets had little overlap with those recorded in visual surveys. The standard lengths of fishes caught in gill-nets were significantly larger than those recorded in the visual surveys, primarily because of differences in the species composition of fishes sampled by the two methods. Resident reef fishes, especially labrids, comprised most of the visual surveys, while transient pelagic species and wide-ranging reef fishes made up the largest proportion of the gill-net catch. The three mesh sizes caught different size fractions of fish populations, but all mesh sizes caught fishes larger than those seen in the visual surveys. There was a significant species × mesh size interaction in the number of fishes caught, indicating that some species were more vulnerable to particular mesh sizes. Both the number of fishes and number of species caught declined sequentially with increasing mesh size. This study shows that visual surveys and the more passive gill-netting sample different fractions of fish populations, and that gill-netting is ineffective at targeting individual species in complex reef habitats.

Keywords: By-catch; Gill-net; New Zealand; Reef fishes; Selectivity; Targeting

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1. Introduction

Gill-nets are commonly used in New Zealand for both commercial and recreational fishing inshore, but few data are available on the composition of nearshore fish assemblages and what fraction of these is susceptible to gill-netting. Because nearshore

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habitats can be diverse and have large effects on the number and species of fishes, it is likely that the effects of gill-netting will be habitat-specific. For example, rocky reef environments in temperate waters support a wide variety of fish species that are dependent on the reef substratum, kelp and associated crustaceans for food and shelter. 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 (Kingett & Choat, 1981; Jones, 1984a,b,c; Choat & Ayling, 1987; Levin, 1993; Carr, 1994).

The problem of comparing fish assemblages on reefs with the portion caught by gill-netting in southern New Zealand is complicated by the fact that most studies of reef fishes in New Zealand have been done in the northeast of the North Island (review in Jones, 1988). Relatively little work on reef fish populations has been done in southern areas, where algal populations have a different biological composition and the large echinoid-dominated areas common in northern localities are reduced to small patches (Schiel, 1990). Despite these obvious differences only very general descriptions are available of the fish fauna associated with rocky reefs in southern New Zealand (Ayling & Cox, 1987; Francis, 1988).

Gill-nets are often used to assess the species and size composition of fish populations (Hamley, 1975; Ricker, 1975; Ryan & Kerekes, 1989). However, little is known about the fraction of actual fish populations that is caught by gill-nets. Studies on the selectivity of nets have been restricted to individual fish species and have concentrated on size selection (review,in Hamley, 1975). Most studies have relied on "indirectly" estimating gill-net selectivity by fishing with several different mesh sizes and comparing the catch, while a few studies have estimated gill-net selectivity "directly" by fishing known (tagged) populations (Koike, 1961; Cucin & Regier, 1966; Sechin, 1969).

The aims of our study were to compare the fish populations seen in visual counts on nearshore reefs with the fishes caught in gill-nets set on those reefs to identify which species or size classes of reef fishes were vulnerable to gill-netting and determine how vulnerability was affected by different habitats.

2. Methods

2.1. Study sites

The study was done from 13 February 1992 to 21 January 1993 around Kaikoura, a large peninsula on the east coast of the South Island (Fig. 1). This region marks the northernmost position of the Subtropical Convergence, also known as the Southland Front (Heath, 1985), and is frequently exposed to high energy oceanic swells and storm waves. Annual water temperatures range from 8.5 °C to 19 °C (Ottaway, 1976). Because there is considerable agricultural run-off and the dominant rock type in the area is limestone, there are often heavy sediment loads in inshore waters, making underwater visibility usually poor. Furthermore, the composition of the underwater habitats, particularly rocky pinnacles with reef and gravel between them, often make it difficult to keep long transects within single habitat types. It was therefore necessary to derive a

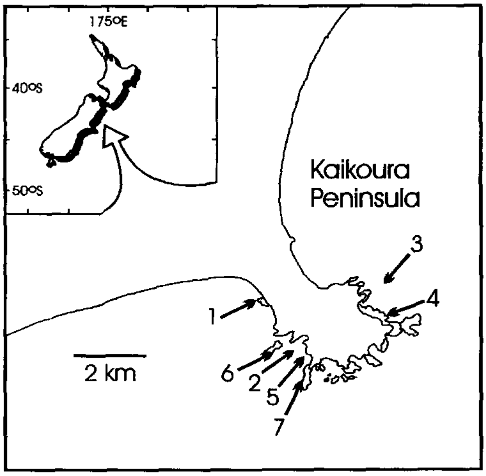


Fig. 1. The Kaikoura Peninsula on the east coast of the South Island of New Zealand with the seven study sites shown (see Fig. 5 for habitat descriptions).

sample unit that optimised the precision of estimates of reef fish numbers in average conditions, while keeping within logistical constraints (McCormick & Choat, 1987).

2.2. *Sampling methods*

A fibreglass surveyor's tape was laid out along the substratum from randomly-selected starting points and in an arbitrarily-chosen direction on a reef (Leum & Choat, 1980; Choat & Ayling, 1987; Kingsford et al., 1989). The precision and effort of five strip-transect sizes (50 m × 5 m, 40 m × 5 m, 30 m × 5 m, 20 m × 5 m, 10 m × 5 m) were compared. A 5-m wide transect (i.e. 2.5 m either side of the transect line) was chosen because it allowed fishes to be counted in most diveable conditions. Three replicates of each transect size were done on the same reef area at 15 different sites, encompassing different substrata and algal types, to allow for general application of the transect size optimisation throughout the subsequent study. The species and standard length of all reef fishes (excluding small benthic fishes) seen in each transect were recorded. The precision, calculated as the standard error divided by the mean density estimate of the three replicate transects (Downing & Anderson, 1985; McCormick & Choat, 1987), 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 15 different sites. Precision was determined for total fish numbers, and individually for the two most common species, the labrids *Notolabrus celidotus* and *Notolabrus fucicola*.

2.3. *Fish assemblage and habitat structure*

Before we could do experimental work, it was necessary to categorise habitats. From preliminary surveys, five basic habitat types were identified: (1) rocky pinnacles with mixed algae at depths of 0–20 m; (2) rocky reef with *Marginariella boryana* stands at

5–10 m; (3) flat reef with a carpet of understory algal species at 0–10 m; 4) rocky reef dominated by crustose coralline algae at 15–20 m; and 5) sandy bottom with small patch reefs dominated by coralline turf at 5–20 m.

Three of these habitats (rocky reef with *M. boryana* stands, flat reef with carpet of understory algal species and rocky reef with crustose coralline algae) occurred only in discreet depth bands, while two habitats (rocky pinnacles with mixed algae and sandy bottom with small patch reefs) were observed across a range of depths. Subsampling within these two habitats at several depths revealed no significant differences in species composition or abundance so the results were pooled across depths. The apparent consistency of reef fish assemblages at different depths within these two habitats was probably due to the abrupt topography of reefs in the region. Rocky pinnacles and steep-sided reefs resulted in large depth changes over a small horizontal scale, obscuring depth-related patterns of fish abundance.

The abundance of fishes was assessed at 36 sites along the northeast coast of the South Island, encompassing the five habitat types. At each site, visual transects were done by divers using the optimised design described below. Each set of transects was done within a single habitat. The species identity and standard length of each fish were recorded. Because of the heterogeneous nature of the coastline, each habitat type was not found within each site.

The abundance of each species and the total fish numbers within each habitat were analysed with ANOVA. Before comparisons were made, Cochran's tests for homogeneity of variances were done and, where appropriate, transformations of data were done prior to analysis. The total number of species in each habitat was also analysed with ANOVA. Treatment means were compared with the Tukey-Kramer method. Species associations were assessed with correlation analysis.

2.4. *Effects of gill-nets*

To test the effects of differing mesh sizes of gill-nets on fish populations, and whether these effects varied among sites, seven sites that encompassed the five main habitat types previously identified were selected for experimental fishing (Fig. 1). Five 30 × 5 m visual transects were censused at each site and the species, number and standard length of all reef fishes seen in the transects were recorded. The experiment was done over 10 days from 17 February 1993 to 27 February 1993. At each site, the visual counts were completed between 0800 and 1000, and the area of the counts was marked with a surface buoy. On the same day, nine gill-nets were set randomly at the marked site. The nets were set from a 6-m boat and hauled by hand. Each net was set in a random direction and the ends were anchored with concrete weights and marked with surface buoys. At least 10 m separated each net. Three replicate nets of each of three mesh sizes (Table 1) were set for 6 h from late morning to late afternoon. The mesh sizes were those commonly available in New Zealand. At the completion of each set, the nets were taken back to the laboratory with the fishes still entangled in them. The fishes were removed and measured. The combined catch at each site was derived by pooling the catch from one randomly-selected net of each mesh size, yielding three replicates of combined mesh sizes at each site.

Table 1
The dimensions of the gill-nets used for experimental fishing

Dimension	Measurement		
Mesh size (inches)	2.5	3.5	4.5
Net length (m)	30	30	30
Net height (m)	1.80	1.75	1.72
Filament size (mm)	0.30	0.48	0.58

Mesh size is given in inches by the manufacturers and is measured as the diagonal length of a stretched mesh. Filament size is the diameter of the monofilament.

Comparisons of species richness and abundance observed during the visual counts and in the subsequent gill-net catch at each site are presented graphically. The number of fish from each species observed in each of the five transects at each site was compared with ANOVA, and the Tukey-Kramer method was used to test differences between treatment means. Correlation analyses were done on the total number of fish and species counted and caught at each site, the total number of each species counted and caught, and on the proportion of the total count and catch that each species comprised. The total number of fish and species caught in each mesh size was compared with a two-way (mesh × species) 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, transformed data were used.

3. Results

3.1. Fish assemblage and habitat structure

Variability of population estimates decreased with increasing transect size (Fig. 2). Transects of 30×5 m were used since they provided representative samples while allowing more replicates per dive.

Eleven species of reef fishes were recorded during the visual surveys of 36 sites (Table 2). Pooling sites by habitat showed that there was considerable variation in abundance of fish species across the five habitats (Fig. 3). *Notolabrus celidotus* was the most abundant fish in all habitats except rocky reef with crustose coralline algae. There were significant differences in the abundance of *Notolabrus celidotus* among habitats ($F_{4,175} = 8.38$, $p < 0.001$), with greatest densities of around 23 fish per 150 m^2 occurring in Habitat 5, with sandy bottom and patch reefs. The two species of 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 (15–20 m depth) than in the other habitats. The three large carnivores *Nemadactylus macropterus* ($F_{4,175} = 4.84$, $p < 0.001$), *Latridopsis ciliaris* ($F_{4,175} = 11.52$, $p < 0.001$) and *Parapercis colias* ($F_{4,175} = 30.05$, $p < 0.001$) were all observed in signifi-

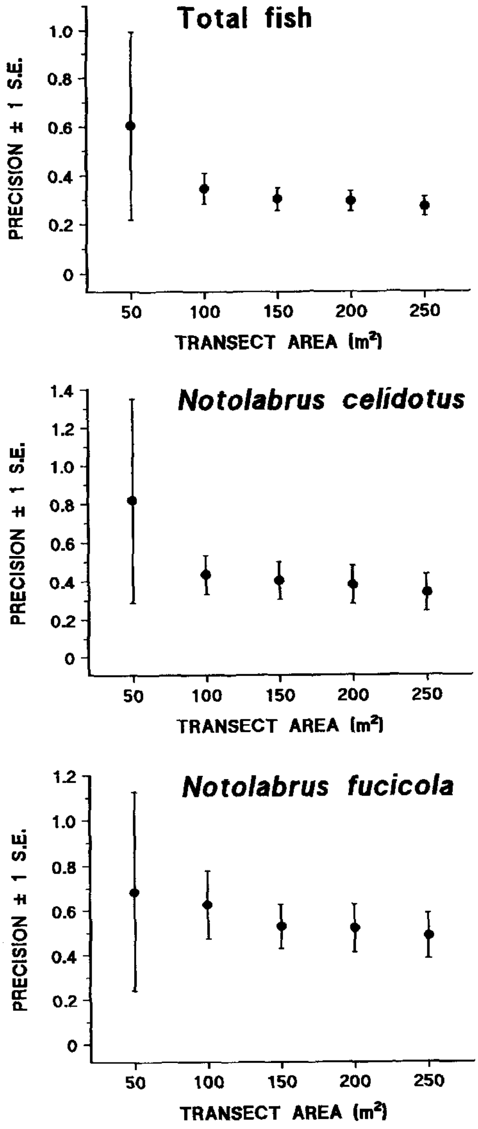


Fig. 2. Precision (± 1 SE) for all species (total fish), *Notolabrus celidotus* and *Notolabrus fucicola*, in relation to the area searched in each transect size (10 × 5 m, 20 × 5 m, 30 × 5 m, 40 × 5 m and 50 × 5 m).

cantly higher numbers over the sandy bottom of Habitat 5. The total fish numbers per transect were also significantly different among habitats ($F_{4,175} = 6.48$, $p < 0.001$) with greatest numbers in Habitat 5. *Notolabrus fucicola* was common in all habitats and showed no significant difference among them ($F_{4,175} = 2.17$, $p = 0.074$).

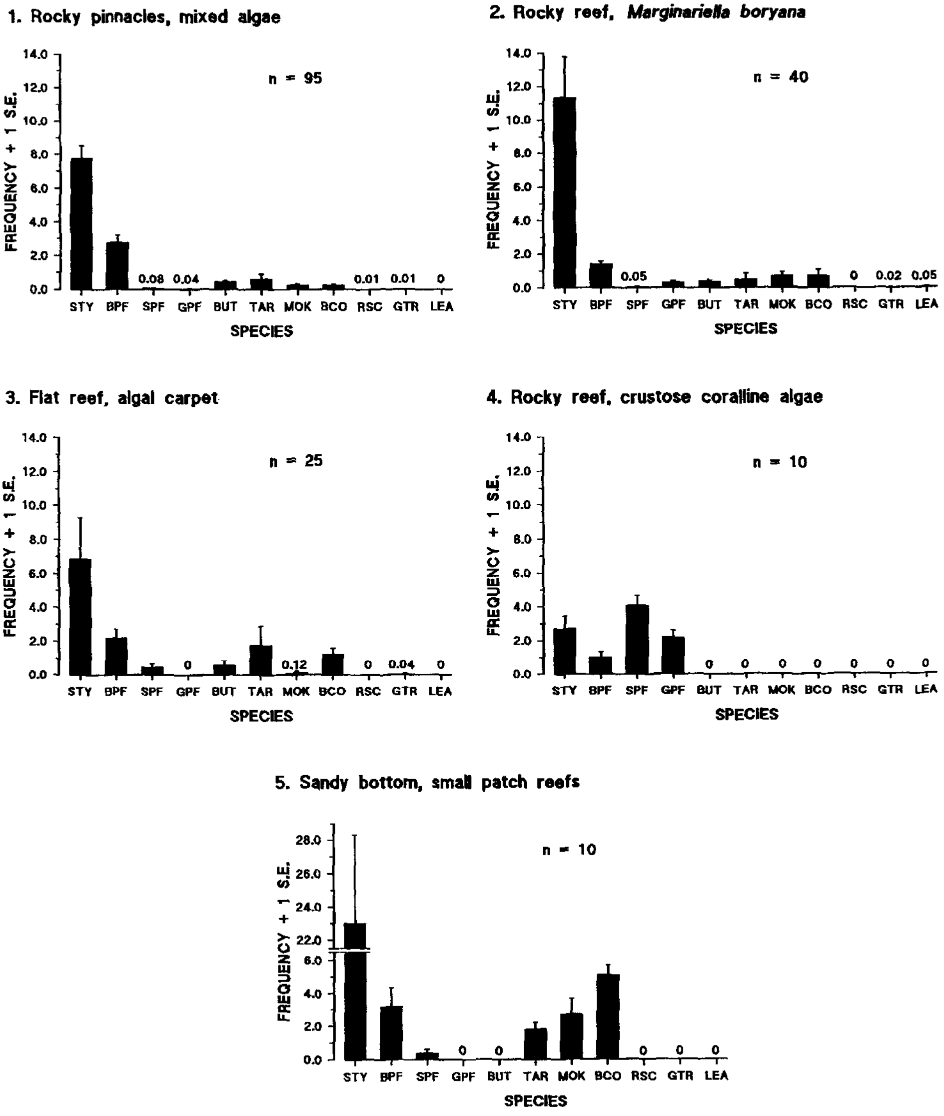
Relatively few species were recorded in each visual transect, ranging from an aver-

Table 2
The species, common name and code used in figures (from NZ Ministry of Agriculture and Fisheries) of 19 species of fish observed during visual transects and caught in gill-nets in this study

Family *species* (Authority)	Common name	Code	Counted	Caught
Triakidae				
Mustelus lenticulatus Phillipps, 1932	Rig	SPO	–	×
Scorpaenidae				
Scorpaena cardinalis Richardson, 1842	Red rock cod	RSC	×	×
Arripidae				
Arripis trutta (Bloch & Schneider, 1801)	Kahawai	KAH	–	×
Aplodactylidae				
Aplodactylus arctidens Richardson, 1839	Marblefish	GTR	×	×
Cheilodactylidae				
Cheilodactylus spectabilis (Hutton, 1872)	Red moki	RMO	–	×
Nemadactylus macropterus (Bloch & Schneider, 1801)	Tarakihi	TAR	×	×
Latrididae				
Latridopsis ciliaris (Bloch & Schneider, 1801)	Blue moki	MOK	×	×
Latridopsis forsteri (Castelnau, 1872)	Copper moki	CMO	–	×
Mendosoma lineatum Guichenot, 1849	Telescope fish	TEL	–	×
Mugilidae				
Aldrichetta forsteri (Cuvier & Valenciennes, 1846)	Yellow-eyed mullet	YEM	–	×
Labridae				
Notolabrus celidotus (Bloch & Schneider, 1801)	Spotty	STY	×	×
Notolabrus cinctus (Hutton, 1877)	Girdled wrasse	GPF	×	–
Notolabrus fucicola (Richardson, 1840)	Banded wrasse	BPF	×	×
Pseudolabrus miles (Bloch & Schneider, 1801)	Scarlet wrasse	SPF	×	×
Odacidae				
Odax pullus (Bloch & Schneider, 1801)	Butterfish	BUT	×	×
Pinguipedidae				
Parapercis colias (Bloch & Schneider, 1801)	Blue cod	BCO	×	×
Gempylidae				
Thyrsites atun (Euphrasen, 1791)	Barracouta	BAR	–	×
Istiophoridae				
Seriolella brama (Günther, 1860)	Blue warehou	WAR	–	×
Monacanthidae				
Parika scaber (Bloch & Schneider, 1801)	Leatherjacket	LEA	×	–

× = observed, – = not observed.

age of 2.6 to 4.6 (Fig. 4). The differences were significant among the five habitats ($F_{4,175} = 6.84$, $p < 0.001$), with Habitat 5 having the greatest average number of species per transect. *Pseudolabrus miles* and *Notolabrus cinctus* were usually found together in Habitat 4 ($r_{178} = 0.590$, $p < 0.001$), which extended into deeper water. The large carnivores *L. ciliaris* and *Parapercis colias* were usually found together in habitats that contained open areas of sand or gravel ($r_{178} = 0.305$, $p < 0.001$). The algal grazing butterfish, *Odax pullus*, and *Parapercis colias* were negatively correlated ($r_{178} = -0.146$, $p < 0.05$), with the former being present in algal-dominated habitats (1–3) and the latter being more common in the sandy Habitat 5.



1. Rocky pinnacles, mixed algae

2. Rocky reef, *Marginariella boryana*

3. Flat reef, algal carpet

4. Rocky reef, crustose coralline algae

5. Sandy bottom, small patch reefs

Fig. 3. Mean number (+ 1 SE) per 30 × 5 m transect of 11 species of reef fishes in each of five different habitats (n = number of transects). See Table 2 for species codes. Mean number above axis for small values.

3.2. *Effects of gill-nets*

There was considerable variation in the species of fishes seen in the visual surveys of the seven experimental sites (Fig. 5). For example, *Notolabrus fucicola* was common at five sites and rare in Site 2 ($F_{6,28} = 5.40$, $p < 0.001$). *Pseudolabrus miles* was recorded at four sites, *Notolabrus cinctus* at only two sites, and *Parapercis colias* at five sites.

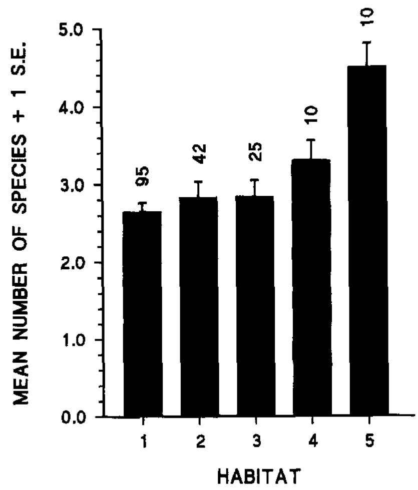


Fig. 4. Mean number (+1 SE) of species observed per transect in each of the five habitats (number of transects given above bars).

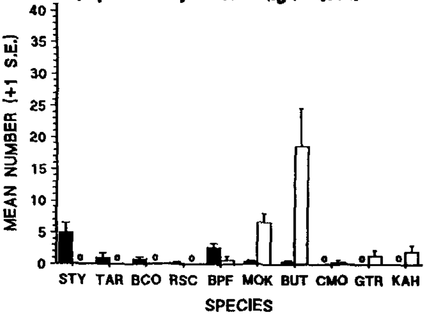
Butterfish, *O. pullus*, were not commonly seen but were recorded at six sites and not seen in Site 6. Overall, the average number of individual fish seen at the experimental sites ranged from 10 to 25 per transect (Fig. 6; $F_{6,28} = 0.60$, n.s.), while the number of species recorded ranged from 2 to 4 per transect ($F_{6,28} = 1.13$, n.s.).

Both the number of individuals and the number of species caught by gill-nets (pooled mesh sizes) were greater than those seen in visual transects at all sites (Fig. 6). The abundance of the catches also varied among sites with the average number of fishes caught ranging from 25 to 60 ($F_{6,14} = 5.79$, $p < 0.001$). The number of species caught ranged from ≈4 to 7 and did not vary significantly among sites ($F_{6,14} = 2.14$, n.s.).

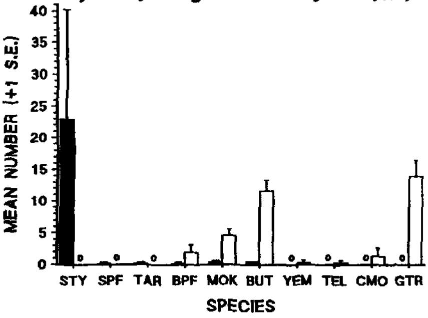
Overall, the species caught in greatest abundance was *O. pullus*, which had only a small representation in the visual surveys (Figs. 5 and 7). The herbivorous, bottom-dwelling marblefish, *Aplodactylus arctidens*, made up 7.1% of the total catch but was rarely observed during the visual surveys (0.3% of fish seen). The wide ranging species *Arripis trutta* (12.5%) and *Seriolella brama* (4.2%) were captured at some sites but not seen during visual surveys. *O. pullus* comprised 53% and *L. ciliaris* 13% of the gill-net catch, although these species were only a small fraction of fish seen in the visual surveys. *Nemadactylus macropterus*, *Parapercis colias* and the labrid fishes, which were relatively common at all sites, were under-represented in the gill-net catches. For example, 295 *Notolabrus celidotus* were counted in the visual surveys but only four were caught in nets. The largest ratio of observed to caught labrids was 13:3 for *Pseudolabrus miles*. Overall, there was no correlation between the total number of fishes counted and caught at each site ($r_5 = 0.161$ n.s.) or the total number of species counted and caught at each site ($r_5 = 0.209$ n.s.; Fig. 7).

Only three species were observed and subsequently caught in great enough numbers to be compared by ANOVA (Table 3). There was no significant difference in standard length between treatments for *Notolabrus fucicola* or *L. ciliaris*. This suggests that the

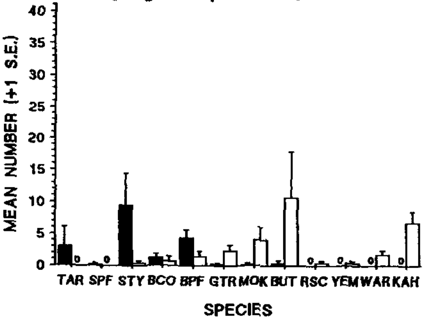
1. Rocky pinnacles, mixed algae (7m)



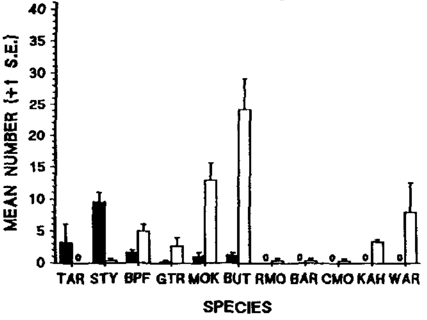
2. Rocky reef, *Marginariella boryana* (8m)



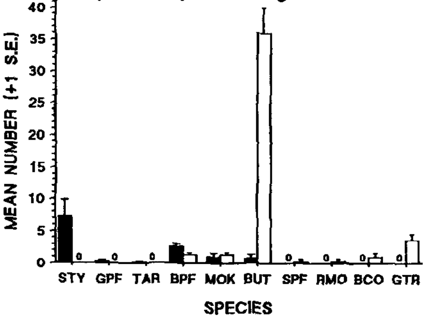
3. Flat reef, algal carpet (13m)



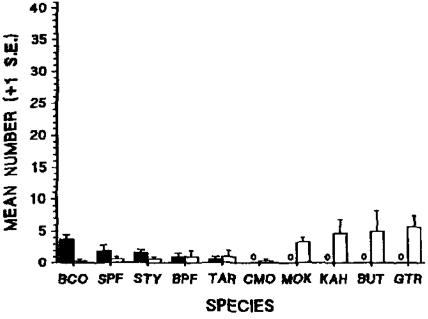
4. Rocky pinnacles, mixed algae (5m)



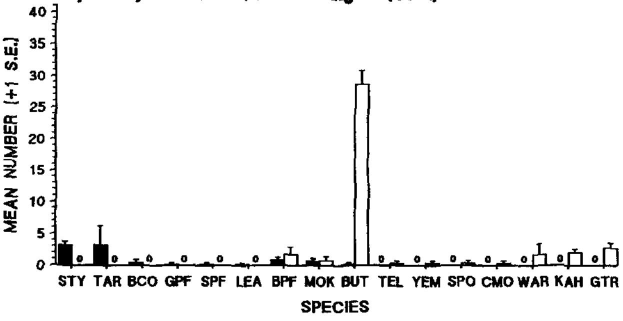
5. Rocky pinnacles, mixed algae (11m)



6. Sandy bottom, small patch reefs (12m)



7. Rocky reef, crustose coralline algae (15m)



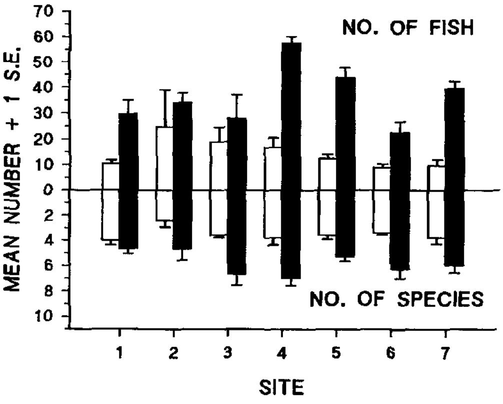


Fig. 6. Mean number (+ 1 SE) of fishes and mean number of species observed per visual transect (open bars), and caught per set (solid bars) at seven sites around the Kaikoura Peninsula. Catch data were pooled across mesh sizes (see Methods).

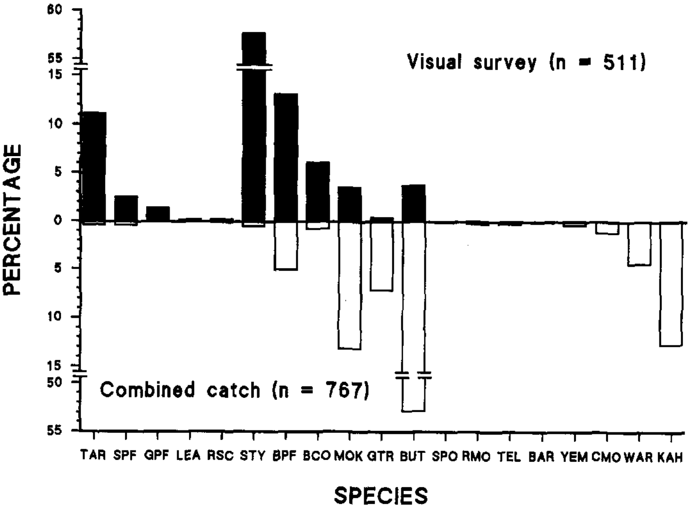


Fig. 7. Percentage composition by species of the total number of fishes observed during the visual surveys, and of those subsequently caught in the gill-nets. See Table 2 for species codes.

size classes of these species observed in the visual surveys were representatively sampled by the three mesh sizes. The mean size of *O. pullus* caught in the gill-nets was significantly larger than those seen in the visual surveys. A comparison of the standard lengths of all fishes observed during the visual surveys and all fishes caught in the gill-nets showed a significant difference in sizes, with the average size of caught fishes being

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Fig. 5. Mean number (+ 1 SE) of each species observed in five transects of a visual survey (solid bars), and caught in three replicate sets of three mesh sizes (pooled) of gill-nets (open bars) at seven sites around the Kaikoura Peninsula. See Table 2 for species codes.

Table 3
ANOVA table and means of standard length of three species observed during visual surveys and subsequently caught in gill-nets

Species	Source	df	MS	*F*	*p*		*n*	Mean	SD
Notolabrus fucicola	Visual/gill-net	1	240	0.12	n.s.	Visual	67	207	48.5
	Error	104	1986			Gill-net	39	204	36.7
	Total	105							
Latridopsis ciliaris	Visual/gill-net	1	692	0.21	n.s.	Visual	18	231	54.3
	Error	117	3279			Gill-net	101	238	57.8
	Total	118							
Odax pullus	Visual/gill-net	1	12650	9.43	<0.01	Visual	19	257	91.3
	Error	422	1341			Gill-net	405	283	32.1
	Total	423							
All fish	Visual/gill-net	1	4987804	1516.24	<0.001	Visual	511	139	58.6
	Error	1276	3290			Gill-net	767	267	56.5
	Total	1277							

All Cochran's tests were n.s.

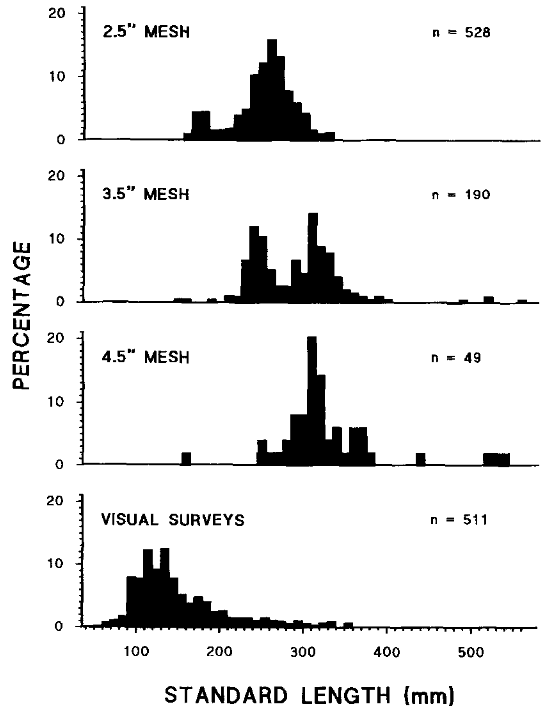

Fig. 8. Length frequency distributions of the catch from each of the mesh sizes and the length frequency distribution of the total fish population observed during the visual surveys. n = total number of fish sampled.

almost double that of observed fishes. Small labrids comprised most of the fishes observed in the visual surveys while larger reef and pelagic species made up most of the catch.

The three mesh sizes caught different size fractions of fish populations, but all mesh sizes caught fishes larger than those commonly seen in the visual surveys (Fig. 8). For each mesh size there was a bi-modal distribution of sizes. The lesser mode generally was caused by fishes being wedged into nets while the larger mode was of fishes that were properly gilled (Winters & Wheeler, 1990). The 2.5″ mesh caught fishes with size peaks around 180 and 260 mm SL. These were mostly labrids, which were generally smaller than other species, and juvenile *O. pullus*. The 3.5″ mesh caught fishes with size peaks at 230 and 300 mm SL. A wide range of species was caught in this mesh size but it was clear that the smaller juveniles of all species (particularly *O. pullus*) were not caught. The 4.5″ mesh caught mostly larger fishes, with peaks at 310 and 360 mm SL. The catch from this mesh size overlapped considerably in size with that of the 3.5″ mesh, although fewer small fishes were captured.

Butterfish, *O. pullus*, were of particular interest because they represented such a large proportion of the overall catch. Butterfish smaller than 350 mm were especially vulnerable to being caught in the 2.5″ mesh nets, with larger individuals being caught mostly in the 3.5″ mesh and few being caught in the 4.5″ mesh (Fig. 9). Most of the fishes caught were smaller than the size of maturity, which occurs at around 320 mm SL (Ritchie, 1969). The smallest juveniles (<260 mm) were rarely caught in nets.

There was a significant species × mesh size interaction in the number of fishes caught ($F_{34,1080} = 35.15$, $p < 0.001$), supporting the observation that some species tended to be vulnerable to particular mesh sizes (Fig. 10). For example, *S. brama* was caught mostly in the 3.5″ mesh nets, while several species such as *O. pullus*, *Notolabrus fucicola*, and

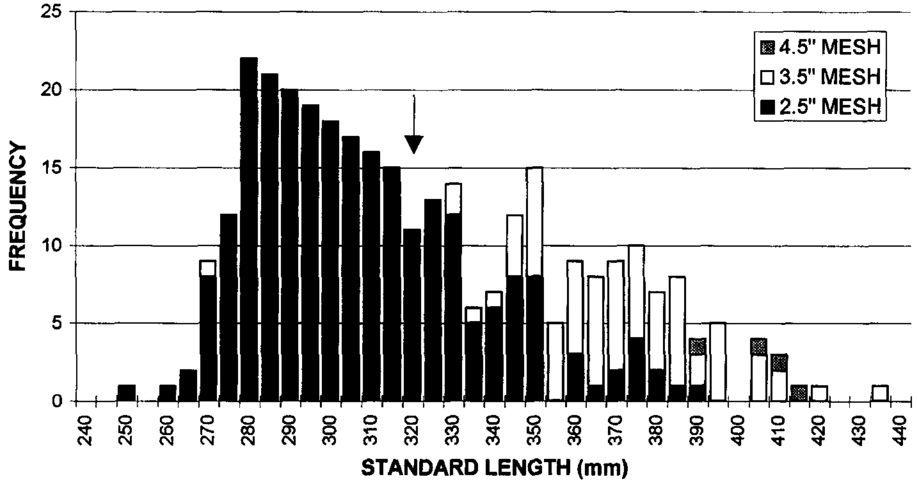

Fig. 9. Length frequency distributions of butterfish, *O. pullus*, caught in gill-nets. The arrow indicates the approximate standard length at which butterfish are mature (Ritchie, 1969).

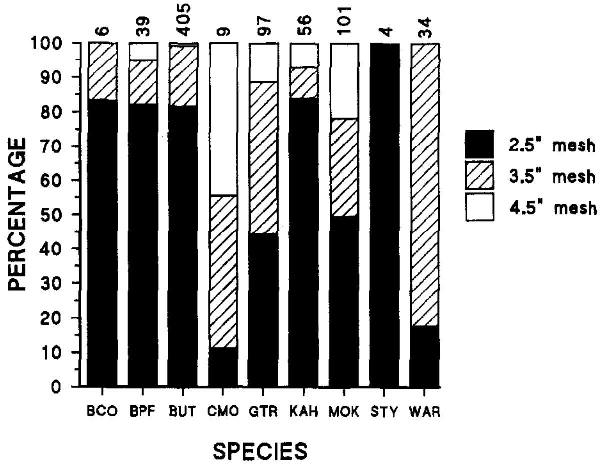

Fig. 10. Relative proportions of nine species of reef fishes caught in three mesh sizes of gill-net. See Table 2 for species codes.

Arripus trutta were most vulnerable to the 2.5″ mesh nets. Only the largest *Notolabrus fucicola*, *O. pullus*, cheilodactylids, *L. ciliaris*, *Aplodactylus arctidens*, and *Arripis trutta* were caught in the 4.5″ mesh.

Overall, there were significant differences among mesh sizes both in the numbers of fishes caught ($F_{2,1080} = 102.35$, $p < 0.001$) and the number of species caught ($F_{2,60} = 29.81$, $p < 0.01$; Fig. 11). The 2.5″ mesh caught the most fishes ($\bar{x} = 25$ fish per 30 m net) and the most species ($\bar{x} = 4.5$). Both the number of fishes and number of species caught declined sequentially with increasing mesh size.

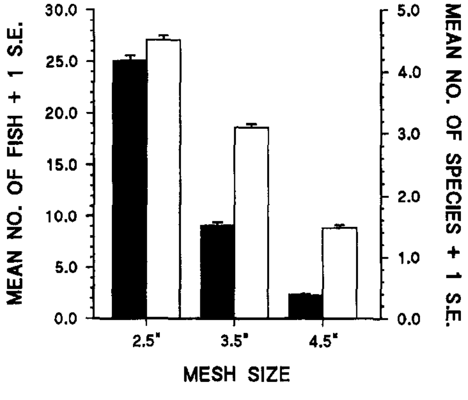

Fig. 11. Mean number (+1 SE) of fishes (solid bars) and species (open bars) caught per gill-net (mesh sizes pooled) at the seven sites around the Kaikoura Peninsula.

4. Discussion

It is clear from this study that gill-nets and visual surveys sample different aspects of fish populations and that both of these are related to habitat structure. The herbivorous *O. pullus* was found exclusively along reefs dominated by large brown algae where it feeds mostly on mature fucoid and laminarian algae (Russell, 1983; Choat & Clements, 1992). This species tends to swim below algal canopies and is not usually found on open reef or sandy habitats. The labrid fishes *Notolabrus celidotus* and *Notolabrus fucicola* were ubiquitous and occurred throughout all habitats, while *Notolabrus cinctus* occurred predominantly in deeper habitats below 10 m depth. The latrid species *L. ciliaris*, the cheilodactylid *Nemadactylus macropterus*, and the pinguipedid *Parapercis colias* occurred in areas where large algae were sparse, particularly along sandy bottoms. Choat & Ayling (1987) noted that these large carnivores appear to forage predominantly in open reef areas.

Visual surveys and experimental gill-netting produced significantly different estimates of relative abundances of reef fishes and transient species. Most fishes seen during the visual survey were small labrids, *Parapercis colias* and juvenile *Nemadactylus macropterus*. However, most fish caught were larger *O. pullus*, *Arripis trutta* and *L. ciliaris*. The large pelagic fish (*Arripis trutta* and *Trachurus declivis*), and even some large cryptic reef fish (*Aplodactylus arctidens*), were rarely seen during the visual surveys. This resulted in the visual surveys underestimating the abundance of cryptic and transient species, while the gill-net catch underestimated the abundance of some species of reef fishes, and distorted the size frequency distribution of others. These differences are primarily due to the contrasting sampling patterns of the two techniques.

Visual surveys take an instantaneous short-term sample of a reef fish population while gill-nets take a cumulative sample over a much longer period. During a sampling period, fishes 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 fishes 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).

Further differences in the population samples provided by the two methods may be a result of behavioural differences between species. Observations of fish behaviour within 1 m of gill-nets (Hickford & Schiel, unpubl.) showed differences in several species of reef fishes. For example, the common labrid *Notolabrus celidotus* often came close to nets but rarely contacted them. They were also frequently able to escape if they did become entangled. Other species such as *O. pullus*, *Aplodactylus arctidens* and *L. ciliaris* were more commonly caught when they came near gill-nets. *O. pullus*, for example, swim beneath the algal canopies, and when they encountered gill-nets set among kelp they tended to hit the nets while swimming at full speed. The fusiform body shape and sinusoidal swimming motion of this species make it unlikely that butterfish will escape from a net once caught. *L. ciliaris*, *Nemadactylus macropterus* and other laterally compressed fishes are generally weak swimmers (Doak, 1991), and once entangled by a fin or operculum they appear unable to gain enough thrust to escape from a net. The labriform swimming motion (Webb, 1973; Lindsey, 1978) of *Notolabrus* *celidotus* and *Notolabrus fucicola* appears to assist them in avoiding capture in gill-nets by enabling them to scull backwards out of the mesh before becoming firmly entangled. Species with a carangiform swimming motion such as *L. ciliaris* and *Arripis trutta* can only attempt to force their way through the mesh of a gill-net if they become caught.

The results of this study show that gill-nets are effective at catching commonly targeted species (i.e. *O. pullus*, *L. ciliaris* and *Arripis trutta*) but that there is little justification for the belief that gill-nets fish selectively for these species on inshore reefs. The number of species caught in gill-nets depends on mesh size, but ranges from two to five per set and over all sets ranged from zero to eight species. The 2.5″ mesh is particularly destructive of fish populations, removing an average of 25 fishes from up to 8 species per set. Most of these species have no commercial or food value (labrids and *Aplodactylus arctidens*, in particular). The mesh sizes used in this study were those that are readily available from sports shops and are commonly used for fishing inshore reefs, particularly by recreational fishers.

Gill-nets generally remove the larger individuals from a reef fish assemblage. If reefs are fished extensively, this can remove a significant proportion of reproductive individuals and may have negative consequences on the structure and dynamics of fish populations (Russ & Alcala, 1989; Buxton, 1993; Grigg, 1994). The removal of large males from a protogynous hermaphrodite species, such as *O. pullus* and *Notolabrus fucicola*, is not necessarily detrimental to the local population. Removal of the larger males will provide the opportunity of sex change in dominant females (Shapiro, 1987; Buxton, 1993) and the males removed will eventually be replaced. However, the removal of large females may have population consequences. The exponential relationship between size and egg production (Larkin, 1978; Bohnsack, 1990) means even a small decrease in the size structure of a population could result in large decreases in egg production (Buxton, 1993; Dugan & Davis, 1993).

The removal of large numbers of butterfish by gill-nets is of particular concern because a significant portion of the local population may be removed. Many of the butterfish caught were at or near maturity and probably at least 4 yr old (Ritchie, 1969). The removal of this pre-reproductive stock could have longer term effects on the structure of the local population, particularly if coupled with the removal of larger reproductive stock. The consequences of removal of the labrids was probably not great because of the fewer numbers caught and the generally smaller size classes of fishes caught. For example, few large males of *Notolabrus fucicola* were caught during the study. Those that were caught were usually able to shake themselves free of the net.

The species × mesh size interaction in the number of fish caught in gill-nets implies that certain mesh sizes can be particularly destructive in some habitats. For example, a 2.5″ gill-net set in a reef area with heavy algal cover will catch large numbers of juvenile butterfish, *O. pullus*. However, intense fishing pressure can have both direct and indirect effects and a far wider impact on the fishes assemblages than the predicted decreases in abundance of target species. Russ & Alcala (1989), for example, found that intense non-selective fishing led to a significant decline in the density of targeted species and that there was also an associated decrease in the density of non-targeted species that were caught as a by-catch.

The passive nature of the fishing action of gill-nets, their ability to cross habitats, and the length of time they must be set prevent effective targeting of individual species and make it likely that high numbers of common reef species of no commercial value will also be captured.

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