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Depth distribution and abundance of benthic organisms and fishes at the subtropical Kermadec Islands

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Abstract Subtidal areas of the Kermadec Islands have not previously been described; samples from a bay at Raoul Island are discussed here. Abundances and percentage cover of benthic organisms were assessed from the high intertidal to 20 m depth using quadrat sampling. Fish abundances were assessed subtidally by random transects in shallow (3–6 m deep) and deep (14–20 m) areas of the reef. Hard corals occurred at 2–18 m depths at densities of 5 colonies per m^2, but colonies were generally small. Soft coral colonies occurred at similar densities, but were confined to depths of 5–13 m. The mean percentage cover of corals did not exceed 20% at any one depth, and coral reefs did not occur. Fucalean and laminarian algae were not seen. The most abundant algae were foliose and filamentous species, and encrusting red algae. These covered over 80% of the reef at some depths. Grazing invertebrates were not abundant. Echinoids were found primarily in shallow water, reaching a density of 5 per m^2 at 5 m depth. The most abundant gastropod was the endemic limpet, *Patella kermadecensis*, which reached densities of 21 per m^2, and was confined entirely to a zone in the low intertidal-shallow subtidal region. Mid to high intertidal areas were mostly barren, with high numbers of *Nerita atramentosa*, but few other invertebrates. Forty-five species of fish were seen, 11 of which were new records for the Kermadec Islands. Several herbivorous fish (kyphosids, pomacentrids, and aplodactylids) were found mostly on shallow areas of the reef. Labrids were abundant, especially *P. luculentus*. The inshore communities seen at Raoul Island represent a mixture of temperate and tropical forms. Corals were sparsely distributed and stands of large brown algae were not encountered. Sea urchins were abundant in patches, whereas larger herbivorous fish were found only in shallow water. The geographic isolation of these islands and their relatively recent geological history may be the most important factors affecting species composition for this area of the Pacific Ocean.

Keywords Kermadec Islands; distribution; abundance; benthic organisms; fish; subtropics; biogeography; new records

INTRODUCTION

The Kermadec Islands are an isolated group of 11 islands and islets located north-east of New Zealand at a latitude of 30°S. They are of considerable biogeographic interest because they lie equidistant between temperate New Zealand and tropical Tonga and are one of the few subtropical island groups of the western South Pacific Ocean. The others are Lord Howe Island, off the east coast of Australia, and Norfolk Island, lying approximately midway between Australia and New Zealand (Fig. 1). Unlike these island groups, however, the marine biota of the Kermadecs have been only cursorily examined. Their isolated location, active volcanos, rugged coastline, and precarious boat landings have made expeditions difficult (Smith 1896; Healy et al. 1965; Sykes 1965). These islands are uninhabited except for 5 persons who maintain a weather station.

The Kermadecs are a young group of active volcanic islands, no older than the Pleistocene (Brothers & Searle 1970; Doyle et al. 1979), and are summits of volcanic cones arising from the Kermadec sub-oceanic ridge (Lloyd & Nathan 1981). These islands lie at a minimum distance of 750 km from any land mass and the currents flowing past them are poorly described. Presumably, it is a major hurdle for organisms to reach the Kermadecs. As for other remote islands, we expected the marine biota to reflect this biogeographic isolation (cf., Dell 1958; Randall 1976, 1978). The terrestrial flora has been extensively surveyed and is derived mostly

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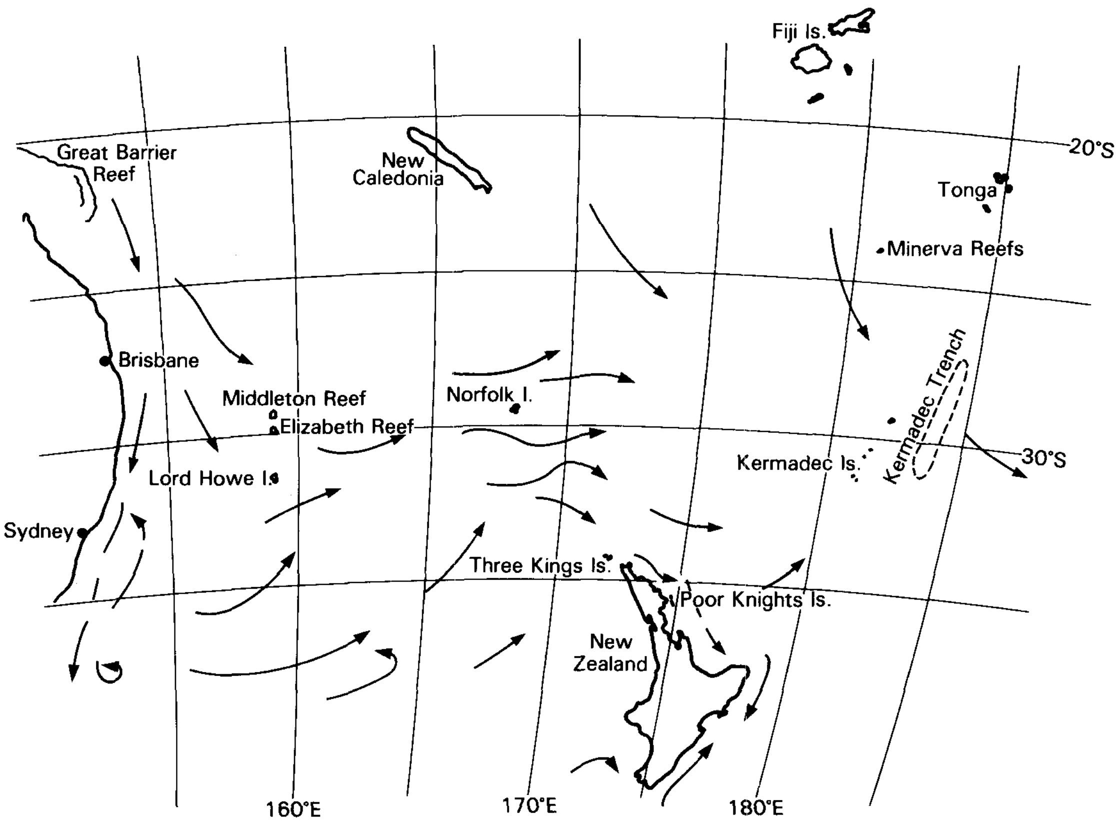

Fig. 1 Map of the south-west Pacific Ocean showing locations of the major land masses. The major oceanic currents are indicated by arrows. Current patterns were compiled in consultation with Professor S. Harris from information in Wyrtki (1960, 1962), Donguy & Henin (1977), Habib et al. (1982), and Couper (1983).

from northern New Zealand, with a relatively low incidence of endemism (Hemsley 1888; Oliver 1910; Sykes 1969, 1977).

We had several interests in examining the marine biota of the Kermadec Islands. The temperature shores of northern New Zealand and its offshore islands are characterised by stands of large brown algae and associated organisms (Choat & Schiel 1982). Many species of carnivorous benthic-feeding fishes are abundant, whereas herbivorous species are less numerous (Russell 1977; Leum & Choat 1980; Ayling 1982; Jones 1984). The most important grazers are regular echinoids, and several species of herbivorous gastropods are common (Ayling 1981; Choat & Schiel 1982). There is considered to be a strong subtropical influence in the fauna of northern New Zealand (cf., McDowall 1979; Powell 1979; Ayling 1982), and several groups, for example labrid and pomacentrid fish, are more abundant at lower latitudes. In contrast to temperate areas dominated by macroalgae, tropical shores are characterised by reefs of hermatypic scleractinian corals (Veron 1974; Abel et al. 1983; Lubchenco et al. 1984). The dominant grazers are many species of herbivorous fishes (Sale 1980; Russ 1984a, b). The land mass of New Zealand does not extend into subtropical seas, however, so it is of special interest to examine the closest subtropical area where both temperate and tropical species can co-occur (cf., Choat 1982).

Of particular interest to us were the abundance and depth stratification of major species. Stands of fucalean and laminarian algae are found in depths of < 20 m on most temperate shores, with the major concentration of biomass < 7 m (Mann 1972; Kain 1979; Choat & Schiel 1982; Foster & Schiel 1985). This has potential importance in areas where macroalgae and corals may co-occur. The decrease

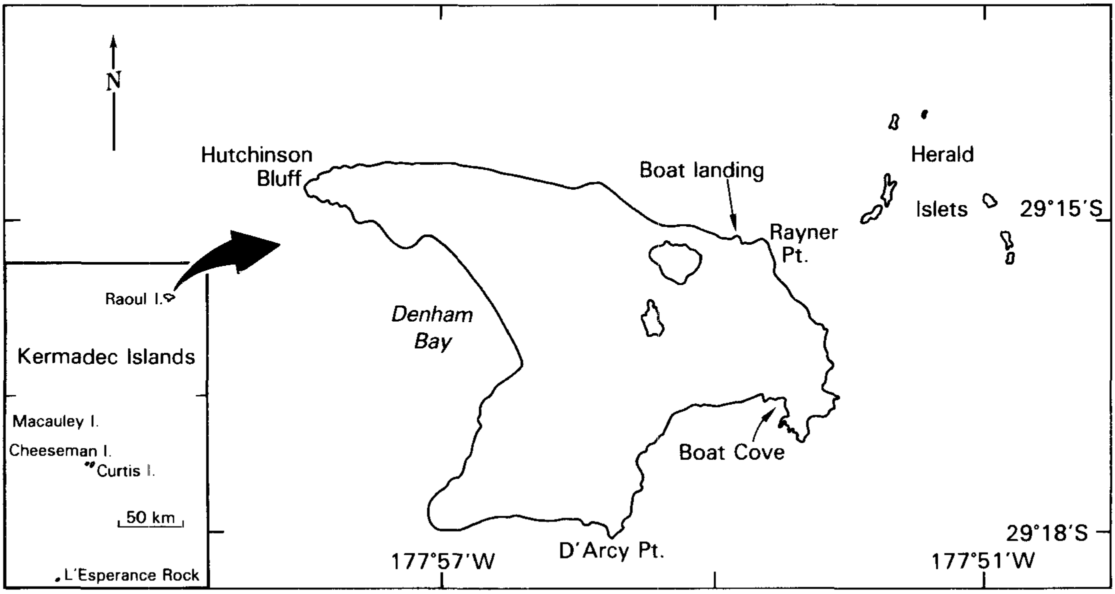

Fig. 2 Map of the Kermadec Islands (inset) and details of Raoul Island.

in the abundance of corals to the south of tropical areas of Australia has been attributed to increasing competition with macroalgae (Johannes et al. 1983). In other tropical localities, Lubchenco et al. (1984) suggested that the low abundance of macroalgae is the result of intense grazing pressure by fishes and some invertebrates. An area where macroalgae and corals co-occur, such as the Kermadec Islands (Morton & Miller 1968), provides an ideal location to examine the relationships of these dominant reef organisms in terms of their distribution and abundance.

The chief purpose of our expedition was to assess the distribution and abundance patterns of: corals and large brown algae; herbivorous invertebrates, particularly sea urchins and gastropods; fishes, with particular reference to browsing and grazing herbivorous species. We could then compare these patterns of distribution and abundance with northern New Zealand and with nearby subtropical and tropical areas.

MATERIALS AND METHODS

Study locality

This study was done during March 1984 at Raoul Island (29°15′S, 177°57′W), the largest and northernmost island in the Kermadec group (Fig. 1, 2). Raoul Island is 29.25 km^2 in size and has an extremely rugged coastline, with cliffs 130 m high around most of the island. It is exposed to a large oceanic swell, particularly on the northern and eastern sides. Our intent had been to visit as many areas as possible in a week, but transport problems after two days at the Kermadecs modified our sampling plans and restricted sampling to one site. All of the subtidal data were gathered using SCUBA gear at Boat Cove, on the south-east side of Raoul Island. This site is normally more sheltered than the rest of the island, but it is exposed to occasional large storms.

The current patterns in this area of the Pacific Ocean are not well known, but are of interest for biogeographic comparisons. Available information indicates that the main flow is eastward from New South Wales towards Norfolk Island, then on towards northern New Zealand (Habib et al. 1982). Currents may approach the Kermadec Islands predominantly from the west and north-west. A slight seasonal flow is also suggested northward from New Zealand to the Kermadec Islands (Wyrtki 1960, 1962; Donguy & Henin 1977; Habib et al. 1982; Couper 1983; Prof S. Harris, Leigh Marine Laboratory, pers. comm.).

Sampling for benthic organisms and fish

Replicated, random quadrats were used to sample benthic organisms at various distances along a depth gradient from the high intertidal to a depth

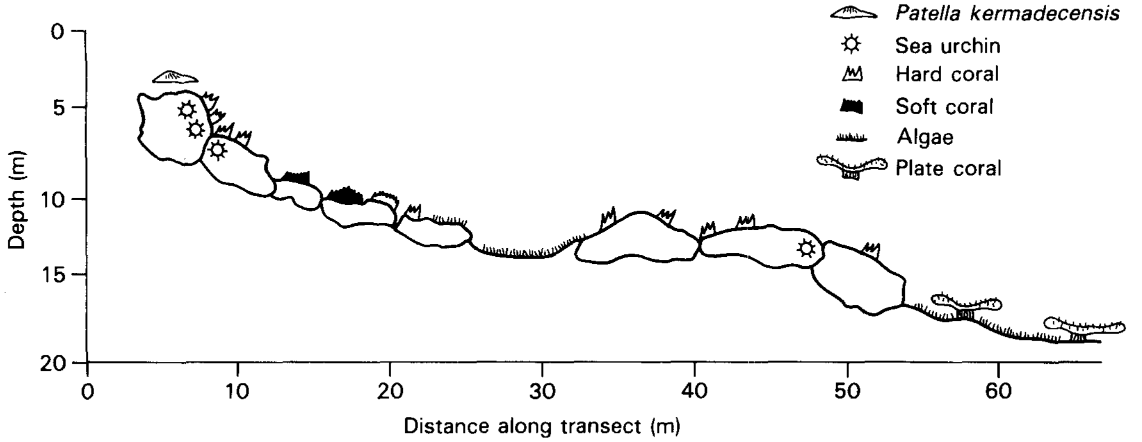

Fig. 3 Diagrammatic representation of a generalised transect from the immediate subtidal to a depth of 20 m at Boat Cove. The major benthic organisms are shown schematically.

of 20 m. A fibreglass tape was placed down the shore in Boat Cove. Random numbers were used to place quadrats ($n \geqslant 4$) within 10 m of this line at each depth interval. Samples were taken of many benthic organisms for later identification in the laboratory. Some of these were lost during transport and, consequently, the species list is incomplete. The remaining specimens are held at the Leigh Marine Laboratory, University of Auckland, and the National Museum of New Zealand, Wellington.

Intertidal sampling was done at two levels on the shore within the 2 m tidal range. Ten 0.24 m² quadrats were assessed at the upper level of the shore and at mid-tide level, over a horizontal range of 10 m. Another 10 quadrats were sampled at the surgy low-tide mark. Algae and invertebrates were counted, where possible. Percentage cover of attached organisms was assessed using the random point contact (RPC) method (n = 10 points per quadrat) described by Foster (1982). Limpets were measured for total shell length in these and other haphazardly-selected quadrats.

For subtidal sampling, the number and percentage cover of benthic organisms were assessed along a profile from 1 m below mean tide level to 20 m depth. Quadrats of 1 m² ($n \geqslant 5$) were sampled along a 10 m horizontal distance at 2.5 m depth intervals. The depth change of the reef below 12 m was gradual, and a depth of 20 m was reached some 100 m from shore. The percentage cover of attached organisms was assessed using the RPC method. Mobile invertebrates and the maximum widths of corals were measured. In addition, samples were taken of many species of algae, corals, molluscs, and echinoderms.

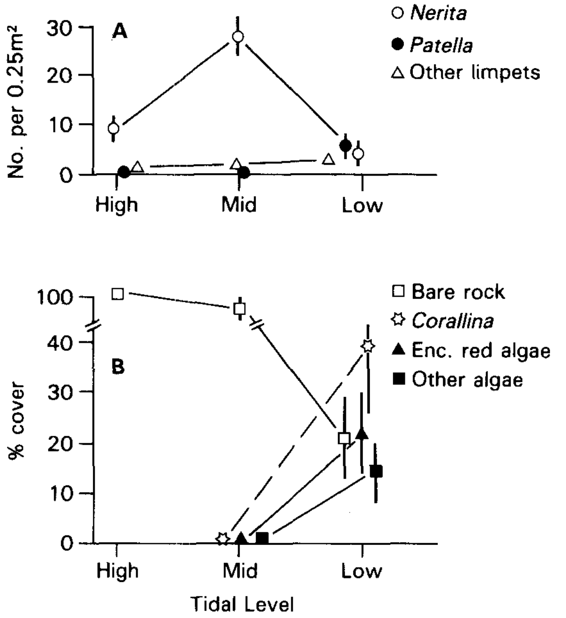

Fig. 4 The abundances of intertidal benthic organisms in random quadrats at Boat Cove. Mean numbers (±1 S.E.) per 0.25 m² are shown for the gastropods (**A**), and mean percentage cover (±1 S.E.) for algae (**B**). The vertical distance between high and low tides was 2 m.

Fishes were counted in 50 × 10 m (500 m²) transects (n=3) at a shallow (3–6 m) and deep (14–20 m) site (cf., Russell 1977; Leum & Choat 1980).

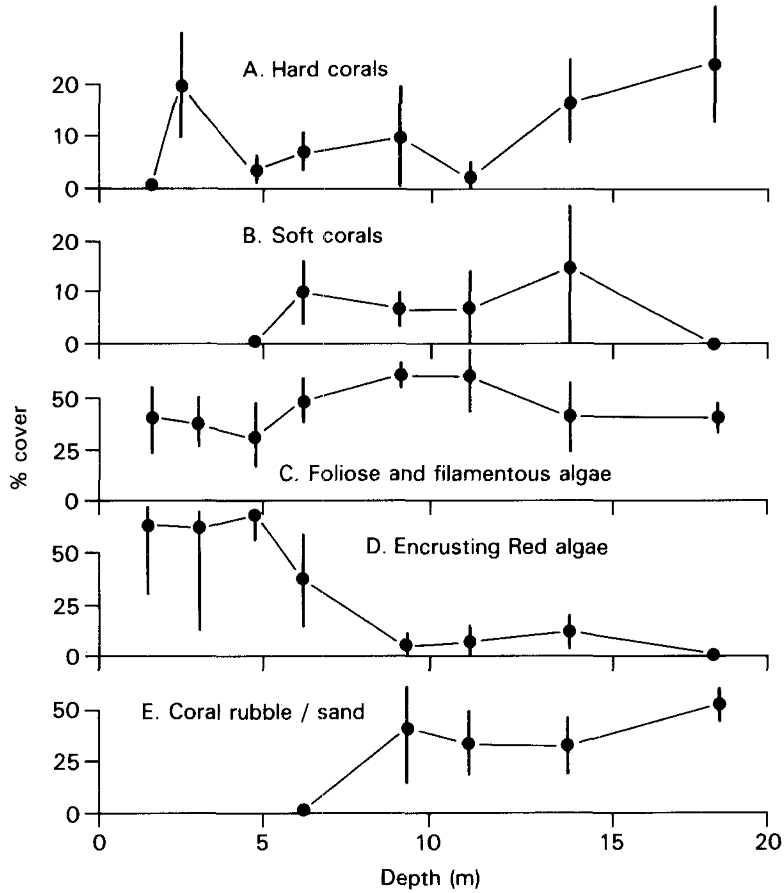

Fig. 5 The abundances (mean ±1 S.E.) of corals and grazing invertebrates in random 1 m^2 quadrats at various depths at Boat Cove. The major groupings of benthic organisms surveyed are shown on graphs.

Individuals of each species were noted and the standard lengths of most fish were estimated visually. Samples of most species encountered were taken by hand spears, and they are catalogued in various museums (see Results). The information presented here is a species list and species abundances at two depths.

RESULTS

Benthic organisms

Relatively small colonies of hard and soft corals were abundant, particularly at shallower depths, and larger plate corals were seen in deeper water (shown diagramatically in Fig. 3). Tuft and encrusting algae were common at all depths along the reef. No fucalean or laminarian algae were seen in Boat Cove or in other inshore areas observed from boats. The most abundant grazing invertebrates encountered were limpets in the immediate subtidal, and sea urchins of various species in patches in shallow water and as isolated individuals scattered along the reef.

Most of the intertidal area of Boat Cove consisted of bare rock, with few encrusting organisms and little or no algae at the high- and mid-tide marks (Fig. 4). The most abundant organism was the snail *Nerita atramentosa* Reeve, which occurred at mean densities of 10 per 0.25 m^2 on the high shore and 28 per 0.25 m^2 on the middle shore (Fig. 4A). Barnacles, *Tesseropora* sp., were found as scattered individuals, and *Leptograpsus* sp. were the only other animals seen in the high to mid intertidal.

The most conspicuous animal at the extreme low-tide mark was the endemic limpet *Patella kermadecensis* Pilsbry. These occurred at densities of 5 per 0.25 m^2(Fig. 4A), and individuals were usually located in homing scars amongst the turf algae. Other endemic limpets, *Cellana craticulata* (Suter) and *Siphonaria raoulensis* Oliver 1915 (Powell

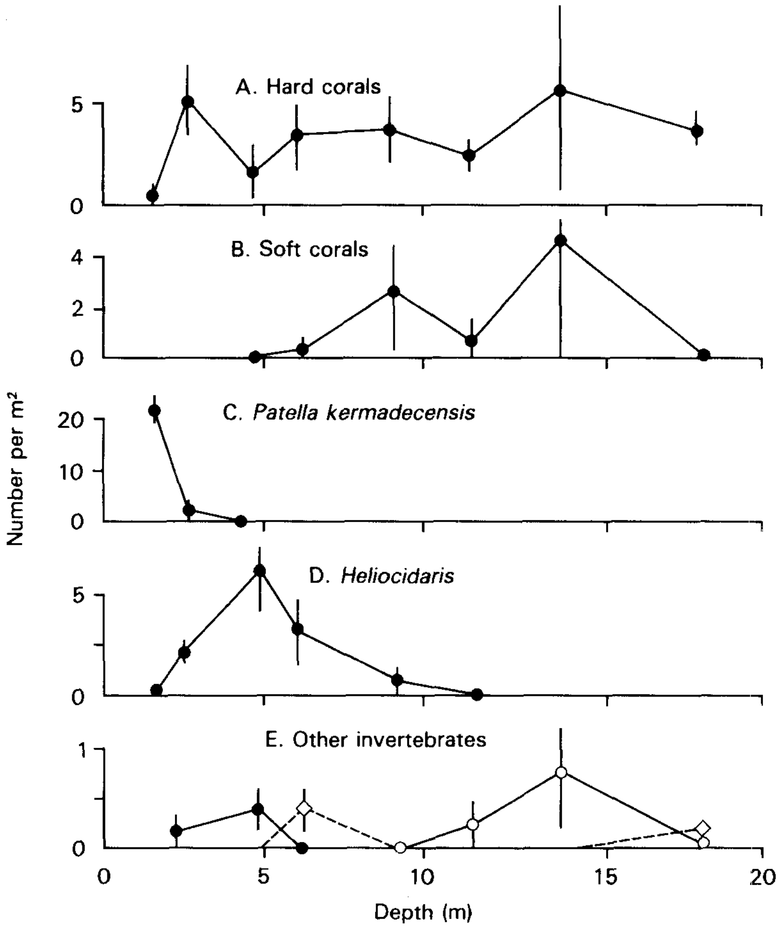

Fig. 6 Percentage cover (mean ±1 S.E.) of corals and algae in random 1 m² quadrats at various depths at Boat Cove. The major groupings of benthic organisms surveyed are shown on graphs.

1973), were also found in the same areas, at a combined density of about 2 per 0.25 m² (Fig. 4A). At the low tide mark, there was c. 75% cover by algae of several species (Fig. 4B; we did not identify to the species level in the field). Articulated coralline algae (*Corallina* sp.) covered 39% of horizontal rock surfaces, and encrusting red algae (possibly *Lithothamnion* sp. and *Apophloea* sp.) had 22% cover. Other algae, mostly filamentous reds and greens, had a cover of 14%.

We have categorised the attached benthos found in subtidal areas into five groups: hard corals, soft corals, foliose and filamentous algae, encrusting algae, and coral rubble/sand. Hard corals were found over the entire depth range sampled, except at the shallowest station in the immediate subtidal (Fig. 5A). The hard corals in our samples were *Goniastrea favulus* (Dana), *G. australensis* (Edwards et Haime), *Montastrea curta* (Dana), *Cyphastrea* sp., *Pocillopora* sp., and the large plate coral *Turbinaria* sp. The mean numbers of hard coral colonies reached 5 per m² at 3 m depth, but there were similar mean numbers of 2–3 per m² at most depths (Fig. 5A). Peaks in the mean percentage cover occurred at 3 m and at 13–18 m, but the variance was high at some depths (Fig. 6A). There were differences, however, in the sizes of corals with depth. From 2–13 m in depth, coral colonies were generally small in size, ranging from 20–128 mm in diameter in our samples ($\bar{x}$ = 61.4 mm, s.d. = 34.81, n = 45). In deeper water (13–20 m), however, plate corals (*Turbinaria* sp.) were also found (Fig. 7), measuring from 0.1–2.4 m in diameter ($\bar{x}$ = 76.2 cm, s.d. = 58.69, n = 18).

The mean number of colonies of soft corals, mostly *Efflatounaria* spp., at depths of 5–13 m was 1–4 per m², but the variance was high, indicative of their patchy distribution (Fig. 5B). Soft corals had a mean percentage cover of 8–10% at depths from 5–13 m, and were not seen at the shallowest

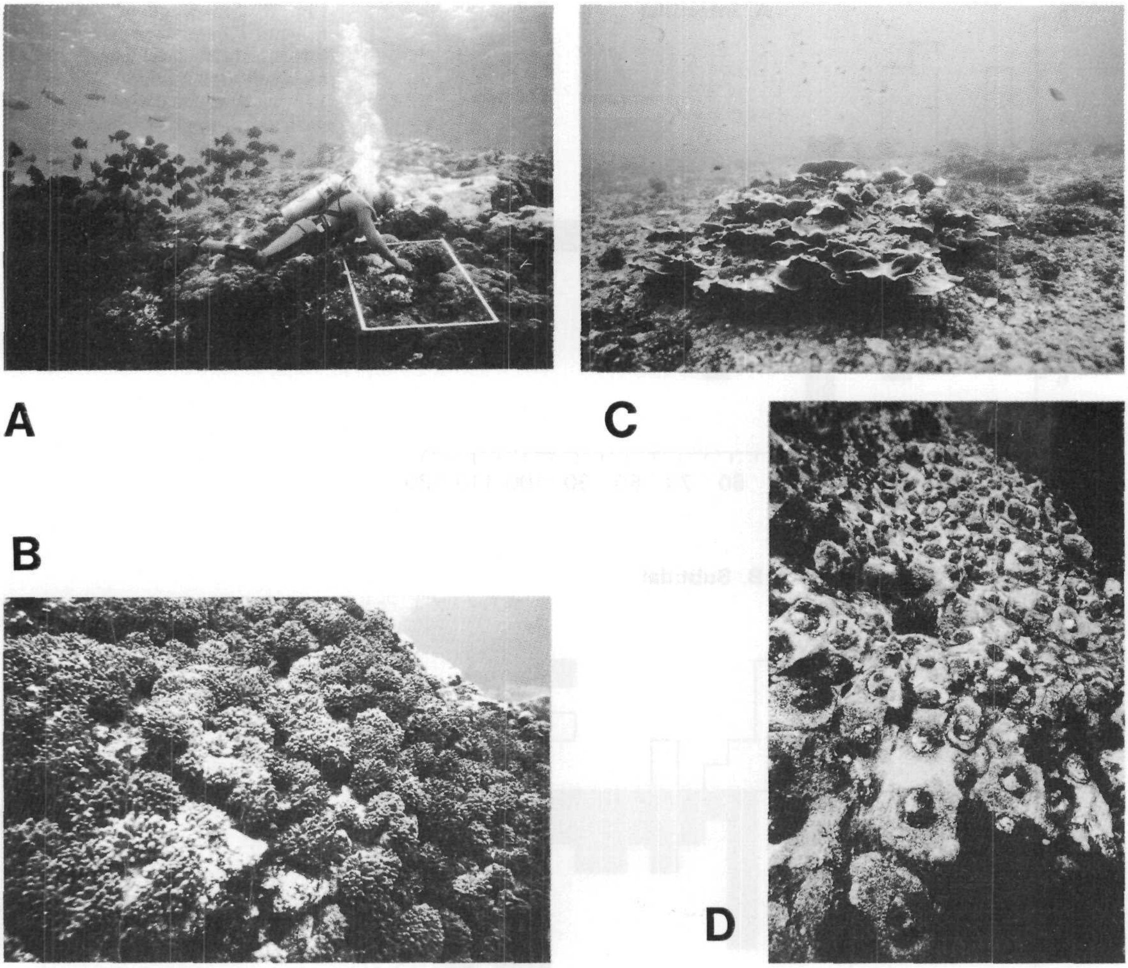

Fig. 7 Photographs showing various features of subtidal habitats at Boat Cove, Raoul Island. **A.** Shallow reef (3 m depth) showing patches of soft corals (darker areas on boulders) and hard corals (in the whitish patch above diver). Quadrat is 1 m^2. Fish in the background are *Kyphosus fuscus* and *Girella cyanea*. **B.** Patch of soft corals, *Efflatounaria* spp., at 7 m depth. Patch is ~1.5 m across. **C.**Plate coral, *Turbinaria* sp., at 18 m depth. Small fish above coral are *Chrysiptera rapanui*. Coral is ~1 m across. **D.** *Patella kermadecensis* on boulder at 1–2 m depth. Area shown is ~1 m across.

or deepest stations (Fig. 6B). Although individual colonies ranged from 35–190 mm in diameter ($\bar{x}$ = 95.9 mm, s.d. = 42.71, n = 14), they often formed large aggregations over 1 m in diameter, and completely covered the surfaces of many boulders at intermediate depths (Fig. 7).

Foliose and filamentous algae, mostly reds, had mean percentage covers in the range of 28–55%, at all depths sampled (Fig. 6C). This cover extended from the hard, rocky substratum of boulders in shallower areas to the reef flats in deeper water. Encrusting red algae had a mean coverage of c. 65% at depths to 5 m, gradually falling off to 5% or less beyond 9 m depth (Fig. 6D). This decline coincided with the occurrence of coral rubble in deeper water. A compacted substratum of coral rubble, sand, and some algae occupied 30–50% of the reef surface between 9 m and the deepest stations that we sampled (Fig. 6E). Species of several genera of algae were seen in quadrat samples: *Codium, Caulerpa, Enteromorpha, Feldmannia, Colpomenia, Dictyota, Dictyopteris, Padina, Liagora, Asparagopsis, Delisea, Gelidium, Pterocladia, Corallina, Plocamium, Champia*, and *Polysiphonia*.

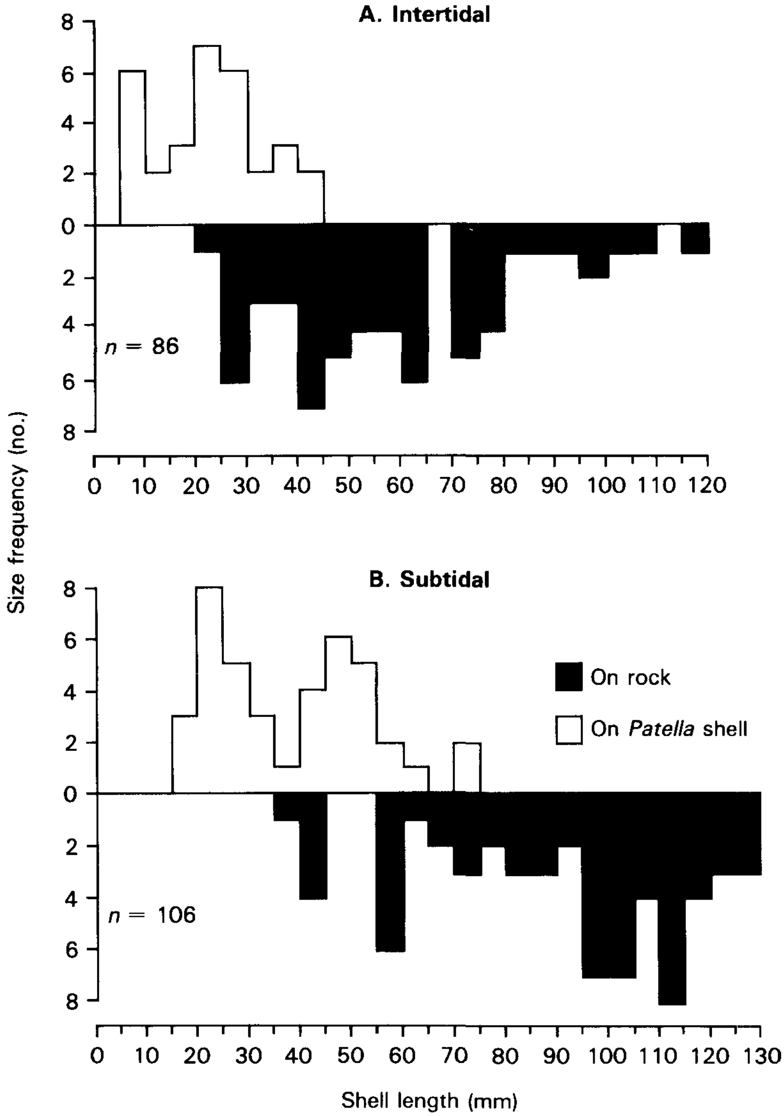

Fig. 8 Size-frequency distributions of *Patella kermadecensis* on low-intertidal boulders (**A**) and high-subtidal boulders (depth = 1–2 m; **B**) at Boat Cove. Shading indicates limpet attached to boulder; non-shaded means attached to another limpet.

Grazing invertebrates were conspicuous on many parts of the reef. Particularly noticeable was the large limpet *Patella kermadecensis* (Fig. 7D). This gastropod reached a mean total density of 21 per m^2 in the immediate subtidal (1–2 m), covering virtually the entire surfaces of some boulders, and did not occur at all below 3 m depth (Fig. 5C). We saw this limpet at similar densities at Boat Landing. In Boat Cove, *P. kermadecensis* were extremely large, reaching shell lengths of 128 mm. A noteworthy difference occurred, however, in the narrow depth zone between the intertidal and subtidal. Most limpets attached to low intertidal rocks were < 75 mm in shell length, the largest being 118 mm (Fig. 8A). Most limpets smaller than 45 mm were attached to the backs of larger limpets, which were often seated in a homing scar. The largest individuals, however, were found on subtidal boulders at 2–3 m depth (Fig. 8B). Most limpets smaller than 60 mm, and all below 35 mm, were found on the backs of larger *P. kermadecensis*. Up to 8 small limpets were seen on the shells of larger specimens.

Table 1 Families, species, and abundances of fish encountered in random transects at two depths (3–6 m and 14–20 m) in Boat Cove. Numbers are mean ± 1 S.E. per 500 m². The recorded distribution of species is indicated: E = Endemic, EA = East coast of Australia, El = Easter Island, LH = Lord Howe Island, N = Norfolk Island, NC = New Caledonia, NSW = New South Wales, NZ = New Zealand, WA = Western Australia, WS = widespread in the tropical Pacific. Sources for zoogeography: Allen (1975), Allen & Hoese (1975), Allen et al. (1976), Ayling (1982), Paulin & Stewart (1985), and Paulin (ms). Samples of some species are held in museums: BM = Bernice P. Bishop Museum, Honolulu; NM = National Museum of New Zealand, Wellington, New Zealand, WAM = Western Australian Museum, Perth, Western Australia; NS = Not sampled, – 〉 not counted.

Family	Species	Shallow	Deep	Distribution	Samples
Aulostomidae	*Aulostomus chinensis* Linnaeus	0.3, 0.3	0	WS, LH	NS
Scorpaenidae	*Pterois volitans* (Linnaeus)	4.0, 1.5	0	WS	NS
Serranidae	*Epinephalus daemelii* (Gunther)	0.6, 0.6	0	LH, NSW, NZ	NS
	Acanthistius cinctus (Gunther)	4.7, 1.2	0.6, 0.3	LH, N, NZ	NS
	Trachypoma macracanthus Gunther	1.6, 1.2	0	LH, NZ	NS
	Ellerkeldia sp.	0.6, 0.3	0		NS
Grammistidae	*Aulocephalus temmincki* Bleeker	3.7, 1.9	0	WS, NSW, LH, NZ	NM
Mullidae	*Parupeneus fraterculus* Gunther	9.3, 4.0	9.7, 5.8	WS, LH, N, NZ	NS
Kyphosidae	*Kyphosus fuscus* McCulloch et Waite	21.0, 4.5	0	LH, N, WS, NSW, NZ	NS
	Girella cyanea Macleay	9.0, 4.7	0	LH, N, NSW, NZ	NS
	Girella fimbriatus (McCulloch)	11.0, 6.7	0	E	NS
Chaetodontidae	*Amphichaetodon howensis* (Waite)	0	0.6, 0.6	EA, LH, NZ	NS
Pomacentridae	*Chromis dispilus* Griffin	–	143.0, 60.0	NZ	NS
	Parma alboscapularis Allen et Hoese	12.0, 3.3	2.0, 1.2	LH, NZ	NM
	Parma polylepis Gunther	1.3, 0.3	0.3 0.3	WS, EA, LH	WAM
	Stegastes fasciolatus (Ogilby)	38.0, 7.5	1.3, 0.7	EA, NC, LH, N	WAM
Cirrhitidae	*Cirrhitus splendens* (Ogilby)	1.7, 0.7	0	LH, NSW	NM
Aplodactylidae	*Aplodactylus etheridgi* (Ogilby)	4.3, 1.5	1.0, 0.6	LH, N, NZ	NM
Cheilodactylidae	*Cheilodactylus ephippium* McCull.et Waite	2.3, 1.9	0.6, 0.3	LH, N, NZ	NS
Labridae	*Anampes caeruleopunctatus* Ruppell	1.0, 1.0	7.3, 2.4	LH, WS	BM
	Anampes elegans Ogilby	1.7, 0.3	7.7, 2.3	LH, N, NSW, NZ	BM
	Coris sandageri (Hector)	1.0, 1.0	9.3, 4.9	LH, NSW, NZ,	NS
	Pseudolabrus inscriptus (Richardson)	1.6, 0.7	1.3, 0.3	LH, N, NZ	NM
	Pseudolabrus luculentus (Richardson)	37.0, 10.0	30.0, 4.0	LH, N, NSW, NZ	NM
	Suezichthys sp. 2	1.3, 1.0	6.3, 0	LH, N, NC, NSW, NZ	NM
	Thalassoma lutescens (Lay et Bennett)	0.3, 0.3	0	EA, LH, NZ, WS	BM
Balistidae	*Thamnoconus analis* (Waite)	0.3, 0.3	5.7, 0.3	LH	NM

Large limpets without these smaller hitch-hikers were conspicous because of a luxuriant cover of red algal turf on their shells. An examination of the gonads of *P. kermadecensis* from our samples indicated that all individuals less than about 60 mm in length were males, and that there was an even sex ratio beyond this size (Creese et al. in prep.). The occurrence of hermaphroditic individuals at the transitional size suggests some form of sequential hermaphroditism.

The sea urchin *Heliocidaris tuberculata* (Lamarck) was the most abundant echinoderm in the subtidal areas of Boat Cove (Fig. 5D). Highest densities occurred just below the *P. kermadecensis* zone, where *Centrostephanus rodgersii* (Agassiz) also occurred as isolated individuals (Fig. 5E). *H. tuberculata* ranged from 89–106 mm in test diameter, and *C. rodgersii* from 74–98 mm test diameter. The pencil urchin *Phyllacanthus imperialis* (Lamarck) occurred as isolated individuals (49–67 mm test

Table 2 Families and species of fish seen at Boat Cove, but which did not appear, or were not counted, in random transects. See Table 1 for key to distribution and samples.

Family	Species	Distribution	Samples
Carcharhinidae	*Carcharhinus galapagensis* Snod. et Heller	WS	NS
Muraenidae	*Gymnothorax* spp.	WS	NS
Exocoetidae			NS
Scorpaenidae	*Scorpaena cookii* Gunther	LH, N, NSW	NM
	Pterois sp.	WS	NS
Labracoglossidae	*Bathystethus cultratus* (Bloch et Schneider)	LN, N, NZ	NS
	Labracoglossa nitida McCulloch et Waite	LH, N, NSW, NZ	NS
Carangidae	*Seriola lalandi* Cuvier et Valenciennes	WS, NZ	NS
Arripidae	*Arripis trutta* (Bloch et Schneider)	LH, N, NZ, EA	NS
Pempheridae	*Pempheris analis* Waite	LH, WA	NM
Kyphosidae	*Atypichthys strigatus* (Lacepede)	LH, N	NM
	Scorpis violaceus (Hutton)	LH, NZ	NS
Pomacentridae	*Chrysiptera rapanui* (Greenfield et Hensley)	EI	WAM
Blennidae	*Plagiotremus* sp.	WS	NS
Labridae	*Thalassoma trilobatum* (Bleeker)	WS, LH	BM
Ostraciidae	*Ostracion cubicus* Linnaeus	WS	NS
Tetraodontidae	*Torquigener altipinnis** (Ogilby)	LH, NSW, NZ	NM

*Caught on handline at Boat Landing.

diameter, $n = 5$), particularly at a depth of 10–15 m (Fig. 5E). All were found in cracks and crevices. A few *Diadema* sp. were seen beneath the large plate corals in deep water. This species had a blue-violet aboral coloration, unlike the reddish hue of *D. palmeri* Baker found at the Poor Knights Islands off north-eastern New Zealand. One other sea urchin species was seen, but did not appear in our quadrat samples. *Tripneustes gratilla* (L.) was sparsely distributed, but observed at depths from 10–15 m.

Few grazing gastropods were seen in the subtidal areas of Boat Cove. The peaked topshell *Tectus royanus* (Iredale) occurred at low densities at 6 m depth (Fig. 5E). These were relatively large in size, 40–76 mm across the oral surface. No other large herbivorous gastropods were found. A few individuals of the predatory whelk, *Morula (Neothais) smittii* (Brazier), were found.

With the exception of fish, other animals that were seen subtidally were the crown-of-thorns seastar, *Acanthaster planci* (L.). This species was found occasionally on patches of coral in both shallow and deep water, and occurred at 2 per 500 m^2 at 13–20 m depth ($n = 3$ transects). The seastar *Petricia vernicina* (Lamarck) was also seen. One spanish lobster (Scyllaridae) and also green turtles (*Chelonia* sp.) were observed.

Fish

The major families of tropical herbivores, Scarids, Acanthurids, and Siganids, were not seen in Boat Cove. Families commonly found in temperate waters were well-represented. Especially abundant in shallow water were the herbivorous kyphosids, pomacentrids, and aplodactylids and the carnivorous serranids, scorpaenids, and a grammistid. The labrids *Coris sandageri, Suezichthys* sp. 2, and *Anampses* spp., and the balistid *Thamnaconus analis* were found more abundantly in deeper water. Of the 28 species of fish that occurred in our transects at Boat Cove, 15 were found more commonly in shallow sites at the time of our sampling (Table 1).

Total fish densities in our transects (not including *Chromis*) averaged 170 per 500 m^2 in shallow water and 85 per 500 m^2 in deep water. The most abundant fish in our counts along the entire reef was *Pseudolabrus luculentus*, reaching densities of 37 per 500 m^2 in shallow water and 30 per 500 m^2 in deep water. Seventy percent of the individuals of this species in shallow water and 85% in deep water were juveniles (80–110 mm standard length). These fish were seen in schools swimming just above the bottom. The three kyphosid species *K. fuscus, Girella cyanea,* and *G fimbriatus* occurred in large schools in the shallow subtidal. Individuals varied in size from 350–550 mm standard length (SL). The pomacentrid *Stegastes fasciolatus* was also abundant in shallow water, at mean densities of some 38 per 500 m^2 (size range = 70–160 mm S.L.).

Particularly impressive was the large serranid *Epinephalus damelli.* Many individuals over 1 m in length were observed under ledges of boulders in shallow water (3 m depth). It may have been absent from deep water at Boat Cove because of the lack of suitable boulder overhangs.

Sixteen other species of fish were seen, but did not appear in our transects (Table 2). Of the 45 species observed at Raoul Island, 18 have not been recorded from New Zealand. One endemic species, *Girella fimbriatus*, was found. Ten species were of widespread tropical groups: *Aulostoma chinensis, Pterois volitans, Pterois* sp., *Kyphosus fuscus, Stegastes fasciolatus, Anampses caeruleopunctatus, Thalassoma lutescens, T. trilobatum, Scorpaena cookii*, and *Ostacion cubius*. Large aggregations of the small pomacentrid *Chrysiptera rapanui* (30–50 mm SL) were seen in both shallow and deep water. This and several other species were observed in the study area, but not counted (Table 2). *Chrysiptera rapanui* is known only from Easter Island. Interestingly, *Chromis dispilus* was the only species observed that has a distribution restricted to New Zealand and the Kermadec Islands. Numerous blennioids were observed in areas of shallow broken rock, but they were not identified.

DISCUSSION

Our observations at Raoul Island were remarkable for the groups of organisms that were rare or absent altogether. No fucalean or lamination algae were seen and corals, although common, formed small and patchy colonies. Few species of large herbivorous invertebrates were encountered, the most obvious being the endemic limpet *Patella kermadecensis* and the echinoid *Heliocidaris tuberculata*, which were both confined to the very shallow subtidal. Prominant tropical families of fish (scarids, acanthurids, and siganids) that are abundant on shallow, coral-dominated reefs were not encountered. Judging from our sampling and from anecdotal information (Dr W. Nelson, Fisheries Management Division, MAF; Dr R. Grace, Marine Consultant & Photographer, pers. comm.), we consider these general observations to be reasonably representative, rather than an anomaly of sampling at only one locality.

The benthic flora and fauna at Boat Cove were depauperate in species and numbers of large brown algae and gastropods when compared to northern New Zealand (although probably not in smaller species of subtidal algae (Nelson & Adams 1984)). This was particularly noticeable in intertidal areas where there were low numbers of attached organisms, and the middle and high shore consisted mostly of bare space. The absence of fucalean and laminarian algae from shallow reefs was surprising. Oliver (1915), in a general description of the Kermadecs, reported a belt of *Sargassum* that became exposed at low spring tides. Morton and Miller (1968) noted a midtidal band of *Sargassum fissifolium (S. cristaefolium* C. Ag.) at Meyer Island. Another species of *Sargassum* has been recorded from the attached flora of Raoul Island, and a single healthy specimen of *Ecklonia radiata* has been dredged from Macauley Island (Nelson & Adams 1984). Stands of these algae, however, have not been reported. Species of the family Sargassaceae are common in northern New Zealand (Choat & Schiel 1982; Schiel 1985), and the genus *Sargassum* is abundant in warmer seas, forming dense stands in some tropical localities (DeWreede 1976). It is noted for its long-range dispersal and ability to invade shallow coastal areas (Fletcher & Fletcher 1975; Critchley 1983). *Sargassum* and other macroalgae are common at Lord Howe Island (Kraft 1978; Veron & Done 1979), which has the southernmost coral reef of the Indo-Pacific. Kraft (1978) found that most of the non-endemic flora of Lord Howe Island showed tropical affinities, and had little in common with southern Australia and New Zealand. In addition, *Ecklonia radiata* is abundant at the Abrolhos Islands off Western Australia (28–29°S latitude), where the annual temperature range is 18–26°C (Wilson & Marsh 1979; Johannes et al. 1983). Temperatures probably fall within this range generally at the Kermadec Islands (Ridgway & Heath 1975). We recorded temperatures of c.24.5°C. The scarcity of large macroalgae from the Kermadec Islands, therefore, is probably attributable to the lack of long-range dispersal of propagules in sufficient amounts to establish populations.

Comparisons of coral groups and abundances from Raoul Island with the closest tropical areas is more difficult because of the sketchy information available. More intensive collecting expeditions at Lord Howe Island, however, have allowed some comparisons. Fifty-seven species of 33 genera of hermatypic Scleractinia occur there, and all except two species are known from the Great Barrier Reef (Veron & Done 1979). The species of hard corals identified from our sampling all occur at Lord Howe Island (cf., Veron & Done 1979). From our experiences and other anecdotal information, however, it seems clear that there are no reefs formed by corals at the Kermadec Islands. The depth distribution of soft corals, *Efflatounaria* spp., at Raoul Island is comparable to that on tropical reefs. Dinesen (1983) found that soft corals decreased in abundance in shallow, exposed areas on the central Great Barrier Reef.

There were few species of large herbivorous gastropods at Boat Cove. Intertidally, the most abundant mollusc was *Nerita atramentosa*. This species is also common along the coast of New South Wales (Underwood 1975) and in northern New Zealand. Neritidae are predominantly tropical (Powell 1979).

The low intertidal-shallow subtidal provided a striking contrast to southern temperate shores. In New Zealand and on the south-east coast of Australia, this zone is usually occupied by a dense assemblage of fucalean algae, and gastropod abundances are low (Underwood & Jernakoff 1981; Choat & Schiel 1982). The greatest numbers of herbivorous species occurred at the intertidal-subtidal interface at Raoul Island (cf., Oliver 1915). The large prosobranch limpet *Patella kermadecensis* was particularly abundant. This gastropod reaches shell lengths > 160 mm and its present distribution is restricted to the Kermadec Islands, although fossil evidence indicates a wider range in Oligocene times (Fleming 1973). Apart from a few endemic *Cellana craticulata* and *Siphonaria raoulensis*, no other grazing invertebrates were seen in the intertidal.

Herbivorous invertebrates were also much less common subtidally than in northern New Zealand. The only large gastropod seen below 3 m depth was the trochid *Tectus royanus*, which occurred in very low numbers. In contrast, limpets and trochid and turbinid gastropods are abundant subtidally along northern New Zealand, commonly reaching densities of 10 per m^2 on parts of most reefs (Andrew & Choat 1982; Choat & Schiel 1982). The common New Zealand echinometrid sea urchin *Evechinus chloroticus* was not seen, and probably does not occur at the Kermadec Islands (Dix 1970). This echinoid is commonly found at mean densities of 3 per m^2 within kelp stands and > 10 per m^2 outside of them in coastal areas of northern New Zealand (Ayling 1981; Choat & Schiel 1982). It is also abundant at the Poor Knights Islands (Schiel & Choat in prep.), which are affected by the East Auckland Current (flowing around northern New Zealand from the direction of Lord Howe Island) and at the Three Kings Islands to the north of New Zealand. Two of the three commonest echinoids at Boat Cove (cf., Fig. 5), *Heliocidaris tuberculata* and *Centrostephanus rodgersii*, also occur in northern New Zealand (Choat & Schiel 1982) and in New South Wales (Dakin 1952). Another echinoderm, the crown of thorn seastar, *Acanthaster planci*, was probably at the southern limit of its distribution (Knox 1963; McKnight 1978).

Despite the large numbers of individuals counted in transects at Boat Cove, fish were generally inconspicuous over most of the reef, except for occasional schools of kyphosids. We observed 45 species of fish at Boat Cove, 11 of which were new records for the Kermadec Islands. The high incidence of new records was attributable to our use of SCUBA observations and collections, whereas previous lists were compiled mostly from catches by handlines (Waite 1910; Paulin ms).

The general distributional patterns of herbivorous fish were similar to those described for northern New Zealand (Russell 1977; Choat et al. in prep.) At Boat Cove, the larger species of pomacentrids, kyphosids, and aplodactylids were primarily in shallow water, where they are also abundant along temperate reefs. The pomacentrid *P. alboscapularis* occurred at similar densities in Boat Cove and at the Poor Knights Islands (Schiel, unpub. data). Major differences between these areas, however, were the large numbers of *Stegastes fasciolatus* in shallow water and the planktivorous *Chrysiptera rapanui* around plate corals in deep water at Raoul Island. Neither species has been recorded from New Zealand (Allen 1975). The planktivorous *Chromis dispilus* was the only species encountered that has a distribution restricted to New Zealand and the Kermadec Islands.

Nine species of labrids were found at Boat Cove, only 6 of which have been recorded from New Zealand. *Pseudolabrus luculentus* was the most abundant species encountered in both shallow and deep water at Boat Cove. Most of these were small juveniles. Densities of *P. luculentus* were much greater than those reported for the Poor Knights Islands (2 ± 1.2 per 500 m^2; Schiel, unpub. data). This species was recorded as the most abundant labrid in lagoon and outer reef habitats at Lord Howe Island (Allen et al. 1976).

Although the ichthyofauna of Raoul Island resembles that described for other subtropical areas of the south-west Pacific in the types of fish present, Lord Howe Island has a stronger tropical element and many more species recorded (Allen et al. 1976). Comparisons of fish abundances with other subtropical and nearby tropical areas are difficult. The literature contains no information on densities of fish at Norfolk Island, Lord Howe Island, New South Wales, or the tropical islands to the north of the Kermadecs (Tonga and Fiji), although species lists for some of these areas are available.

Although our data give a truncated view of the marine flora and fauna of Raoul Island, an intriguing picture emerges. Neither corals nor larger macroalgae were abundant in a place where both can probably tolerate the conditions physiologically. It seems unlikely that herbivory or competition have a major effect on these abundances. There were low numbers of species and individuals of herbivorous fishes and invertebrates, in contrast to tropical areas where they may play a major role in the distribution of macroalgae (Hay 1981; Lubchenco et al. 1984). We also found no evidence that the low number of corals was a result of competitive interactions with large algae, as has been hypothesised for other subtropical areas (Johannes et al. 1983). It seems more likely that the geological history and isolation of the Kermadec Islands are the most important factors in explaining the peculiar suite of species present. No major currents that we know of flow through these islands, which may contribute to their present-day isolation. Geologically, the Kermadecs probably emerged during the Pleistocene, never having a land bridge to another land mass (Brothers & Searle 1970), and would have had to rely completely on dispersal of organisms or their propagules from distant areas for colonisation. In contrast, Lord Howe Island, and Middleton and Elizabeth Reefs to the north, were affected by rapid submergence and temperature changes during the Pleistocene, and are relicts of a much larger Pleistocene or late Tertiary reef system (cf., Fleming 1979; Veron & Done 1979).

It seems likely that our data from Raoul Island describe only the more common species on shallow reefs of the Kermadec Islands. The steep drop-offs around the Herald Islets, and the extensive areas of shallow reefs between Rayner Point and Hutchinson Bluff will undoubtedly harbour species we did not encounter. An understanding of distributional and biogeographic patterns in the south-west Pacific Ocean, and an appreciaton of the community structure of inshore reefs in subtropical areas, will only be achieved when systematic sampling for abundances of fish and benthic organisms is combined with collecting specimens, and when the patterns of current flow are better understood.

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