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Abundance and diversity of fish on mussel farms in New Zealand

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Abstract

Fish are often attracted to floating structures, particularly as juveniles, and in many parts of the world longline mussel farms provide complex, three-dimensional floating structures in coastal waters. There have been few quantitative studies of the assemblages of fish living on and around mussel farms. We sampled fish on mussel farms at three sites in the north of the South Island of New Zealand over a year to characterise the assemblages present and their variability. Predictions of the species likely to be present were made on the basis of their occurrence in the general area, habitat preferences, and occurrence around floating structures in previous studies. The farms differed in their degree of exposure, distance from shore and degree of riverine and oceanic influence. Fish were sampled by underwater visual census, and a remote-operated vehicle, and destructively sampled using an anaesthetic. Abundances of fish on the mussel lines were small (median values up to 1.25 fish m^{-1} of line) and were dominated by small, demersal species characteristic of rocky reefs in the area, notably triplefins (*Forsterygion lapillum* and *Grahamina gymnota*, Family Tripterygiidae) and the wrasse *Notolabrus celidotus*. The abundances and species of fish present differed among sites and among sampling methods (but the small and inconsistent numbers of fish recorded precluded formal statistical testing of differences). Few large, commercially or recreationally important species (demersal or pelagic) were recorded. Triplefins may recruit to the lines at settlement from planktonic larvae and spend their entire lives there. *N. celidotus*, in contrast, may recruit to stands of macroalgae on nearby rocky reefs and move to farms later. Direct recruitment of *N. celidotus* may be limited by the low abundances of macroalgae on the mussel lines.

Keywords: Mussel farm; Longline; Fish; Habitat; New Zealand

1. Introduction

In many parts of the world, including New Zealand, longline mussel farms provide extensive, three-dimensional structures with complex substrata of ropes and mussel stock, often located in nearshore, relatively sheltered environments. Many types of

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coastal fish associate with floating structures, including drift algae, gelatinous zooplankton and flotsam (Kingsford and Choat, 1985; Kingsford, 1992, 1993), and there is "good evidence of association with structures in the pelagic environment" for 16 families (Kingsford, 1993). Angel and Ojeda (2001) found that the trophic structure of fish assemblages was more complex in complex habitats, including floating structures in the form of kelp beds, than in structurally simple ones. Thus, mussel farms may act as fish aggregation devices (FADs), which are known to attract pelagic fishes in tropical and temperate waters (e.g., Fréon and Dagorn, 2000; Dempster and Kingsford, 2003) or provide substrata for direct recruitment of fishes and be colonised by demersal species.

Longline mussel farms are often used as fishing sites by recreational anglers and anecdotal evidence suggests that they are considered good places to catch fish. This has been used as a mitigating argument in disputes over occupation of space by mussel farms in the coastal zone, but the evidence that recreationally or commercially important fish are more abundant around farms, whether associated with the floating structure or the seabed, has not often been tested. Carbines (1993) studied the distribution of the labrid *Notolabrus celidotus* (spotty), a species of no commercial or recreational importance, around mussel farms in the Marlborough Sounds, New Zealand. He found large numbers of individuals around the anchor blocks mooring the mussel lines to the seabed, and on the bed beneath the lines, but relatively few on the lines themselves. New recruits were predominantly found among macroalgae on nearby shallow reefs, and Carbines concluded that they later migrated in small numbers to mussel farms, rather than recruiting directly. This species is not targeted recreationally or commercially. There is also anecdotal evidence of fish feeding on mussel spat on farms in the Marlborough Sounds, the main culprits being spotties, but also leatherjackets (*Parika scaber*) and snapper (*Pagrus*

Table 1
Species of fish identified as being potential colonisers of longline mussel farms in the Marlborough Sounds and Golden Bay

Species	Common name	Family	Reason[a]
Pelagic			
Aldrichetta forsteri[b]	Yellow-eyed mullet	Mugilidae[b]	Locally common, recorded in association with drift algae
Arripis trutta[b]	Kahawai	Arripidae[b]	Locally common, recorded in association with drift algae
Engraulis australis[b]	Anchovy	Engraulididae	Locally common, recorded in association with drift algae
Hyporhamphus ihi[b]	Garfish	Hemiramphidae	Locally common
Sardinops neopilchardus[b]	Pilchard	Clupeidae	Locally common, recorded in association with drift algae
Seriola lalandi	Kingfish	Carangidae[b]	Locally common, family recorded in association with drift algae
Thyristes atun	Barracouta	Gempylidae	Locally common
Trachurus novaezelandiae[b]	Jack mackerel	Carangidae[b]	Locally common, genus recorded in association with drift algae
Zeus faber	John Dory	Zeidae	Locally common on reefs
Demersal			
Forsterygion spp.[b]	Triplefin	Tripterygiidae	Locally common on reefs, recorded in association with drift algae and complex topography
Grahamina spp.	Triplefin	Tripterygiidae[b]	Locally common on reefs, often associated with sessile invertebrates
Hippocampus abdominalis[b]	Seahorse	Syngnathidae[b]	
Notolabrus celidotus[b]	Spotty	Labridae	Locally common, recorded in association with benthic and drift algae and complex topography
Pagrus auratus[b]	Snapper	Sparidae	Locally common, recorded in association with drift algae
Parika scaber[b]	Leatherjacket	Monacanthidae[b]	Locally common on reefs, recorded in association with drift algae and sessile invertebrates
Ruanoho spp.[b]	Triplefin	Tripterygiidae[b]	Locally common on reefs, recorded in association with drift algae
Solegnathus spinosissimus	Spiny sea dragon	Syngnathidae[b]	Locally present, associated with macroalgae
Stigmatopora spp.[b]	Pipefish	Syngnathidae[b]	Locally common, associated with macroalgae

[a] Information derived from Kingsford and Choat (1985), Jones (1988), Kingsford (1993), Davidson (2001), Francis (2001) and personal observations.
[b] Family, genus or species reported in association with floating objects (Kingsford and Choat, 1985; Kingsford, 1992, 1993).

auratus) (Meredyth-Young, 1985, cited by Carbines, 1993). Kingsford (1992) found all 3 of these species among drift algae.

The top of the South Island of New Zealand, including the Marlborough Sounds, is a major area for longline culture of mussels. We identified a suite of species that might associate with marine farms in this geographical area (Table 1). This was based on comparisons of the species of fish found in the area (Davidson, 2001; Cole, unpublished data), the families and species known to associate with floating structures (Kingsford and Choat, 1985; Kingsford, 1992, 1993), information on habitat–species relationships for New Zealand coastal fish (Choat and Ayling, 1987; Jones, 1988; Syms, 1995), and information on the patterns of distribution of larval fish in coastal waters of New Zealand (Kingsford and Milicich, 1987; Kingsford, 1988; Kingsford and Choat, 1989; Tricklebank et al., 1992; Hickford and Schiel, 2003). The pelagic species listed might be expected to be attracted to, but associate loosely with, farm structures whereas the demersal species might be expected to recruit to and associate more closely with farm structures and the mussel crop.

The objective of the present study was to assess whether these species would consistently inhabit longline shellfish farms in the north of the South Island, by quantifying numbers and types of fish on marine farms, comparing fish assemblages among 3 farms in different environments, and quantifying variation in fish assemblages over time. The study sites were an exposed, open bay where the farms are distant from shore, and 2 sites in the Marlborough Sounds, where the farms are in relatively enclosed waters and within 200 m from shore, and incorporating 2 sites differing in the amounts of riverine and oceanic influence.

2. Methods

2.1. Study sites

Three farm sites were used in the study, one in each of Beatrix Bay, Kenepuru Sound and Golden Bay (Fig. 1). Beatrix Bay is semi-enclosed and located in the outer Marlborough Sounds. The study farm was at the mouth of the bay. The second farm was at the entrance to Kenepuru Sound, a sheltered bay in the inner Marlborough Sounds. Golden Bay is a large, open embayment and the marine farms are clustered in a block on the western side (hereafter referred to as 'Collingwood'). Water depths at the farms were 20–31 m, 14–30 m and 10–13 m at Beatrix, Kenepuru and Collingwood, respectively. The inner boundary of the farms in Beatrix and Kenepuru was ca. 50 m from shore, while that in Collingwood was ca. 2300 m.

The study farms consisted of up to 10 longlines supported by buoys and oriented parallel to the adjacent shoreline (see Jeffs et al., 1999). Each longline consists of 2 parallel surface ropes up to 100 m long and ca. 1 m apart. From these, dropper ropes bearing the crop of mussels hang down to a depth of 12–13 m at Beatrix, 8–10 m at Kenepuru and 7–8 m at Collingwood. Spacing of droppers in the water column along the horizontal axis varied among farms, with median distance between adjacent droppers of 0.8 m (range 0.6–0.9 m), 0.6 m (0.5–0.8 m) and 0.4 m (0.3–0.6 m) at Beatrix, Kenepuru and Collingwood, respectively. The size of the mussel stock at any one time varies from line to line across the farm because mussel spat are seeded onto lines throughout the year (at ca. 1–2 cm shell length). They are harvested after about 2 years growth at a size of around 10 cm.

2.2. Sampling methods

Sampling was done at irregular (roughly 2–3 monthly) intervals between May 2003 and April 2004. Sampling times were strongly influenced by weather conditions, particularly at the exposed Collingwood site. At each time of sampling, 2 longlines were sampled at each farm. Where possible, lines with mature mussel stock (shell lengths about 90 mm) were selected each time, so that for a given farm, different lines were sampled each time.

Most methods of sampling fish are selective in terms of the species and life-stages recorded. To sample as wide a selection of the fish fauna as possible, we used three methods: underwater visual census by diver ('diver counts'); visual census using a remote-operated video (ROV); and destructive sampling using an anaesthetic. These methods are discussed below.

Diver counts were done by divers working in pairs at 2 places on 2 longlines sampled per farm. At each place on each longline, the first diver counted fish associated with the general farm environment by

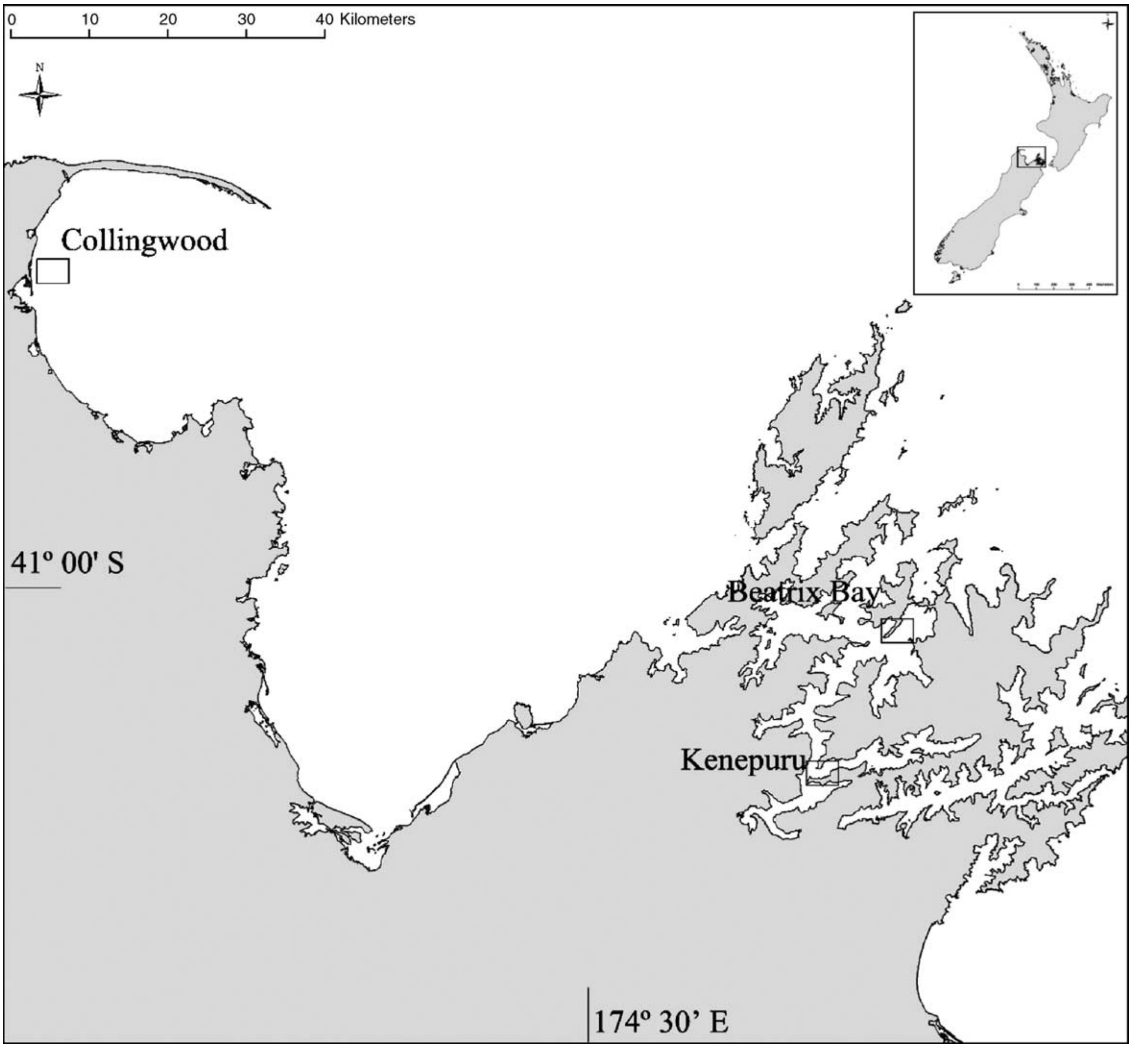

Fig. 1. Map of the northern part of the South Island of New Zealand, showing the 3 study sites (Beatrix Bay, Kenepuru Sound and Collingwood). See text for details.

searching on or around the dropper ropes in a 4-m-wide horizontal strip between 4 and 8 m water depth along a 30-m-long transect (plus an uncounted 10-m lead in). The second diver concentrated on smaller, cryptic fish closely associated with dropper ropes by searching each rope between 4 and 6 m water depth along three replicate 10-m sections of the 40-m tape (0–10 m, 15–25 m and 30–40 m). Divers estimated the lengths of any fish seen. During the April sampling at Kenepuru, divers also counted and estimated lengths of fish along two 30×4-m transects parallel to the shore and at 6-m depth at each of two locations inshore of the farm. The second diver searched three 10×2-m sections of each transect in more detail. These counts were intended to provide a snapshot comparison of numbers, species and sizes between the farm structures and nearby, natural habitats. The seabed at these sites consisted of cobbles bordered by coarse sand on the offshore side. Visibility underwater ranged from 4 to 8 m at Beatrix and Collingwood, and 2 to 4 m at Kenepuru.

ROV counts were intended to sample small fish living in association with the droppers and mussels, without the potential disturbance caused by the presence of divers. The ROV was flown down and up 5 droppers on the 2 longlines sampled per farm, videoing continuously over the full length of each dropper. It was positioned so that the dropper rope and mussel crop filled roughly half of the width of the field of view, allowing small fish to be visible for counting on playback. Depth was recorded continuously on the video tape.

Destructive sampling of fish on the dropper ropes used the fish anaesthetic Aqui-S® (active ingredient 50% isoeugenol: Aqui-S New Zealand Ltd, http://www.aqui-s.com). Conventional methods of sampling fish using toxicants such as rotenone could not be used because of the mussel stock for human consumption and droppers are too large to enclose and remove. On the 2 longlines per farm, the section between 4 and 6 m depth on each of 3 haphazardly chosen droppers was enclosed in a polythene sheet. The vertical edges of the sheet (stapled to wooden battens) were brought together and fastened so that the dropper was enclosed

Table 2
Median, maximum and minimum numbers of fish per m of dropper by sampling method for each site at each time of sampling

Date	Aqui-S			ROV			Diver 10 × 2-m			Diver 30 × 4-m
	Median	Min	Max	Median	Min	Max	Median	Min	Max	Total
Beatrix										
30/04/2003	1.25	0	2.50	0	0	0.08	0.04	0	0.15	0
26/05/2003	0.50	0	1.50	0	0	0.08	0	0	0.08	0
14/10/2003	1.25	0	2.50	0	0	0.08	0	0	0.12	0
14/01/2004	0.25	0	4.50	0.08	0	0.39	0.10	0	0.29	10[a]
11/02/04	1.00	0	2.00	0	0	0.15	0.03	0	0.23	0
Overall	1.00	0	4.50	0	0	0.39	0.02	0	0.29	
Kenepuru										
28/05/2003	0	0	1.50	0	0	0	0.04	0	0.12	0
20/08/2003	nd	nd	nd	0	0	0	0	0	0	1[b]
16/10/2003	0	0	0.50	0	0	0.11	0	0	0.04	0
15/01/2004	1.00	0	2.50	0	0	0.11	0.03	0	0.11	0
13/02/2004	0.50	0	2.00	0	0	0.22	0	0	0.12	1[c]
7/04/2004	0	0	0.50	0	0	0	0	0	0.03	0
Overall	0.25	0	2.50	0	0	0.22	0	0	0.12	
7/04/2004										
Shore site 1							1.70	0	4.10	56[d]
Shore site 2							2.05	0	3.70	38[e]
Collingwood										
5/06/2003	0.25	0	1.50	nd	nd	nd	0	0	0.03	0
23/09/2003	nd	nd	nd	0	0	0.14	0	0	0.07	0
22/10/2003	1.25	0	3.50	0	0	0.14	0.05	0	0.10	1[f]
17/12/2003	1.25	0	2.00	0.14	0	0.29	0.11	0.02	0.25	0
29/01/2004	1.25	0.50	2.00	0.14	0	0.57	0.13	0.02	0.35	5[g]
Overall	1.00	0	3.50	0	0	0.57	0.05	0	0.35	

Estimates for Aqui-S are based on replicate 2-m sections of droppers, those for ROV on replicate droppers, and those for divers on replicate 10 × 2-m transects. Overall values for each site across all times are also shown. Shore counts at Kenepuru were per m of transect (2 m wide). 'nd', no data. Values for 30 × 4-m diver transects are totals of 4 replicates except for Collingwood 5 June and shore transects, for all of which $n = 2$.

[a] 5 triplefins, 3 spotties, 1 leatherjacket, 1 unidentified (sizes nr.).
[b] Leatherjacket (26 cm).
[c] Leatherjacket (30 cm).
[d] All spotties (3–16 cm).
[e] All spotties (3–20 cm).
[f] Spotty (11 cm).
[g] 4 triplefins (all 6 cm), 1 spotty (6 cm).

in a tube 48-cm diameter and 2 m high. The polythene was tied tightly around the dropper at the top and bottom and water was pumped out of the tube via a flexible plastic pipe connected to a submersible pump. When the tube was empty, 50 L of Aqui-S solution (100 ppm made up in seawater according to manufacturer's instructions) was pumped into the tube. Divers agitated the tube to ensure that the anaesthetic reached all of the enclosed dropper and to dislodge anaesthetised animals. After 15 min the Aqui-S solution was pumped out of the tube via an in-line filter (mesh size 1 mm), which collected any fish or other organisms dislodged from the dropper. Divers ensured all fish seen inside the tube were collected, and all material collected in the filter was preserved in 7% seawater formalin.

Information on the amount and type of fouling organisms and the size of mussel stock on the droppers was recorded as potential correlates with fish abundances. Fouling organisms were recorded qualitatively by divers during the transect counts and Aqui-S sampling, and from the ROV videotapes. Mussel size at each time of sampling was estimated by collecting 30 mussels from droppers adjacent to each of those sampled by Aqui-S in the depth interval 4–6 m. These were measured along their long axis using Vernier calipers.

2.3. Data analysis

For each method of sampling, fish were counted and, when possible, identified to species and their lengths estimated. Numbers of fish (totals across all species) sampled by diver counts, ROV and Aqui-S were standardised to 1-m length of dropper to allow comparisons among the methods. Data for each sampling method were expressed as the median and range for all replicate transects or droppers across both lines sampled at each farm at each time.

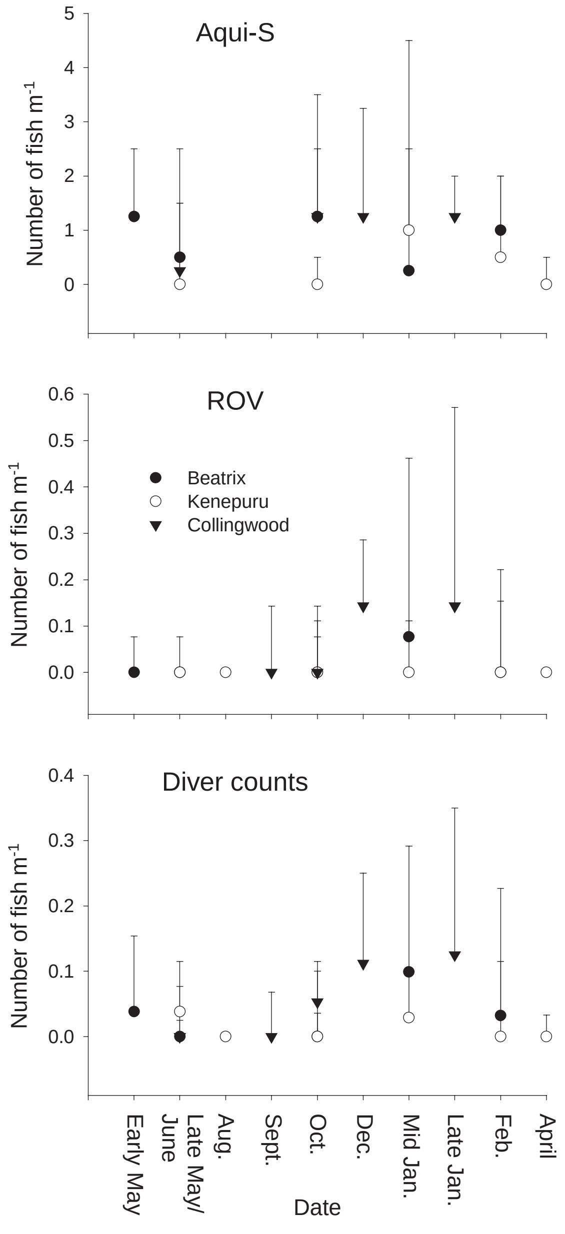

Fig. 2. Median and maximum numbers of fish m^{-1} of dropper at each time of sampling, sampled by 3 methods. Numbers are totals for all species. Diver counts are based only on 10×2-m transects.

3. Results

Sampling revealed a small suite of mainly demersal species present on the lines in low abundances throughout the year (Table 2; Figs. 2–5). The triplefins *Forsterygion lapillum* and *Grahamina gymnota*, spotties, and leatherjackets were the common demersal species present, and a thornfish (*Bovichtus variegatus*) was collected on one occasion. The only pelagic species recorded was the jack mackerel *Trachurus novaezelandiae*. Casual observations of 2 other demersal and 3 pelagic species were also

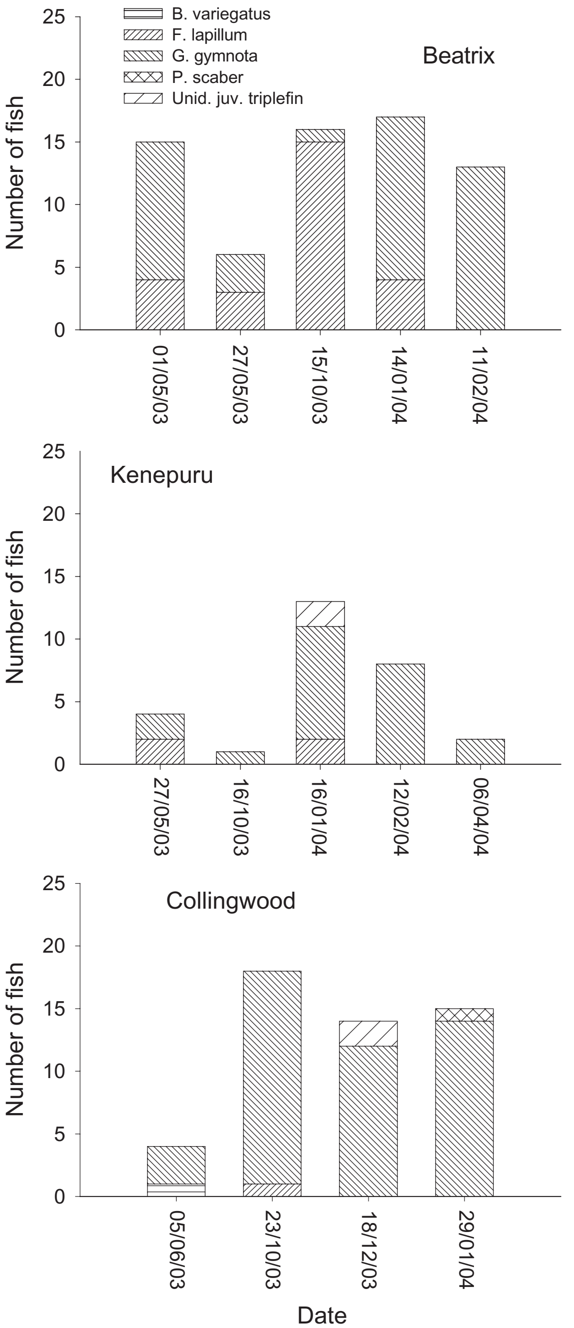

Fig. 3. Numbers of each species of fish collected by the Aqui-S method at each time of sampling. Numbers are totals for all 3 droppers on both longlines sampled each time, and are not standardised to unit length of dropper. Species recorded were *Bovichtus variegatus*, *Forsterygion lapillum*, *Grahamina gymnota*, *Parika scaber* and unidentifiable juvenile triplefins.

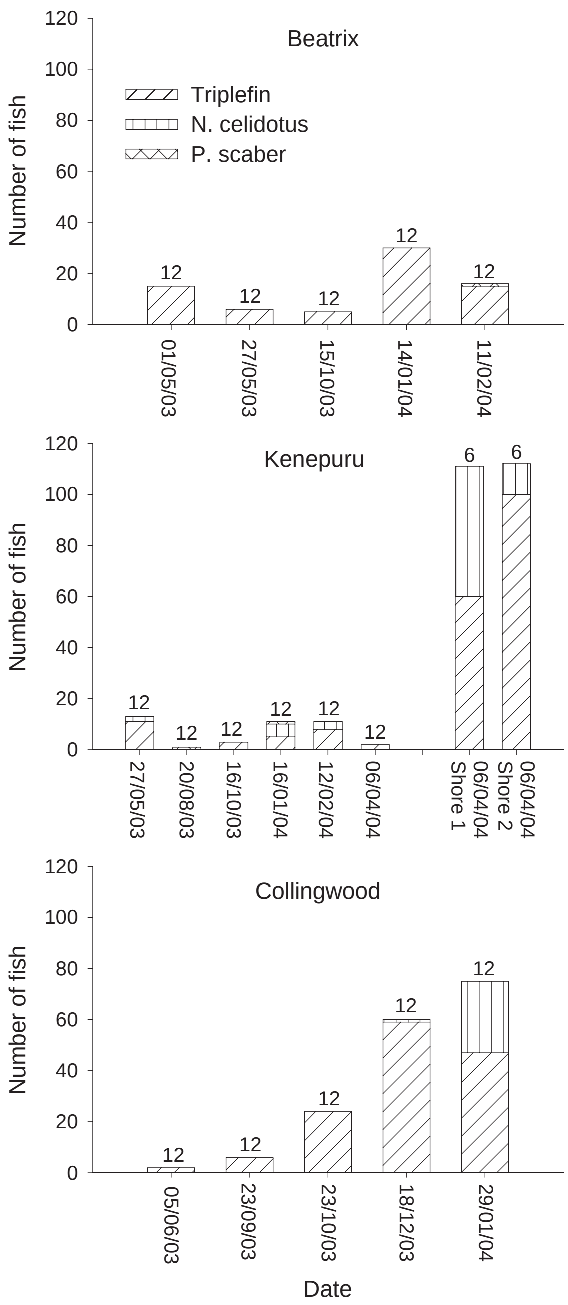

Fig. 4. Numbers of each species of fish recorded in diver counts of 10×2-m transects at each time of sampling. Numbers are totals for all transects on both longlines sampled each time, and are not standardised to unit length of dropper. Numbers above bars are number of transects sampled. Species recorded were triplefins (not identifiable to species), *Notolabrus celidotus* and *Parika scaber*.

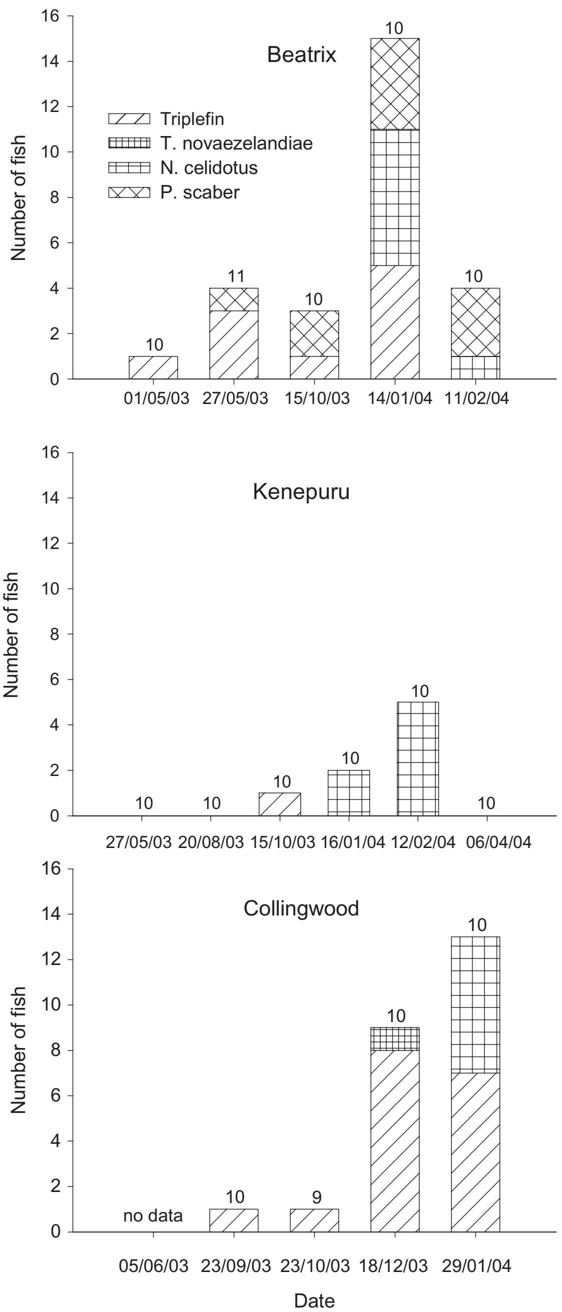

Fig. 5. Numbers of each species of recorded by ROV transects at each time of sampling. Numbers are totals for all 5 droppers on both longlines sampled each time, and are not standardised to unit length of dropper. Numbers above bars are number of droppers sampled. Species recorded were triplefins (not identifiable to species), *Trachurus novaezelandiae*, *Notolabrus celidotus* and *Parika scaber*.

made. Differences among farms in abundances of fish were small but abundances were usually smallest at Kenepuru. Abundances were generally higher in summer.

Median numbers of fish m^{-1} recorded by the Aqui-S method ranged from 0 to 1.25, while maximum numbers ranged from 0.5 to 4.5 m^{-1} (Table 2). Median and maximum abundances were generally lower over the winter (May–October) and increased over the summer (December–February) for all the methods (Fig. 2). Median numbers of fish m^{-1} were usually lowest at Kenepuru irrespective of method used but differences between farms were small (Fig. 2). Fish collected by the Aqui-S method were predominantly triplefins: Fig. 3). Identification of individuals to species was more reliable for this method than the visual techniques and allowed more species to be discriminated, although it was not possible to identify all juvenile triplefins to species. One leatherjacket and 1 thornfish were also collected by Aqui-S. This method did not collect any spotties, even though these were present around the lines, as determined by visual methods.

Diver counts were dominated by triplefins (Fig. 4), but small spotties were commonly recorded, especially over summer (all individuals seen were juveniles smaller than ca. 5 cm total length). Total numbers of fish recorded were, however, usually small for all locations, and particularly for the 30×4-m transects (except for the shore transects). Triplefins and spotties were equally abundant on one of the shore transects at Kenepuru in April but triplefins were dominant on the second. In contrast to the mussel droppers, adult spotties were common at the shore sites. ROV counts were generally dominated by triplefins during winter, but by spotties in January and February (Fig. 5).

Small and inconsistent numbers of fish recorded by all methods precluded formal statistical comparisons among farms, times of sampling or methods. Comparisons of standardised counts (Table 2) showed that the Aqui-S method consistently recorded more fish m^{-1} than either diver or ROV counts. The maximum number of fish m^{-1} was highest using Aqui-S for all 13 occasions. On only 3 out of 13 sampling occasions in Table 2 where all 3 methods were used was the median count (m^{-1}) for Aqui-S the same as or less than that of another method. On 2 of these occasions the median was 0 for all methods. Differences between diver and ROV counts were not consistent, suggesting that either the divers caused no more disturbance to fish than the ROV, or that greater disturbance was compensated for by increased intensity of searching. Numbers of fish recorded on the shore transects at Kenepuru in April were much larger than on the mussel lines (compare, for example, diver counts along 30 × 4-m transects in Table 2).

Median lengths of triplefins estimated by divers were 3–5 cm at Beatrix, 6 cm at Kenepuru and 3–7 cm at Collingwood for those times when more than 3 fish were observed (summed across all replicates of 10-m and 30-m transects on both lines for each time of sampling). Median lengths of fish from the shore counts at Kenepuru in April were the same as on the Kenepuru farm (6 cm).

Two of the species recorded were present only as juveniles (thornfish and spotties), and 3 as adults and juveniles (the 2 species of triplefins, and leatherjackets). *G. gymnota* is often associated with larger invertebrates such as mussels (Francis, 2001), and was almost the only species of triplefin recorded at Collingwood (of 47 triplefins identified to species, only 1 individual of *F. lapillum* was found), whereas *F. lapillum* was also consistently present at the other 2 sites.

Casual observations of fish made by divers included solitary adult leatherjackets that often followed divers during Aqui-S sampling at Beatrix. A school of yellow-eyed mullet (*Aldrichetta forsteri*) was seen around the mussel lines at Kenepuru in January, February and April 2004, and an unidentified pipefish was seen at the same site in January. A small school of kingfish (*Seriola lalandi*) was seen on one occasion at Kenepuru and an individual kahawai (*Arripis trutta*) at Beatrix. Seahorses (*Hippocampus abdominalis*) were occasionally found on farm structures.

4. Discussion

4.1. Diversity of fish on mussel lines

The variety of fish recorded during the study was small, consisting of only 5 species of predominantly demersal carnivores typical of shallow reefs and benthic sediment in the area, and 1 pelagic species. Of the demersal species identified as potential occupants of mussel farms (Table 1), triplefins and spotties were the dominant taxa present, while leatherjackets were commonly present. Leatherjackets were recorded more by divers than by the ROV, probably because they were attracted to divers. Two other demersal taxa, seahorse and pipefish, were observed on the farms occasionally. Of the pelagic species, only 1 was recorded during sampling (a jack mackerel recorded by the ROV on one occasion at Collingwood). Kingfish, kahawai and yellow-eyed mullet were, however, seen by divers on a few occasions. Our observations suggest that lines are used by the common demersal species present in the area but that although some pelagic species do pass through the farms, there is no evidence that they make regular use of the farms. Our sampling was limited by depth (apart from the ROV counts), and this may have led to underestimation of diversity. Hair et al. (1994) reported species-specific patterns of settlement with respect to depth among coastal fish in New South Wales. Habitat selection by recruits may reflect vertical distribution of larvae (Carr, 1991).

We did not find any evidence of significant populations of recreationally important species, such as snapper or kingfish, associated with the lines. Our failure to observe pelagic species may have been due to the limited visibility under water. Such species may occur mainly around the boundaries of farms, which would compound the problem. Snapper and other reef-associated species important to recreational fishers could be associated with the seabed around farms, although farms are not placed above reefs and Carbines (1993) did not report these species over sediment or cobbles at his study sites. Snapper are rarely observed by divers in the northern part of the South Island of New Zealand even in places where they are recreationally fished (Cole and Davey, personal observation). Little is known about recruitment of many recreationally important local species, including snapper and blue cod.

4.2. Abundances of fish on mussel lines

The numbers of fish recorded were small and temporally variable, both in absolute numbers and in comparison with abundances in adjacent shallow subtidal areas on the occasion that habitat was sampled. Small fishes “show disproportionately low levels of detectability by diver" (Edgar et al., 2004), and small, cryptic fishes may be underestimated by an order of magnitude even when searched for very carefully (Willis, 2001). The fact that much larger numbers of the same species were recorded on the transects in the shallow subtidal areas suggests that the low abundances on the farms were not an artefact of the method of sampling. Differences in relative abundances of the species recorded by different sampling methods may reflect differences in the way that each species uses the habitat provided by the droppers and the methods are, therefore, complementary rather than comparable. Triplefins hide among the mussels and so get caught by the Aqui-S method, whereas spotties and leatherjackets swim away when disturbed and are not sampled effectively by this method. Fish hiding among the mussels were not visible on the video recordings made using the ROV and this method would underestimate abundances if fish avoided the ROV. Divers, on the other hand, may disturb some species more than the ROV but were able to make more detailed visual searches of the lines. The 30×4-m diver transects recorded very few fish because the diver was focusing on searching for fish in the water column rather than making detailed searches of the droppers. Given the generally poor visibility, therefore, these low counts are not surprising. In retrospect, alternative methods of sampling pelagic species, such as angling or baited or time-lapse video, might have been more effective.

Carbines (1993) also found small numbers of spotties on the upper 4 m of droppers on mussel farms at 4 locations in Kenepuru Sound and Pelorus Sound (near Beatrix Bay), sampled over a year. Abundances were estimated by underwater visual census and highest abundances on droppers at these locations occurred in summer. Carbines' transects were 50 m long and 4 m high, running horizontally along the droppers. Standardising Carbines' data and those from the 30×4-m transects in the present study shows that our maximum recorded values (equivalent to 4 and 23 spotties per 100 m^2 of area searched at Kenepuru and Collingwood, respectively, in January) were similar to or larger than those recorded by Carbines' (maximum average abundance of 5 spotties per 100 m^2 at Kenepuru in summer). These 2 datasets indicate that, for spotties, abundances on mussel lines in the Marlborough Sounds are small relative to nearby reefs and farm anchor blocks, where abundances of up to 240 and 80 per 30×5-m transect, respectively, were recorded (Carbines, 1993).

4.3. Factors affecting diversity and abundance

Recruitment of spotties (and possibly triplefins) is spatially and temporally variable (Jones, 1984a). The small abundances observed may simply be a consequence of low recruitment prior to or during the study, although the fact that Carbines (1993) also found small abundances makes this less likely. Fish are killed or removed from the farm when mussel lines are sequentially harvested through the year (Handley, personal observation), potentially reducing the total farm population between recruitment events. Harvesting is usually attended by large numbers of gulls and other piscivorous birds and, probably, fish, and many fish leaving the lines may be eaten.

Recruitment of juvenile fish to droppers may be limited by low abundance of macroalgae or by antagonistic interactions among individuals or species. Many species of triplefins defend territories (2–3 m^2: Thompson, 1986; Francis, 2001), so their abundance on the lines may be set by territory size. Interspecific aggression by triplefins may also limit recruitment of other species to the dropper ropes. *Forsterygion varium* behaves aggressively towards spotties (Thompson and Jones, 1983; Carbines, 1993), and only larger (≥ 18 cm) spotties are able to dominate in these interactions. Spotties and triplefins overlap in the size and type of prey taken, and territoriality may relate to protection of food resources. However, greatest resource overlap and strongest aggressive behaviour occur between *F. varium* and spotties between 11 and 16 cm long (Thompson and Jones, 1983), whereas spotties recorded on the mussel lines were <8 cm.

Space is less likely to limit abundances of juvenile spotties because they associate in loose groups, rather than occupying territories (Jones, 1984b). Spotties recruit to macroalgae at a length of 1.5–2 cm and their recruitment, and the abundance of juveniles, is strongly correlated with the biomass of macroalgae (Jones, 1984a,b). Carbines (1993) proposed that spotties recruit to stands of macroalgae on nearby shallow reefs and then migrate as larger juveniles to deeper areas with less algal cover, including mussel farm anchor blocks and the seabed beneath the longlines. Observations during this study indicate that juvenile spotty use fronds of *Undaria pinnatifida* on the longlines for shelter, for example when disturbed by a diver. In the Marlborough Sounds, spotties probably spawn in October–January and recruit to macroalgal beds 2 months later (Carbines, 1993). Data from Carbines' study and from ROV counts in this study indicate that peak abundances of spotties on the mussel lines occur in January, and all fish seen on the lines were small (<8 cm). The presence of large algae on the lines is temporally variable, being least on lines with young stock, but varying even among lines with mature stock. The biomass of *Undaria* (the only large macroalga found on the mussel lines deeper than ca. 1 m) is minimal over the summer (Brown, 1999 and observations from the present study). Recruitment of spotties to the lines may, therefore, be limited by the abundance of macroalgae. *Undaria* is an introduced species and around our study sites is predominantly present on mussel farm structures, though it is recorded from natural substrata in other parts of the Marlborough Sounds (Brown, 1999). Carbines (1993) also noted that spotties recruited in small numbers to the mooring lines of mussel farms, and that removal of the fouling assemblages on the lines reduced abundances.

Triplefins generally live for about 3 years (Francis, 2001), and it is possible that those on mussel lines spend their entire lives there after settlement. Maximum sizes for *F. lapillum* and *G. gymnota* are 8 and 9 cm, respectively (Francis, 2001), so most of those recorded in this study may not have been fully grown. *F. lapillum* matures at about 5 cm, which is around the median size of individuals at all 3 sites for at least some sampling times, suggesting that the populations on the farms are capable of breeding (the larvae are planktonic and settle at a length of 1.5–2 cm: Francis, 2001). Both species are usually associated with shallow reefs, which makes it likely that those on the Collingwood farm at least have recruited onto the farm and spent their whole lives there since they are not likely to have moved there from the adjacent coast across >2 km of open, muddy seabed.

5. Conclusions

Our study did not support the hypothesis that mussel farm structure provides habitats for significant numbers of recreationally or commercially important fish in the Marlborough Sounds or Golden Bay. Rather, fish assemblages were dominated by species characteristic of local demersal habitats. Generalising from our study to a broader spatial scale, the composition of the fish fauna of longline mussel farms may depend on the available pool of species in the area and the suitability of farms as habitats for each species. The species composition and relative abundances of demersal species from this pool are likely to vary temporally in response to changes in factors such as larval supply and as a result of biological interactions, including the types and abundances of fouling organisms. Abundances of pelagic species will also vary seasonally in response to population movements, availability of larvae and juveniles, and hydrodynamic factors. As a result, the fish fauna of a given farm is likely to be site-specific, variable over time and difficult to predict. The importance of farms in providing additional habitat for recruitment may be greatest in places where there is high availability of juvenile fish and where the availability of suitable natural habitats is limited (Hair et al., 1994).

The methods used were successful in terms of sampling demersal species, but less so for pelagics, and the use of a set of complementary methods proved to be appropriate. Sampling methods for future studies should be selected on the basis of the types of species likely to be present, and local conditions, particularly water clarity. Where clarity is poor, consideration should be given to the use of methods other than diver counts. Surveys of anglers using farms and surrounding areas may provide useful information on distribution and abundance of target species. Factors that could usefully be incorporated into future work include variation in distribution of fish with depth, availability of recruits around farms, patterns of development of fish assemblages from seeding of the longlines to harvest, and the fate of fish at harvest.

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