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The development and dynamics of a small artificial reef community

B. C. Russell

*Marine Research Laboratory, University of Auckland;
R. D. Leigh, New Zealand*

KURZFASSUNG: **Die Entwicklung und Dynamik einer kleinen künstlichen Riffgemeinschaft.** An der Nordostküste von Neuseeland wurde ein künstliches Riff durch Autoreifen, die in 20 m Tiefe deponiert worden waren, geschaffen und die Entwicklung der auf und im Bereich dieses Substrats lebenden Organismengemeinschaften während eines Beobachtungszeitraums von 12 Monaten verfolgt. Sessile Arten (*Hydroides norvegicus*, *Balanus trigonus*, Bryozoen, *Lithothamnion*, *Plumularia*) besiedelten die Außenflächen dieses Riffes. Außerdem traten kleinere mobile Evertebraten (u. a. Gastropoden, Einsiedlerkrebse, Mysideen und Garnelen) sowie Fische auf. Die Intensität der Wasserbewegung beeinflußte diese Lebensgemeinschaften in erheblichem Maße und schränkte die Entwicklung der Epifauna beträchtlich ein. Wasserströmungen spielten offensichtlich für die Riffbesiedlung und Verbreitung der aufgefundenen Species eine wichtige Rolle. 7 Fischarten traten zumeist ständig auf; das Artenspektrum änderte sich im Verlauf des Jahres nur wenig, doch schwankte die Individuendichte. Schätzungen der Biomasse der Fische, die im Bereich dieses künstlichen Riffs lebten, ergaben um das 10- bis 14fache höhere Werte als in den nahegelegten natürlichen Felsriffen. Insbesondere dominierte der Mullide *Upeneichthys porosus*, der auch die umliegenden Sandbiotope bewohnte.

INTRODUCTION

Within recent years there has been a growing interest in artificial reefs as a means of increasing productivity in impoverished areas or in areas depleted by overfishing. Extensive investigation of artificial reefs has been carried out particularly in the United States and Japan (for comprehensive bibliographies see Oren, 1968 and Steimle & Stone, 1973). But despite the large number of artificial reefs which have been created there have been comparatively few detailed studies of the communities associated with them. Work by Randall (1963) in the Virgin Islands, and by Carlisle et al. (1964) and Turner et al. (1969) in southern California provide notable exceptions. Recent studies by Fager (1971) and Coustalin (1972) on the development of epibenthic communities on experimental artificial substrates are also noteworthy.

The present paper investigates the development of the community on an artificial reef built from rubber car tyres. This work was an adjunct to a study of the ecology of rocky reef fishes (Russell, 1971b and in preparation). As such, particular attention was directed towards the fishes, especially to factors important in their establishment on artificial reefs. From this point of view, the overall dynamics of the community have been examined.

MATERIAL AND METHODS

The artificial reef was sited on a sandy bottom at a depth of 20 m about 100 m off Goat Island, near Leigh, on the coast of north-eastern New Zealand (Fig. 1). Goat Island is generally sheltered to the south-east by the Hauraki Gulf, but to the north it is exposed to the full influence of the South Pacific Ocean and north-easterly swells prevail. Moderate swells (1–2 m wave height) occur on most days (Fig. 2) and waves

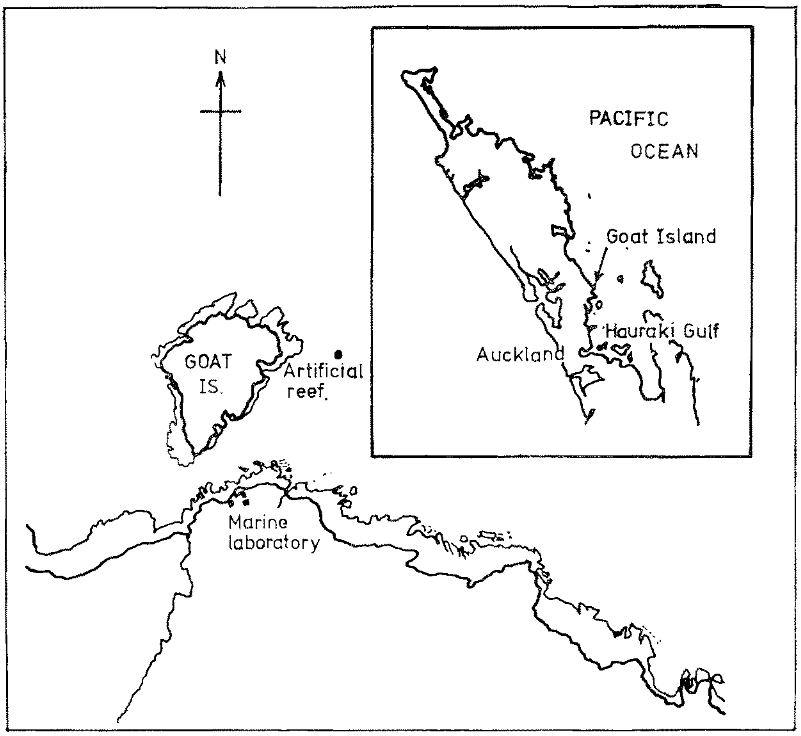

Fig. 1: Goat Island and the artificial reef site. Inset shows location of Goat Island on the coast of north-eastern New Zealand

up to 4.5 m have been recorded (unpublished shore climate observations, Leigh Marine Laboratory 1969–1970). Sea surface temperatures range from about 13° C in winter (August–September) to about 21° C in summer (January–February). A general account of the sublitoral ecology of the area, with particular reference to the sessile biota, is given by AYLING (1968). The ecology of the fishes has been considered by the author (RUSSELL in preparation).

Used car tyres, bolted together, were used in the construction of the artificial reef. Other studies (e.g. STONE et al., 1974) have demonstrated the suitability of rubber tyres as an artificial reef substrate. The initial plan was for a small Y-shaped reef (for construction details see RUSSELL, 1971a) but this proved unstable, and about 4 weeks after

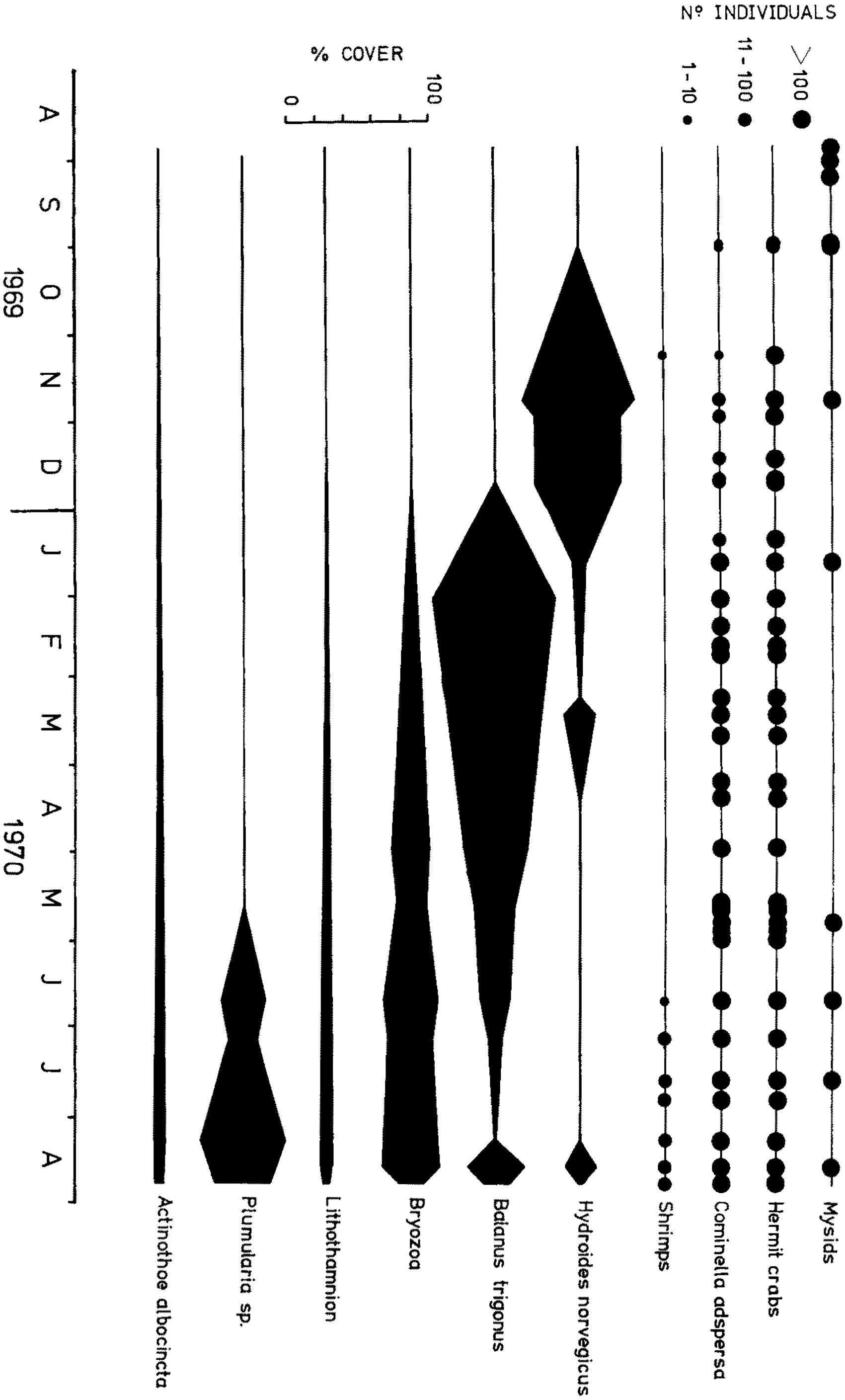

Fig. 3: Changes in the numbers and densities of epibenthic organisms on the artificial reef

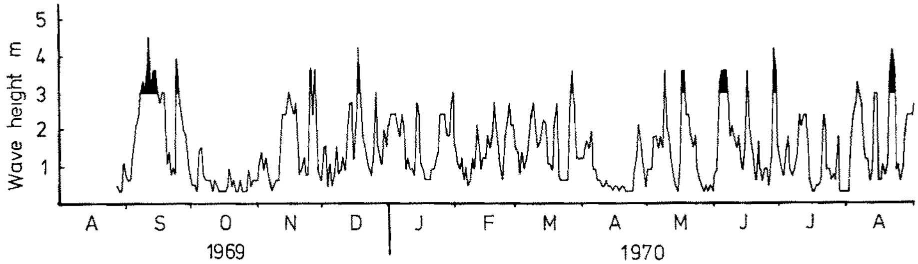

Fig. 2: Daily wave height data for Goat Island, August 1969 – August 1970. Days on which wave height was 3 m or greater have been shaded

laying was broken up by a storm. The resulting jumble of tyres covered an area of about 25 m². Further serious damage to the reef was prevented by stabilising it with a heavy mooring chain draped over the tyres.

Observations were made using SCUBA and a total of 35 dives were made over a 12 month period. At least one dive was made every month, and in some cases (e.g. after storms) dives were made on several consecutive days. On each survey the numbers of fishes present were noted. The abundance of mobile invertebrates was recorded as absent, rare (1–10), common (11–100), abundant (> 100), and the percentage cover of the sessile fauna of two tyres was estimated visually. Biomass of fishes was estimated on two surveys using the method outlined by Brock (1954). This involved estimating the lengths of the fishes, these estimates later being converted to weights using the equation $W = K L^3$; where W = wet weight, K = the species constant, based on known lengths and weights (Russell, 1971b), and L = estimated length (TL).

RESULTS

Two surveys were made prior to laying the reef. The only animals recorded within a 10 m radius of the proposed site were 3 hermit crabs (*Pagurus* sp.) and mysids (Mysidacea), patchily distributed in small loose swarms close to the sand. Other dives made over similar open sandy bottoms off Goat Island have revealed little obvious animal life on the sand. The artificial reef was laid on 27–28 August 1969. Subsequent surveys showed a fairly rapid colonisation by epibenthic organisms (Fig. 3).

Sessile epifauna

The earliest noticable change in the surface of the tyres was the presence of a slippery film, probably composed of diatoms, in September (33 days). A single sea anemone (*Actinothoe albocincta*) was also noted at this time. The number of anemones continued to increase through the arrivals of individuals associated with driftweed and by asexual budding. However, they occurred only in small groups and on only a few of the tyres, and overall cover was sparse. Anemones seemed little affected by the effects of surge and sand scouring and their density showed little change as a result of storms.

Serpulid worms *(Hydroides norvegicus)* settled out early in November (71 days). They reached maximum density by the end of November (87 days) and then declined. Further light settlement of *H. norvegicus* occurred in March and again in August but this cover was quickly reduced, mainly by the scouring effects of wave action.

Heavy settlement of barnacles *(Balanus trigonus)* occurred in January 1970 (134 days) and they reached maximum density by the beginning of February (156 days). Barnacle cover then tended to decrease. During May and June storms caused extensive sloughing and in July there also marked evidence of predation by fishes. Settlement of *B. trigonus* again occurred in August at about the same time as the *Hydroides*, but much of the barnacle cover was stripped by a severe storm only a few days later.

A few small patches of Bryozoa (notably *Beania hirtissima, Chaperia cervicornis, Escharoides excavata)* also appeared in January (134 days). These persisted despite the ensuing rapid growth and spread of barnacles, but accounted for less than 10 % of the total cover. However, with the death of many barnacles and a decrease in their density, bryozoans gradually extended over the empty shells and bare areas and by July (310 days) accounted for about 40 % of the cover on the tyres. Small patches of red coralline algae (*Lithothamnion* sp.) were associated with the bryozoans but occurred only at a low density. Hydroids (*Plumularia* sp.) were likewise associated with the polyzoans but did not appear until May (265 days). They spread rapidly and formed a dense secondary cover over all the encrusting organisms.

Small tubicolous amphipods (*Corophium* sp.) colonised the reef in May (268 days) and their tubes formed a dense secondary cover over all the tyres. They were short lived however, and wave action in early June decimated the population.

Mobile epifauna

Mysids (Mysidacea) occurred in dense swarms about the reef within hours of laying. They remained abundant during September and October but were seen less frequently thereafter. About 15 hermit crabs (*Pagurus* sp.) had colonised the reef by the end of September (33 days). Their numbers increased rapidly and by November (71 days) there were an estimated 2000 individuals. The population remained at about this number for the rest of the survey period. Five gastropods *(Cominella adspersa)* were seen at the end of September (33 days) and were observed egg laying on the tyres. By the end of November (93 days) most of the eggs had hatched and juveniles were present, this recruitment largely accounting for the abundance of *C. adspersa* in subsequent surveys. Small numbers of shrimps (Peneidae) were seen occasionally on early surveys and become more common later. A small octopus *(Octopus maorum)* was seen in February 1970 and its presence on the reef for the remainder of the study period was inferred by a large accumulation of clean, newly-opened *Pecten* shells – apparently the remains of prey – around one of the tyres. Several other mobile invertebrates *(Coscinasterias calamaria, Plagusia chabrus, Jasus lalandii)* were observed only once and appeared to be transients. Squid egg clusters were also present over the summer months and during February, 6 adult squid *(Sepioteuthis bilineata)* were observed egg-laying (see LARCOMBE & RUSSELL, 1971).

Fish populations

Several fishes were seen within days of laying the reef, but fishes did not become established until November (71 days). These early inhabitants remained more or less as permanent residents. There was little change in species composition between surveys although the number of individuals fluctuated, mainly through the disruptive – dispersive effects of storms (Fig. 4). Seven species of fish were classified as residents (Table 1).

Adult bastard red cod *(Physiculus breviusculus)* were first noted in November (71 days) living within the car tyres. However, this species may well have been a much earlier inhabitant as no thorough search of the inside of the tyres had been made

Table 1

List of the resident fish species of the artificial reef

Family	Species
Gadidae	*Physiculus breviusculus* (RICHARDSON)
Carangidae	*Decapterus koheru* (HECTOR)
Mullidae	*Upeneichthys porosus* (CUVIER)
Sparidae	*Chrysophrys auratus* (BLOCH & SCHNEIDER)
Kyphosidae	*Scorpis violaceous* (HUTTON)
Mugiloididae	*Parapercis colias* (BLOCH & SCHNEIDER)
Balistidae	*Navodon convexirostris* (GUENTHER)

previously. The cryptic daytime habits of this fish made it very difficult to obtain an accurate estimate of the population and numbers are likely to err on the low side. The population of *P. breviusculus* (Fig. 4) appeared to decrease over the summer months (December–March) but increased again in May. Numbers thereafter tended to decrease, rising again in August. Fluctuation in the numbers of *P. breviusculus* corresponded closely with the occurence of storms, although numbers are likely to have been affected also by predation by the blue cod *(Parapercis colias)*.

Juvenile koheru *(Decapterus koheru)* were also first seen in November (71 days) and a school, usually of 100–200 individuals, of this mid-water plankton feeder was present on about half the surveys. Numbers, however, fluctuated (Fig. 4) partly due to rough weather and probably also because of observer error. At times it was apparent that the school had simply ranged further from the reef and was missed in counts.

Red mullet *(Upeneichthys porosus)* were usually the most abundant fish around the reef (Fig. 4). Only 45 adults were present in November (71 days) but with the recruitment of juveniles during December, numbers swelled and about 200 mixed sub-adults and adults were present by March (204 days). The *U. porosus* population

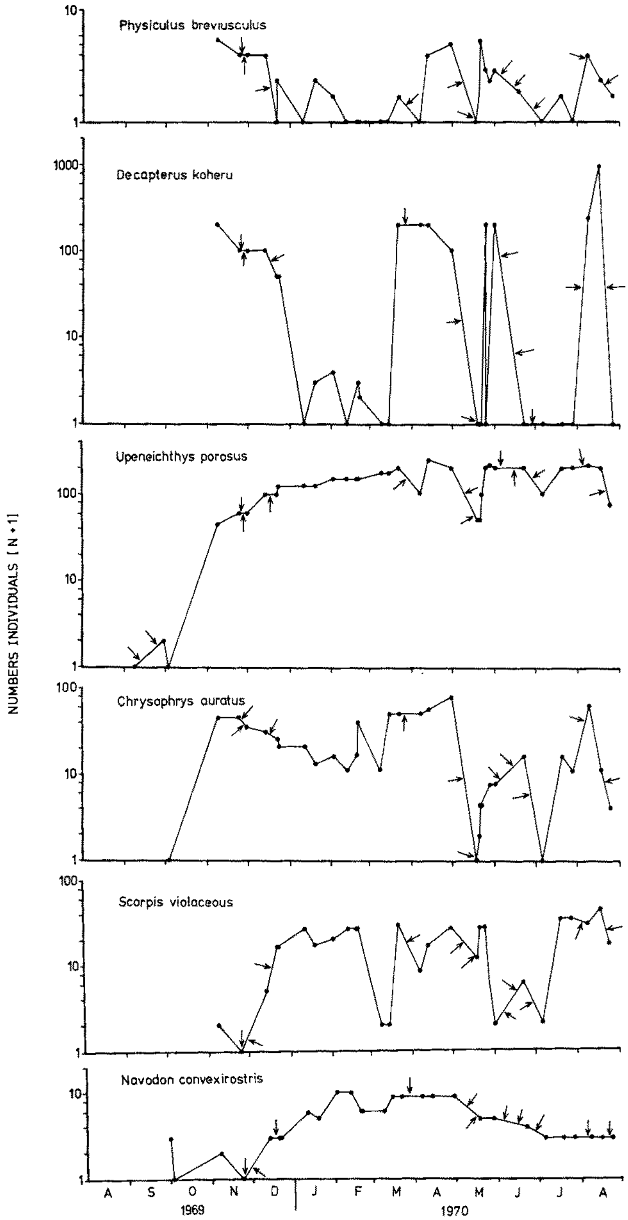

Fig. 4: Fish census data. Changes in the numbers of individuals of six species with time. Note that the scale along the ordinate is Log. and all numbers are N + 1. The arrows indicate storms (wave height > 3 m)

remained more or less stable, although storms seemed to have a temporary dispersive effect and low numbers (50–100) were noted on several occasions.

Snapper *(Chrysophrys auratus)* were also early inhabitants and about 40 juveniles (3–4 cm) had become established by November (71 days). These fishes remained and had grown to about 8 cm by August. A few adult snapper were present at various times and have been included in the counts (Fig. 4). Numbers of *C. auratus* declined over the summer months but increased again in February and April, reaching a maximum (243 days). The population then declined markedly during the winter and showed wide fluctuation between surveys. Tubeworms and barnacles were fed upon heavily by *C. auratus,* and changes in the snapper population reflect well the pattern of settlement – growth – decline of these two species of sessile organism (cf. Fig. 3). Short term fluctuation in numbers were mainly the result of storms.

Blue maomao *(Scorpis violaceous)* aggregated above the reef and fed on plankton. A single adult was first seen in November (71 days) but was not present on subsequent surveys in the same month. Four adult *S. violaceous* were seen in mid-December (107 days) and by January (134 days) numbers had risen to 25. There was some decline in the population during May and July but this was followed by an increase later in July and in August. Much of the fluctuation in the population of *S. violaceous,* particularly decreased numbers, can be attributed to the disorientating-dispersing effects of storms (Fig. 4), but on several occasions the aggregation had probably just ranged more widely and may have been missed. Juveniles were observed on several occasions sheltering close to the tyres but they were only temporary inhabitants and were not included in the census totals.

A single adult blue cod *(Parapercis colias)* was a relatively late arrival and did not appear until December (114 days). This fish remained on the reef for nearly 8 months but was absent on the final survey in August 1970, following a heavy storm just a few days before. A single juvenile *P. colias* was present on one survey in March (119 days) but appeared to be only a temporary inhabitant. *P. colias* is a voracious carnivore and followed the observer about during surveys, snapping at any small crustaceans and fishes which were disturbed.

Leatherjacket *(Navodon convexirostris)* were late colonisers. Adults were noted as early as September (33 days) and in November (87 days) but there were no permanent residents until December (107 days) when 2 sub-adults inhabited the reef. By January (134 days) there were 5 sub-adults and by the beginning of February (156 days) numbers had risen to 9. However, 2 weeks later (173 days) only 5 leatherjacket remained. In March (197 days) these were joined by 3 more individuals which continued to inhabit the reef until the end of April (243 days). Numbers then declined and on the final survey in August 1970 only 2 sub-adult *N. convexirostris* remained on the reef. In general the pattern of the population of *N. convexirostris* (Fig. 4) reflected the pattern of growth and subsequent recession of barnacles (cf. Fig. 3). Leatherjacket fed extensively on barnacles (Fig. 5) and occasionally picked at jellyfish and ctenophores above the reef.

Non-resident fishes seen on or near the artificial reef included: *Torpedo fairchildi* (Torpedinidae); *Leptognathus novaezelandiae* (Ophichthyidae); *Zeus australis* (Zeidae); *Acanthoclinus quadridactylus* (Acanthoclinidae); *Caranx georgianus, Seriola la-*

landi, Arripis trutta (Carangidae); *Pempheris adspersa* (Pempheridae); *Paristiopterus labiosus* (Pentacerotidae); *Nemadactylus douglasii* (Cheilodactylidae); *Genyagnus monopterygius* (Uranoscopidae); *Zeablennius laticlavius* (Blenniidae); *Forsterygion capito, Forsterygion varium, Forsterygion* sp., *Notoclinops bucknilli, Gilloblennius decemdigitatus* (Tripterygiidae), *Scorpaena cardinalis* (Scorpaenidae); and *Mola mola* (Molidae). *Zeus australis* was a regular visitor. This roving piscivore occurred on 10

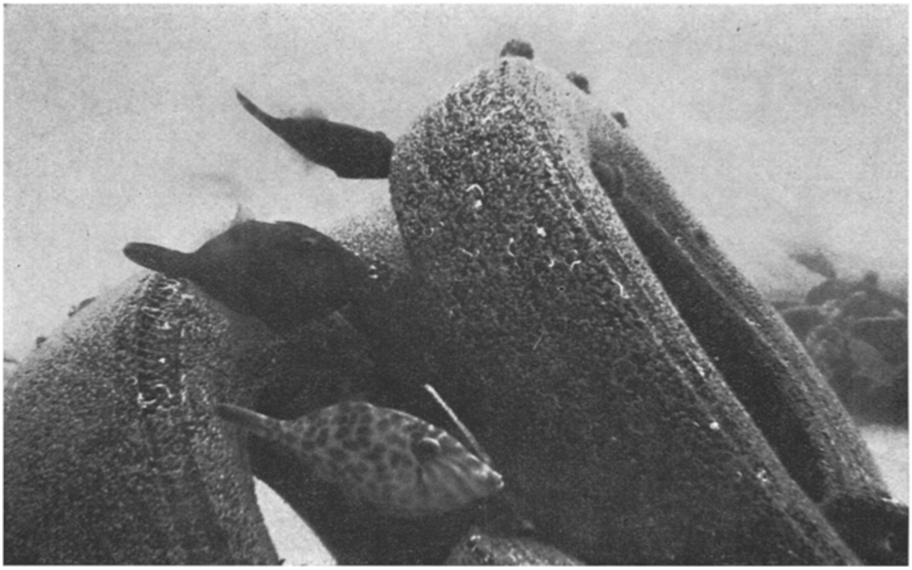

Fig. 5: A group of leatherjacket, *Navodon convexirostris,* feeding on recently settled *Balanus trigonus* on one of the tyres of the artificial reef

of the surveys and was frequently seen stalking the school of *Decapterus koheru* above the reef. Some species *(Torpedo fairchildi, Leptognathus novaezelandiae, Seriola lalandi, Arripis trutta, Paristiopterus labiosus, Nemadactylus douglasii, Genyagnus monopterygius, Mola mola)* were recorded only once or twice and were probably only transients. Except for the tripterygiids and *Zeablennius laticlavius,* the remaining fishes were all juveniles. They appeared to be "castaways" and were temporary inhabitants. Disorientated and dispersed from their usual rocky reef habitats by storms, they probably drifted over the barren sandy bottom, perhaps being carried along with flotsam, until they encountered the artificial reef by chance. These smaller colonisers were probably an important source of prey for the blue cod, *Parapercis colias,* and this may explain their failure to become established as permanent residents.

Standing crop of fishes

The biomass of fishes of the artificial reef was estimated on two occasions, in April (226 days) and in May (271 days). On both surveys conditions were optimal –

good visibility allowed accurate censusing, and calm weather which preceded the surveys ensured that the population was stable. In computing standing crop, the bottom area was taken as 50 m^2 (this included the adjacent sand as well as the reef itself) and only long term resident species were included in the analysis. Results of the biomass and standing crop estimates are shown in Table 2.

Table 2

Population, biomass and standing crop estimates of fishes on the artificial reef. Only resident species have been included in the analysis. Area of reef and adjacent sand surveyed taken as 50 m^2 (two surveys: 12. 4. 1970 and 27. 5. 1970)

Species	12. 4. 1970 No.	12. 4. 1970 Total length (cm)	12. 4. 1970 Weight (g)	27. 5. 1970 No.	27. 5. 1970 Total length (cm)	27. 5. 1970 Weight (g)
Upeneichthys porosus	250	25	56,250	225	150	50,625
Chrysophrys auratus	55	15	750	10	15	500
Scorpis violaceous	16	30	5,600	5	30	1,750
Navodon convexirostris	8	20	800	4	20	400
Physiculus breviusculus	5	5	50	2	5	20
Parapercis colias	1	30	450	1	30	450
Decapterus koheru	200	16	9,000	—	—	—
Total	535		72,900	247		53,745
Standing crop (kg/m^2)			1.458			1.075

Fewer fishes were present on the survey made in May and this also accounted for the lower biomass of fishes compared with the April survey. On both surveys, however, red mullet (*Upeneichthys porosus*) comprised the bulk of the biomass and accounted for 77 % and 94 % of the total weight of fishes respectively.

DISCUSSION

The development of the sessile epifauna occurred in a number of well-defined stages. First stage was the establishment of a slippery film, probably of diatoms. These organisms are important first colonisers of new surfaces and form a "primary film" which facilitates the further settlement of organisms (e.g. Crisp & Ryland, 1960). A primary film was noticeable on the tyres after the first month and persisted for about two and a half months until settlement of larger organisms began. Settlement by most of the sessile forms was heavy and they grew rapidly. Severe water movement and sand scouring, however, resulted in extensive sloughing of much of the cover. Consequently, true biotic succession was difficult to distinguish from simple re-settlement and seasonal progression. Settlement of tubeworms and barnacles is probably a seasonal occurrence; in the case of *Balanus trigonus* for example, heavy settlement on rocky reef areas occurred at the same time (A. M. Ayling, pers. comm.). Settlement of bryozoans is probably also seasonal, but the establishment of *Lithothamnion* and a secondary cover of the hydroid *Plumularia* sp. may indicate the beginning of true biotic succession. This stage was reached near the end of the first year.

The pattern of development of the epifauna shows obvious similarities to the early stages of community development on artificial substrates described by TURNER et al. (1969) and FAGER (1971). FAGER has pointed out that vectorial factors, especially water movement, were important in the formation and maintenance of the communities he studied. The common pattern of settlement-growth-catastrophic mortality seen to varying degrees in all the sessile organisms of the car tyre reef can likewise be largely attributed to the effects of water movement. That biotic succession beyond an early stage did not occur during the first year at least, is a result of this pattern of development and it is likely that water movement would continue to be a major factor limiting further growth of the community. The community would thus seem to be "physically controlled" (SANDERS, 1968) and can be regarded as not having attained its probable real biotic potential.

Colonisation of the reef by mobile invertebrates and by fishes followed a different pattern to that of the sessile fauna, and more or less permanent populations of both components of the community had become established within two months. The number of fish species did not increase, but the number of individuals fluctuated, mainly as a result of storms. In the case of *P. breviusculus* predation also is likely to have been significant. Storms probably have two effects: severe wave action causes disorientation and dispersal and is the most probable cause of the sudden decrease in the numbers of some species. But in the same manner, storms may be important in the dispersal of organisms to the reef. A number of reef colonisers were associated with storm flotsam and other drift material that fouled the tyres, and in this way the early establishment of anemones, hermit crabs, gastropods and some of the smaller fishes seemed to occur. Even the larger fishes which took up residence on the reef probably arrived as refugees. This might also explain why colonisation of the reef was primarily by adult and sub-adult fishes rather than by juveniles or newly-metamorphosed larvae. It probably also explains the fairly rapid recovery of numbers following storms.

CARLISLE et al. (1964) have suggested that the presence of food and shelter "attracts" fishes to artificial reefs, but this seems unlikely. The fact that most rocky reef fishes have only a limited range of movement and rarely venture beyond visual distance from their home reef tends to argue against the possibility that a habitat some distance away could be located in the course of normal activities. Only in the case of the occasional visits by some of the more widely ranging predatory species could the presence of food per se be considered as an attractant to fishes. Food is likely to have been important though, in facilitating the establishment of colonisers. This was clear in the case of both *C. auratus* and *N. convexirostris* which fed mainly on encrusting organisms and whose numbers appeared to be affected by the heavy mortality and sloughing of the epifauna that occurred as a result of storms. The limited feeding opportunities offered by the rather simple epifauna probably precluded the establishment of a number of potential colonisers and it is notable that most of the fishes which took up residence foraged mainly on non-reef food resources – on plankton or on the adjacent sand. These fishes oriented to the reef primarily for shelter. Although the tyres were little utilised as daytime living space by most of the fishes, they probably served as a refuge from predators. On one occasion the school of *D. koheru* was seen sheltering close to the reef when threatened by a group of kingfish *Seriola lalandi*. At night many diurnally active fishes seek cover or move close to the bottom (RUSSELL, in preparation) and the availability of shelter at this time may decisively affect survival (e.g. HOBSON 1968).

Perhaps the most distinctive feature of the artificial reef was the very large concentration of fishes. An average of nearly 300 fishes lived on or about the artificial reef in an area of about 50 m². In terms of standing crop, this was at least 10 to 14 times greater than for nearby rocky reef areas (Table 3).

Table 3

A comparison of the standing crop of fishes on the artificial reef with standing crop estimates made on nearby natural reefs. Transient fishes have been excluded from the natural reef standing crop estimates

Area	Date	Depth (m)	Type of bottom	No. of species	Standing crop (kg/m²)
Artificial reef	12. 4. 1970	20	rubber tyres	8	1.458
	27. 5. 1970			7	1.075
Area B	6. 11. 1970	12–17	broken rock, algal canopy	17	0.071
Area B	8. 2. 1972			18	0.103
Area C	2. 2. 1972	3–20	rock face, boulders	18	0.101

These results are consistent with other studies of artificial reefs. CLARKE et al. (1967) for example, observed an increase in the biomass of fishes around the underwater habitat Sealab II of almost 35 times that of the normal sandy bottom, after only 43 days. The results of work by RANDALL (1963) and FAST & PAGAN-FONT (1973) on artificial reefs in the Caribbean are equally as striking. They reported eleven and ninefold differences respectively, in the standing crop of fishes on artificial reefs compared with nearby natural reefs. RANDALL suggested that the much greater biomass associated with his artificial reef was due largely to the proximity of the seagrass beds that surrounded the reef. These beds were fed upon at night particularly by grunts (Pomadasyidae), which sheltered on the reef by day and dominated the fish population both in number and weight.

A similar explanation seems likely for the inordinately high standing crop of fishes associated with the car-tyre reef in the present study. Cover and feeding opportunity provided by the tyres was certainly no greater than for rocky reef areas. However, the sand adjacent to the artificial reef formed an important habitat and food source area for the large numbers of red mullet *(Upeneichthys porosus)* which aggregated close to the reef. While not strictly a reef inhabitant from a trophic viewpoint, this species is invariably found close to reef areas and must therefore be considered as part of the reef fish population. *U. porosus* accounted for the bulk of the biomass of the fishes of the artificial reef. The total biomass of other fishes supported by the reef itself (i.e. excluding *U. porosus* and pelagic species) was only 2050 kg (April survey) and 1370 kg (May survey). Taking the actual area covered by the reef itself (i.e. 25 m^2) this gives a standing crop of 0.082 kg/m^2 and 0.055 kg/m^2 respectively, these figures being much closer to standing crop estimates obtained for nearby rocky reef areas (Table 3). The bulk of the fish biomass associated with the reef was contributed by fishes living and feeding about the periphery.

Peripheral-living species appear to account for the high concentrations of fishes and may explain the high angler success reported for artificial reefs in the United States (TURNER et al., 1969; BUCHANAN, 1973; STONE et al., 1974). Sand bass *(Paralabrax nebulifer)*, for example, a species inhabiting "sand-rock ecotones", formed a major portion of the fish fauna of southern Californian artificial reefs (TURNER et al.) 1969). Similarly, in Hawaii, where some reefs have been fished commercially, a large part of the fish yield has comprised sand dwelling mullids (MORRIS, 1967).

The apparent predominance of peripheral-living species in these artificial reef fish populations suggests that reef food resources are less important than has been postulated by some workers (e.g. COUSTALIN, 1972) and that high fish biomasses may be dependent more on the provision of shelter than on food. However, the very high fish standing crops reported so far have been for comparatively small artificial reefs. Paradoxically it seems that small reefs have greater numbers of fish per unit area associated with them than have larger reefs, but this may be because peripheral-living species tend to be a dominant component of the fish populations of smaller reefs. With an increase in the size of the reef, the area of the peripheral habitat will be proportionately smaller and it is likely that the overall standing crop of fishes would be less. This suggests that there may then be an optimum size for artificial reefs whereby the standing crop of fishes would be maximised. On the basis of results of experiments with different reef structures TURNER et al. (1969) concluded that for reefs capable of sustaining sportfishing "the overall reef should cover a broad area . . . and incorporate into its configuration large open spaces . . .". Further investigation of the relationship between reef area and fish biomass may provide a rational basis for improving fishing in so called "non-productive" inshore coastal areas.

SUMMARY

1. The development of the community of a small artificial reef built from car tyres was investigated by SCUBA diving over a 12 month period. It was sited on a sandy bottom at a depth of 20 m on the coast of north-eastern New Zealand.
2. Seasonal settlement by sessile organisms occurred in a number of well defined stages (serpulid tubeworms, barnacles, bryozoans, *Lithothamnion*, hydroids). The reef was colonised by small mobile invertebrates – notably gastropods, hermit crabs, mysids and shrimps – as well as by fishes.
3. Wave action was the most important single factor affecting the community. Severe water movement and sand scouring caused extensive sloughing of the epifauna, and a pattern of settlement-growth-catastrophic mortality which limited biotic succession. Wave action was important also in the colonisation by mobile organisms and many of the invertebrates and small fishes were probably carried to the reef associated with drift weed and other storm flotsam.

4. Seven species of fish were more or less permanent residents. There was little seasonal change in the number of fish species but fluctuation in the numbers of individuals occurred, brought about mainly by the effects of storms, and in some cases also by predation and the availability of food.
5. Standing crop estimates of the fishes were 1.458 and 1.075 kg/m^2, or about 10–14 times greater than that of nearby natural reefs. The bulk of the fish biomass, however, was contributed by a single species (*Upeneichthys porosus*) which inhabited the adjacent sand and was not directly supported by the reef itself.

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Author's address: B. C. RUSSELL
The Australian Museum
6–8 College Street
Sydney, Australia