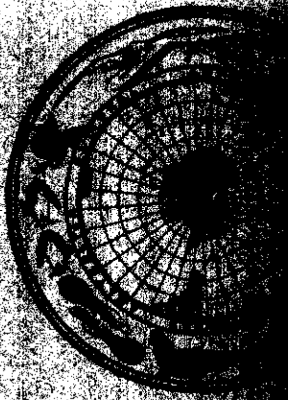

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AUSTRALIAN GOVERNMENT DEPARTMENT OF SCIENCE
ANTARCTIC DIVISION

AUSTRALIAN NATIONAL
ANTARCTIC RESEARCH EXPEDITIONS

ANARE SCIENTIFIC REPORTS

SERIES B (1) ZOOLOGY

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THE SHORE ENVIRONMENT OF MACQUARIE ISLAND

R. D. SIMPSON

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R. D. SIMPSON

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THE SHORE ENVIRONMENT OF MACQUARIE ISLAND

by R. D. SIMPSON*

Antarctic Division, Department of Science, Melbourne, Australia

ABSTRACT

A number of aspects of the rocky shore environment of Macquarie Island were recorded during studies on more specific topics of invertebrate biology and ecology. These aspects included summaries of climate, weather, and the topography of the rocky shores; of the zonation of organisms down the shore; and for the sea, measurements of wave action, temperature, salinity, pH, phosphate, and chlorophyll.

The local zonation was plotted from five transects and related to the universal, biologically defined zonation scheme of Lewis (1961) on the basis of the ecological characteristics of the common biota within the zones. The purpose and worth of using such a zonation scheme are discussed.

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I. INTRODUCTION

Studies of the ecology and biology of molluscs and, to a lesser extent, of echinoderms, of the littoral and sublittoral zones were undertaken at Macquarie Island during 1968-69 (Simpson, 1972) by the author while a biologist with the Australian National Antarctic Research Expeditions (ANARE). Further aspects of this work are in preparation for publication in appropriate, specialist journals.

Fundamental to these studies was the observation and measurement of aspects of the shore environment of Macquarie Island, particularly the biotic zonation of the shore. This report presents the compilation and discussion of some features of such data.

II. MACQUARIE ISLAND

The geography, climate and weather of Macquarie Island have been described previously either in depth (Mawson, 1943; Gibbs *et al.* 1950, 1951, 1952; Commonwealth Bureau of Meteorology, 1953 *et seq.*) or in summary (Taylor, 1955; Law *and* Burstall, 1956; Watson, 1967). However, the following brief descriptions are relevant as an introduction to this report.

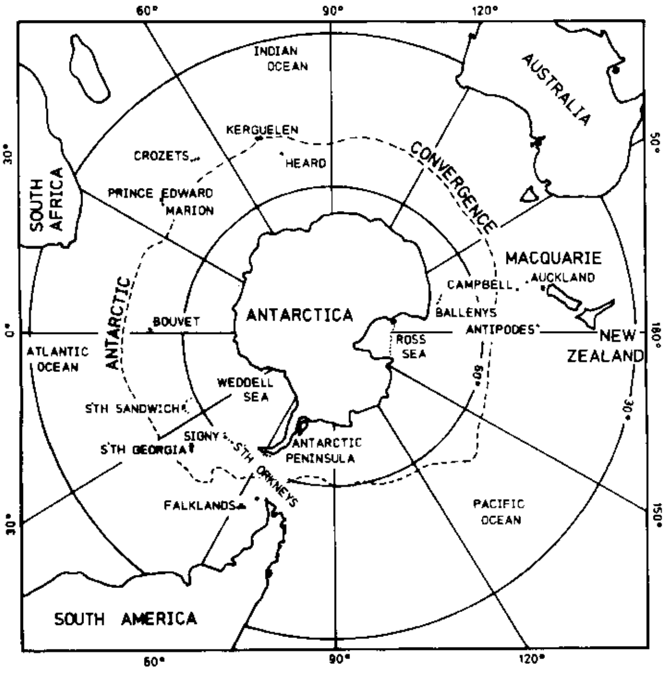


Figure 1
Location of Macquarie and other islands in the Antarctic region.

A. *GEOGRAPHY*

Macquarie Island is located at 54°38'S, 158°53'E, and lies approximately 1 470 km south-east of Tasmania and 1 440 km from the point nearest to the Antarctic continent (Figure 1). The outlying Judge and Clerk Islands (14 km NNE) and Bishop and Clerk Islands (32 km south) are merely large rock outcrops. The land nearest to Macquarie Island is the Auckland Islands and Campbell Island, in the Antipodean group. Macquarie Island is 33 km long and up to 5 km wide; the axis along its length is approximately 15° east of north.

Macquarie lies on a disrupted submarine ridge which stretches from New Zealand to another submarine ridge lying off the Antarctic continent. The island is separated from the Antipodean group by a narrow deep (3 700 to 5 000 metres in depth) and from the Antarctic continent by another far broader deep (Harrington, 1965; Varne *et al.*, 1969). The geological origins of Macquarie Island were discussed by Mawson (1943) whose interpretation has been disputed by Varne and others (Varne *et al.*, 1969; Varne *and* Rubenach, 1972).

Some geological features of Macquarie Island relevant to the shore-line include: (i) the rocks are almost entirely of volcanic origin; (ii) off the east coast the sea floor drops steeply, but off the west coast the slope is more gradual; and (iii) there are sand and shingle beaches on both sides of the island.

An extensive reef on the east coast, in the vicinity of the station area at the northern end of the island, was the location where most of the present study was carried out (see Figures 2 and 3).

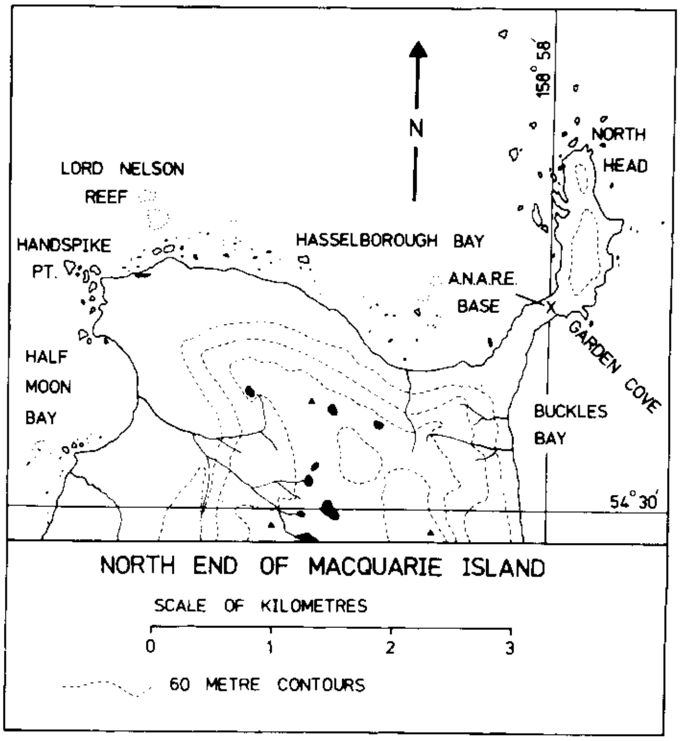


Figure 2
North end of Macquarie Island.

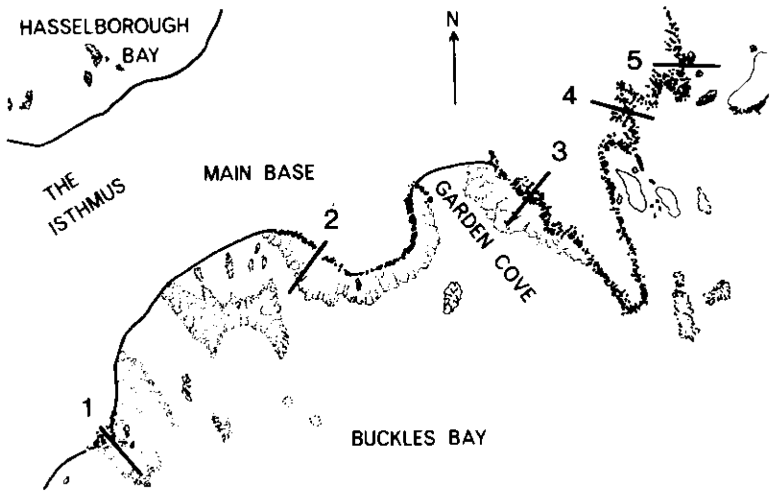


Figure 3
Location of transects on the Macquarie Island isthmus.

B. *CLIMATE AND WEATHER*

The climate of Macquarie Island is characterised by a relatively even, low temperature with high humidity and high wind velocities. Cloudy, wet weather is typical.

Data on the climate of Macquarie Island were obtained from records in *ANARE Data Reports,* Series D (Gibbs *et al.,* Commonwealth Bureau of Meteorology), from a summary by Law *and* Burstall (1956), and from meteorological observations made by ANARE personnel during the 1968 and 1969 expeditions. The highest temperature recorded in these data was 11.4°C, and the lowest was —8.3°C. The range of monthly mean temperatures was 3.0°C to 6.3°C. The mean annual total for precipitation was 103 cm, occurring over approximately 330 days in each year (that is, frequent but light falls). Approximately half of all observations (recorded continuously at 3-hourly intervals) showed a relative humidity of 90% or greater, while approximately one-tenth showed a relative humidity of less than 70%; the mean from these recordings was 88%.

The annual average of bright sunshine was 800 hours, recorded on 264 days in a year. On 101 days no sunshine was recorded. The monthly averages for the daily hours of sunshine varied from less than half-an-hour in June to just over three hours in February, sunshine being concentrated in the period October to March. In six years of operation of a sunshine recorder, there were only 35 days during which more than 10 hours of bright sunshine were recorded.

Cloud cover was persistent; over 90% of the observations showed that the sky was more than half-covered with cloud. Completely cloudless skies were uncommon. Fogs and misty conditions occurred frequently during all seasons.

The prevailing winds were westerlies, two-thirds of all winds being in the sector 255°-345°. The mean wind velocity was about 32 km per hour, and gusts of gale force were recorded on approximately 180 days each year. Heavy seas occurred in all seasons; the coastline is very exposed, with the western shores especially being subject to heavy wave action.

Macquarie Island lies north of the Antarctic Convergence, resulting in its general climate being milder than that of an island (for example, Heard Island) in similar latitude but lying south of the convergence.

Sea-ice does not form at Macquarie Island although, during an exceptionally cold spell, ice may form at the edges of the rock pools high in the littoral zone.

Taylor (1955) classed the climate of Macquarie Island as "cold temperate" or "sub-polar oceanic". The foregoing data exemplify an unusual climate, peculiar to Macquarie (and other sub-Antarctic islands). I believe that such a climate is aptly classed as sub-polar oceanic, but should not be equated with other cold temperate regions of the world.

III. ZONATION

A. *INTRODUCTION*

A number of studies have been made on the zonation of rocky shores in temperate regions of the southern hemisphere, for example, Tasmania (Guiler, 1952; Bennett *and* Pope, 1960) and Victoria (Bennett *and* Pope, 1953) in Australia, Chile (Guiler, 1959), and New Zealand (Morton *and* Miller, 1968); and reviews have been made by Knox (1960, 1963, 1968). The small amount of ecological work which has been done on sub-Antarctic shores generally has been confined to the recording of information about habitat and locality during collections and observations.

Since the establishment by ANARE of a permanent station on Macquarie Island, collections of littoral biota have been made by Kenny and Haysom in 1948 to 1950, by Bennett and Macpherson in 1959, and by Vestjens in 1961-62. Bennett (1971) gave a descriptive account of some of the more common shore organisms. Kenny *and* Haysom (1962) contructed a zonation pattern for the flora and fauna of the rocky shores. Their scheme, however, was restricted to a description applicable solely to the local situation.

The present report examines further the zonal limits, ecological relationships of zones, and tidal levels, with a view to relating the Macquarie Island zonation to the universal scheme of Lewis (1961, 1964).

B. *STUDY AREAS AND METHODS*

1. Transects

Five transects of the shore-line were selected on the east coast of the isthmus area (Figure 3). These were one metre wide and traversed the vertical aspect of the shore at right angles to the shore-line. The transects were used for determining zones as indicated by dominant organisms (those covering the greatest area), and also the common biota in each of the zones, with particular emphasis on molluscs. In order to ascertain any seasonal changes in the positions of zones, recordings were taken along the transects at bimonthly intervals (May, July, September, November, January, March) over a period of one year.

Each transect was marked by pegs; the highest was placed at the upper limit of the *Porphyra* algae and used as a reference point for measurements along the transect line and for the vertical measurements needed for the construction of a profile. Detailed charts of the topography of the transects were made and the positions of the dominant organisms plotted. Areas of biotic dominance were then projected onto the profile figures.

Transect 1 faced directly into the path of the ocean swells; the substratum was solid rock with a sharp drop below the line of holdfasts of the giant kelp *Durvillea antarctica.* Transect 2 was over a large rubble area where the shore was approximately 80° to the swell. Transect 3 traversed solid rock where the shore was approximately 60° to the swell. Transects 4 and 5 had solid rock substrata and faced directly into sea swells, the former dropping sharply at the *Durvillea* holdfast level whereas the latter traversed a gentle slope.

Transect 5 was cleared of *Durvillea antarctica* in April in order to observe any changes in the dominance of organisms marking the zones. Recordings were made just prior to removal of the *Durvillea.* The kelp was removed by cutting the stipes close to the holdfast, leaving the holdfast attached. This method was also employed in other areas.

2. Tidal measurements

Records from a tide gauge over a year were analysed by A. Easton (personal communication), enabling him to calculate the following values:

MHWS (mean high water spring) = MSL + (0.357 m)
MHWN (mean high water neap) = MSL + (0.199 m)
MLWN (mean low water neap) = MSL — (0.199 m)
MLWS (mean low water spring) = MSL — (0.357 m)

where MSL is the mean sea level, calculated as 1.237 m.

During the 1911-1914 Australasian Antarctic Expedition, L. R. Blake surveyed Macquarie Island and established a bench mark 2.73 m above mean sea level (Mawson, 1943). A check of Blake's figures showed that his MSL determination gave the same surveying level as that used in Easton's study (Easton, personal communication).

For each transect, the vertical height of a reference peg was surveyed with respect to Blake's bench mark, and the heights of the tops of all the squares and some other prominent features were obtained in relation to the reference peg. The profile of each transect therefore could be related to the mean sea level and hence to tidal levels using Easton's tidal formulae. EHWS (extreme high water spring) and ELWS (extreme low water spring) levels cannot be derived from tidal formulae, and were set for each transect by recording water levels when calm seas occurred at such tidal times.

C. *RESULTS*

Studies have shown that the rocky shores of sub-Antarctic islands are largely dominated by algae, for example Macquarie Island (Kenny *and* Haysom, 1962), Marion Island and Prince Edward Island (Fuller, 1967). Except for one area where siphonariids (*Kerguelenella lateralis)* were dominant, Kenny *and* Haysom used algae as zonal indicators in constructing a zonation scheme on Macquarie Island (Table 1).

Table 1.
Macquarie Island zonation
(sequence: 1 to 6 = land to sea)

Zone	Dominant Organism	
1. Lichen Zone	Lichens	
2. *Porphyra* Zone	*Porphyra umbilicus*	(alga)
3. Bare Zone	*Kerguelenella lateralis*	(mollusc)
4. Upper Red Zone	*Rhodymenia* sp.	(alga)
5. Kelp Zone	*Durvillea antarctica*	(alga)
6. Lower Red Zone	Encrusting coralline algae, red algae	

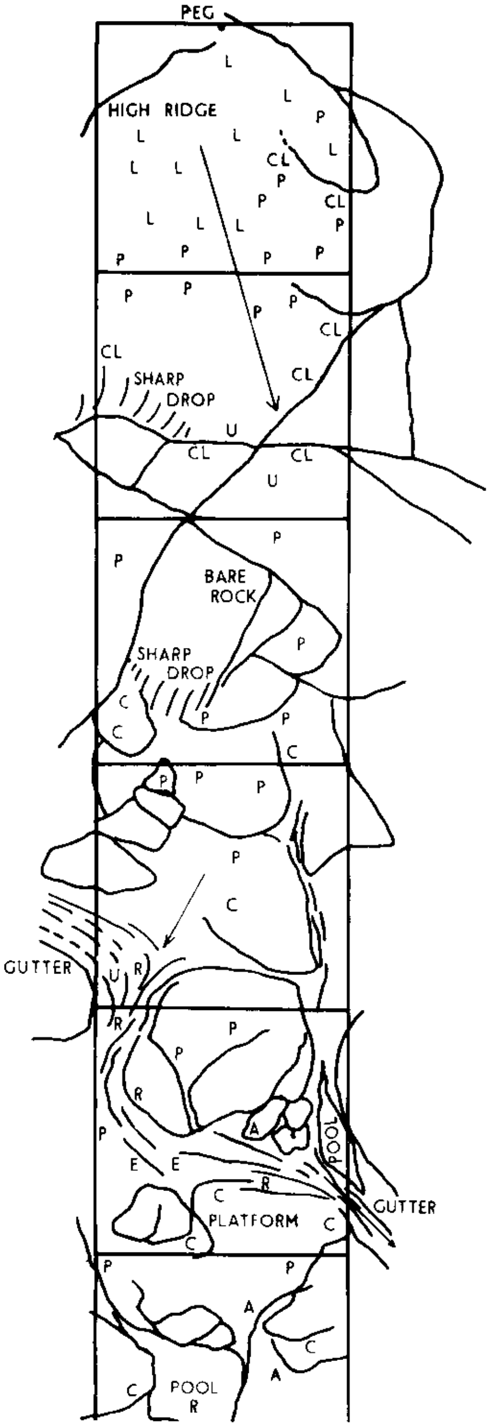
For the present study, Figure 4 shows the plane views of Transects 1 to 5 with the location of algae plotted on the charts. The faunal lists given on the right-hand side of the figure indicate the distribution of conspicuous animals (particularly molluscs) along the transects.

Profile diagrams (Figure 5) were made for each transect. These include tidal levels and areas where the dominant organisms were (i) lichen, (ii) *Porphyra-Cladophora* (algae), (iii) *Porphyra,* (iv) *Ulva-Chaetangium* (algae), (v) *Kerguelenella lateralis,* (vi) *Rhodymenia* (alga), (vii) *Durvillea,* and (viii) coralline algae — red algae.

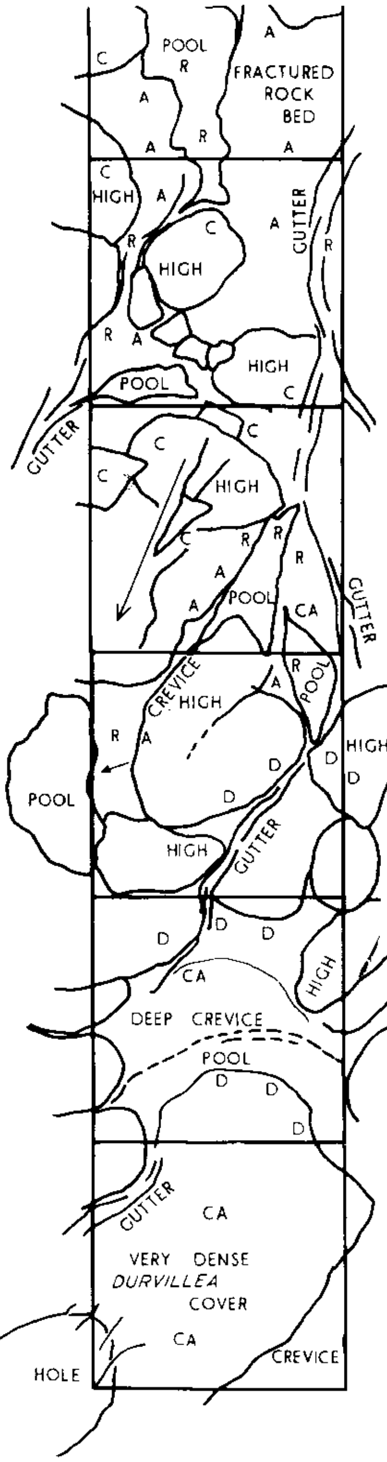
The tidal levels, calculated as described previously, are theoretical water levels presenting rise and fall only during very calm seas.

The six zones previously described by Kenny *and* Haysom (1962) were evident. Plates 1 to 6 show the dominant organisms marking each of these zones. Additional sub-zones were evident where *Ulva* sp. and *Chaetangium fastigiatum* were co-dominant (Transects 2 and 3) and where *Porphyra umbilicus* and *Cladophora* sp. were co-dominant (Transect 1). *Ulva* and *Chaetangium* algae were present in the same areas as the siphonariids, *Kerguelenella lateralis,* and it was apparent that large rubble and a lack of creviced, rocky surfaces (see description of the transects presented later in this report) caused the numbers of *K. lateralis* to decrease and *Ulva-Chaetangium* to be dominant. In Transect 2 the zone of *Ulva-Chaetangium* replaced the zone of *K. lateralis,* whereas in Transect 3 it was additional to this zone.

TRANSECT 1



1	MITES INSECTS INSECT LARVAE OLIGOCHAETES
2	MITES INSECTS INSECT LARVAE
3	MITES *K. LATERALIS*
4	MITES *K. LATERALIS* *L. CALIGINOSA* SMALL BIVALVES AMPHIPODS ISOPODS SEDENTARY POLYCHAETES
5	*K. LATERALIS* *L. CALIGINOSA* SMALL BIVALVES AMPHIPODS ISOPODS SEDENTARY POLYCHAETES
6	*K. LATERALIS* *L. CALIGINOSA* SMALL BIVALVES AMPHIPODS ISOPODS SEDENTARY POLYCHAETES



6

K. LATERALIS
L. CALIGINOSA
SMALL BIVALVES
AMPHIPODS
ISOPODS
SEDENTARY POLYCHAETES

7

K. LATERALIS
L. CALIGINOSA
SMALL BIVALVES
AMPHIPODS
ISOPODS
BRYOZOA

8

K. LATERALIS
L. CALIGINOSA
SMALL BIVALVES
P. MACQUARIENSIS
AMPHIPODS
ISOPODS

9

K. LATERALIS
SMALL BIVALVES
P. MACQUARIENSIS
H. SETULOSUM
P. AURATA
AMPHIPODS
SPIRORBIS AGGREGATUS

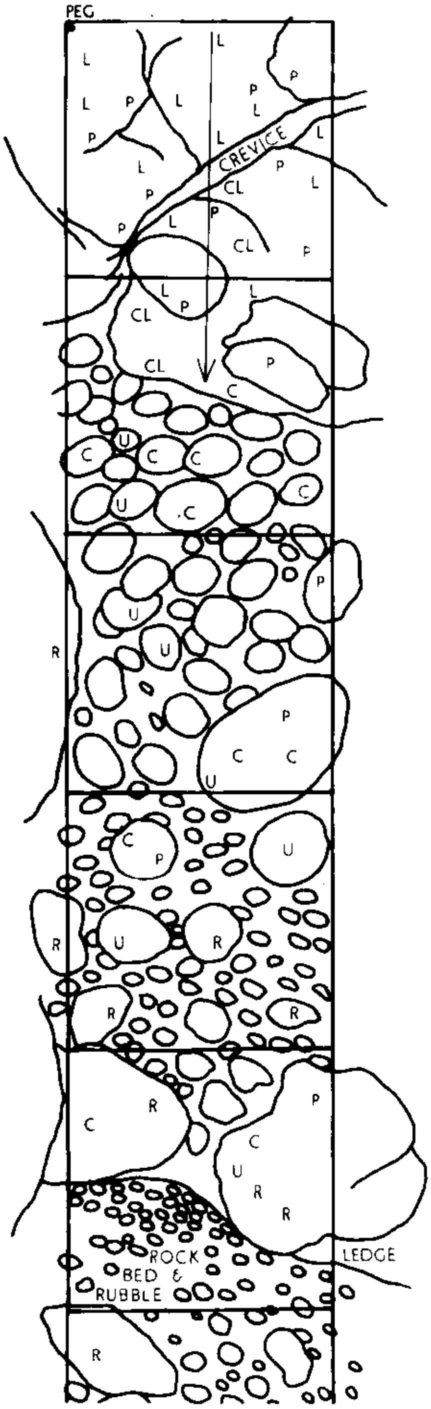
10

P. MACQUARIENSIS
H. SETULOSUM
P. AURATA
AMPHIPODS
SPIRORBIS AGGREGATUS
HOLOTHUROIDS
ANEMONES

11

P. MACQUARIENSIS
H. SETULOSUM
P. AURATA
HOLOTHUROIDS

TRANSECT 2



1

MITES
INSECTS
INSECT LARVAE
OLIGOCHAETES

2

MITES
INSECTS
K. LATERALIS
AMPHIPODS

3

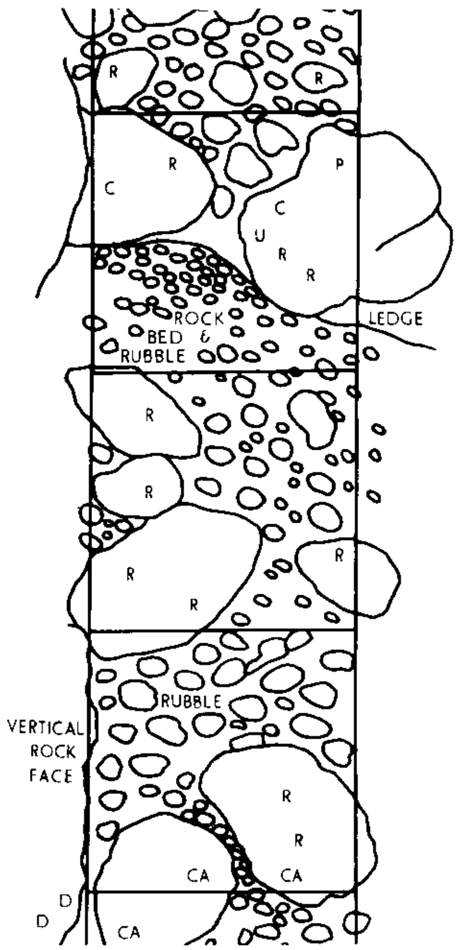
L. CALIGINOSA
P. MACQUARIENSIS
AMPHIPODS
(*K. LATERALIS* IN RUBBLE AREA OF SQUARES 3 AND 4 WERE SCARCE AND ONLY FOUND ON THE TOPS OF LARGE ROCKS)

4

L. CALIGINOSA
P. MACQUARIENSIS
AMPHIPODS

5

K. LATERALIS
L. CALIGINOSA
P. MACQUARIENSIS
AMPHIPODS
ISOPODS



5

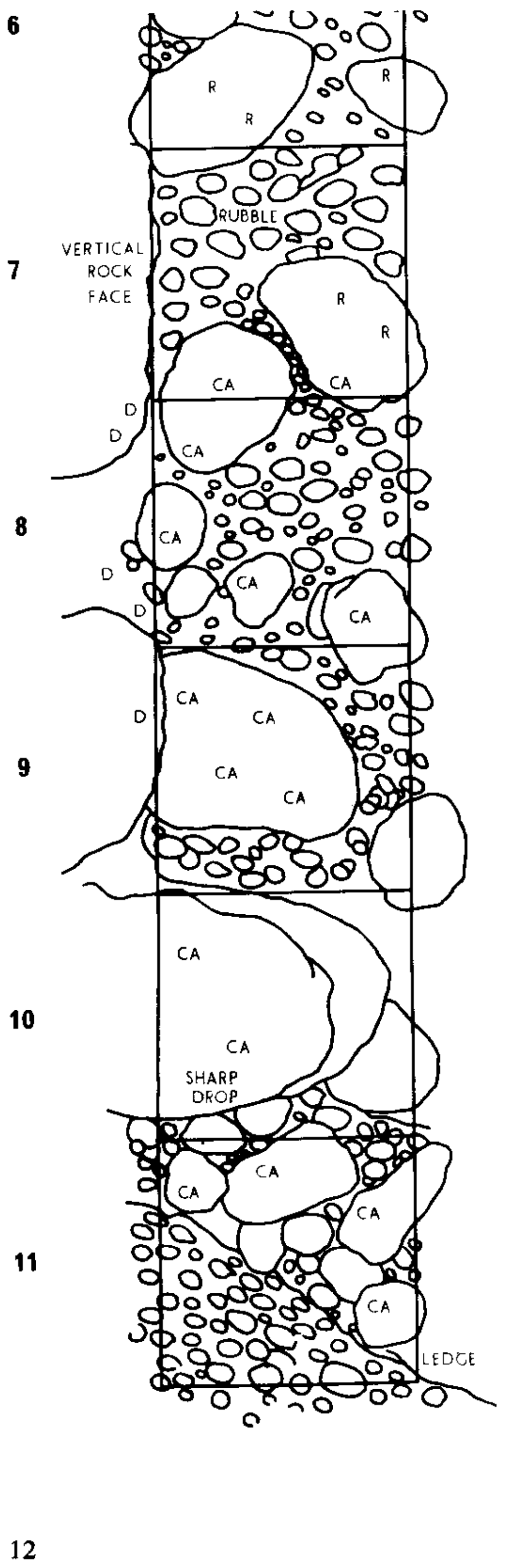
K. LATERALIS
L. CALIGINOSA
P. MACQUARIENSIS
AMPHIPODS
ISOPODS

6

K. LATERALIS
L. CALIGINOSA
P. MACQUARIENSIS
AMPHIPODS
ISOPODS

7

K. LATERALIS
L. CALIGINOSA
P. MACQUARIENSIS
P. AURATA
AMPHIPODS
ISOPODS
SPIRORBIS AGGREGATUS



K. LATERALIS
L. CALIGINOSA
P. MACQUARIENSIS
P. AURATA
AMPHIPODS
ISOPODS
SPIRORBIS AGGREGATUS

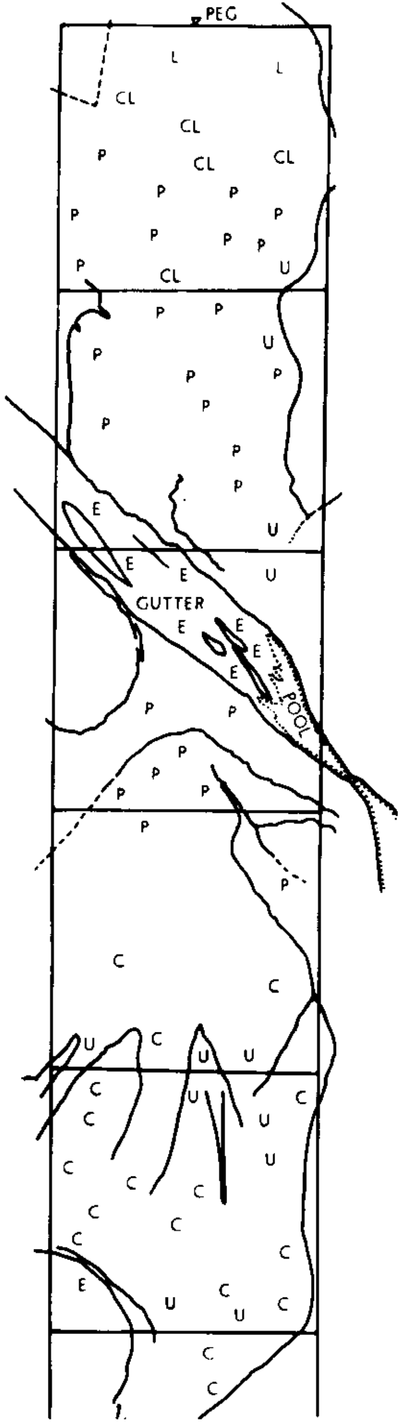
P. MACQUARIENSIS
P. AURATA
C. (P.) CORUSCANS
AMPHIPODS
SPIRORBIS AGGREGATUS
HOLOTHUROIDS
ANEMONES
STARFISH

P. MACQUARIENSIS
P. AURATA
C. (P.) CORUSCANS
AMPHIPODS
SPIRORBIS AGGREGATUS
HOLOTHUROIDS
ANEMONES
STARFISH

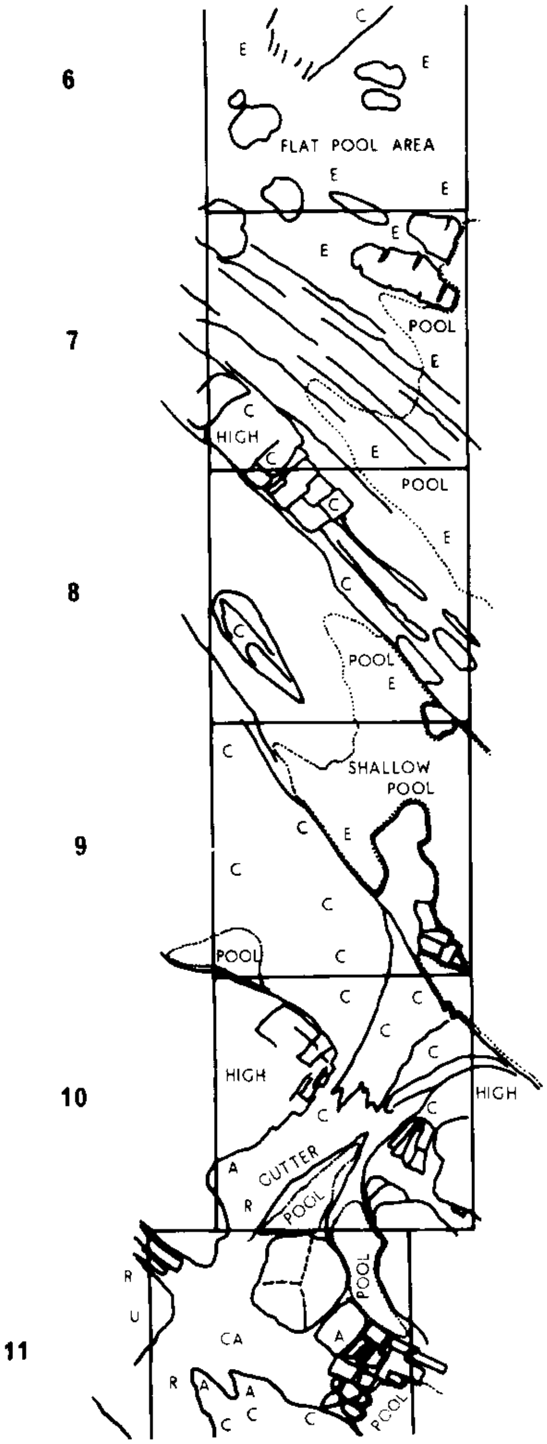
P. MACQUARIENSIS
P. AURATA
C. (P.) CORUSCANS
AMPHIPODS
SPIRORBIS AGGREGATUS
HOLOTHUROIDS
ANEMONES
STARFISH

P. MACQUARIENSIS
P. AURATA
C. (P.) CORUSCANS
AMPHIPODS
SPIRORBIS AGGREGATUS
HOLOTHUROIDS
ANEMONES
STARFISH

TRANSECT 3



1	MITES INSECTS INSECT LARVAE OLIGOCHAETES
2	MITES INSECTS INSECT LARVAE OLIGOCHAETES
3	MITES INSECTS INSECT LARVAE *K. LATERALIS*
4	MITES INSECTS INSECT LARVAE *K. LATERALIS*
5	MITES INSECTS INSECT LARVAE *K. LATERALIS* *L. CALIGINOSA*



K. LATERALIS
L. CALIGINOSA
AMPHIPODS
ISOPODS
SEDENTARY POLYCHAETES

K. LATERALIS
L. CALIGINOSA
AMPHIPODS
ISOPODS
SEDENTARY POLYCHAETES

K. LATERALIS
L. CALIGINOSA
SMALL BIVALVES
AMPHIPODS
ISOPODS
SEDENTARY POLYCHAETES

K. LATERALIS
L. CALIGINOSA
SMALL BIVALVES
AMPHIPODS
ISOPODS
SEDENTARY POLYCHAETES

K. LATERALIS
L. CALIGINOSA
SMALL BIVALVES
AMPHIPODS
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K. LATERALIS
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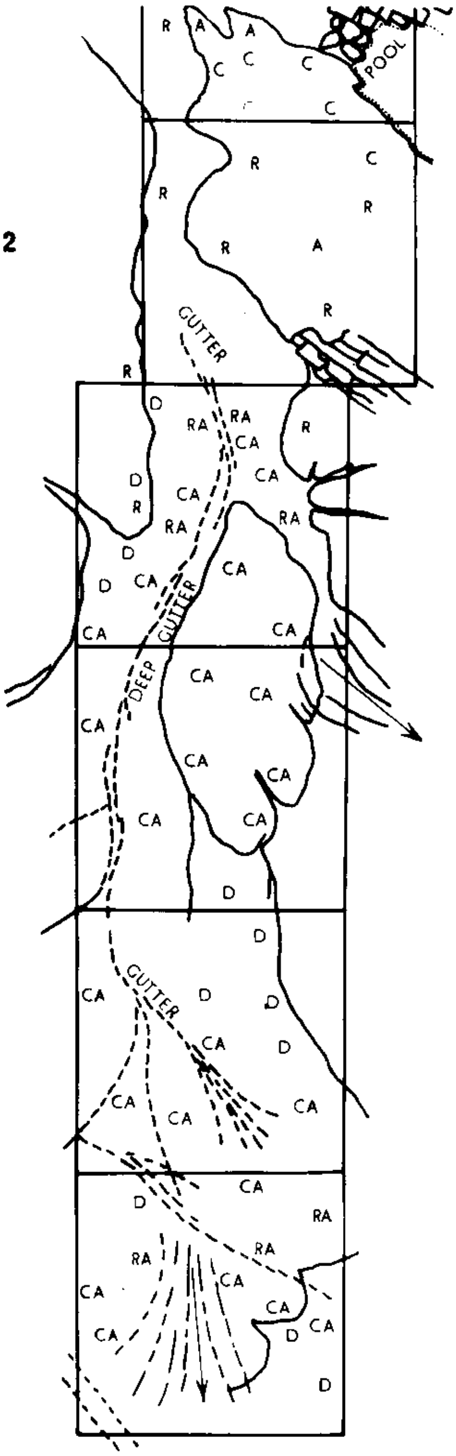
SMALL BIVAVLES
AMPHIPODS
ISOPODS



12

K. LATERALIS
L. CALIGINOSA
P. MACQUARIENSIS
H. SETULOSUM
P. AURATA
AMPHIPODS
GUTTER (HOLOTHUROIDS
(ANEMONES
(*SPIRORBIS AGGREGATUS*

13

P. MACQUARIENSIS
H. SETULOSUM
P. AURATA
AMPHIPODS
SPIRORBIS AGGREGATUS
HOLOTHUROIDS
ANEMONES

14

P. MACQUARIENSIS
H. SETULOSUM
P. AURATA
HOLOTHUROIDS
ANEMONES
SPIRORBIS AGGREGATUS
STARFISH

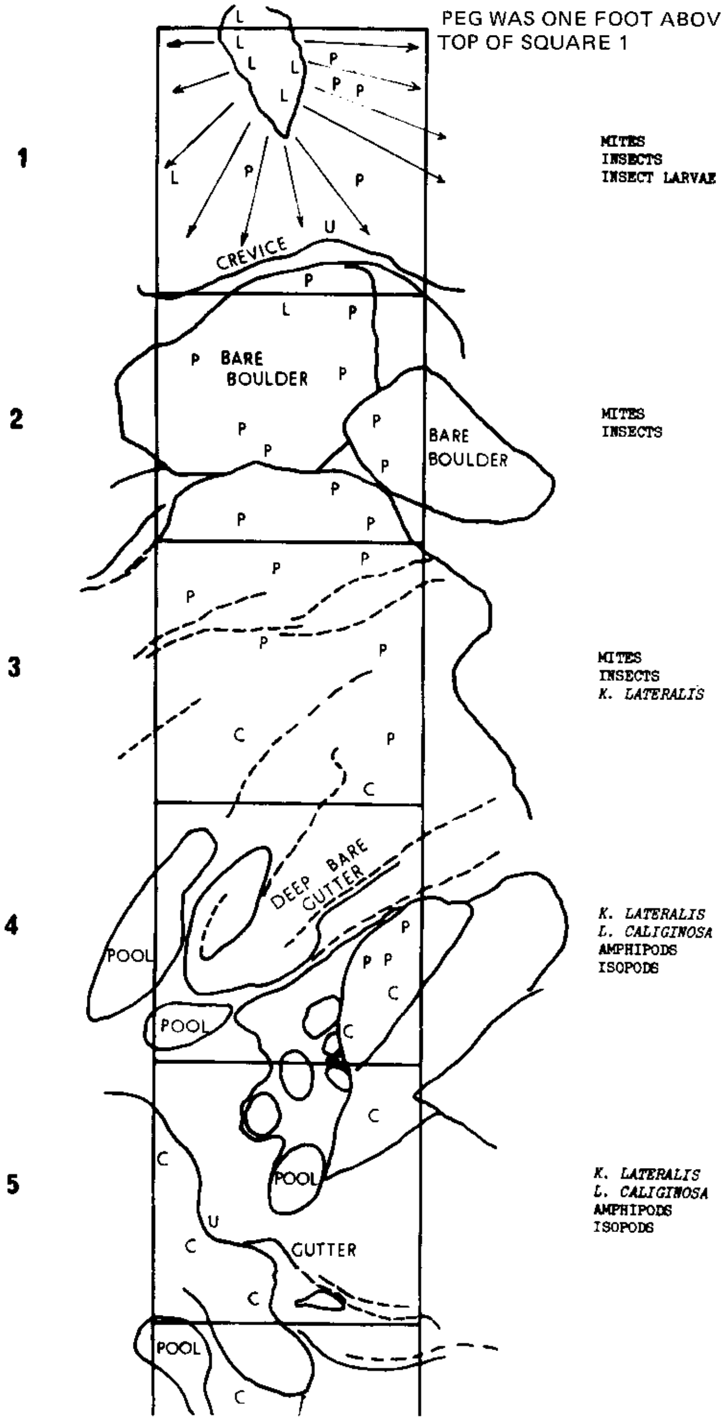
15

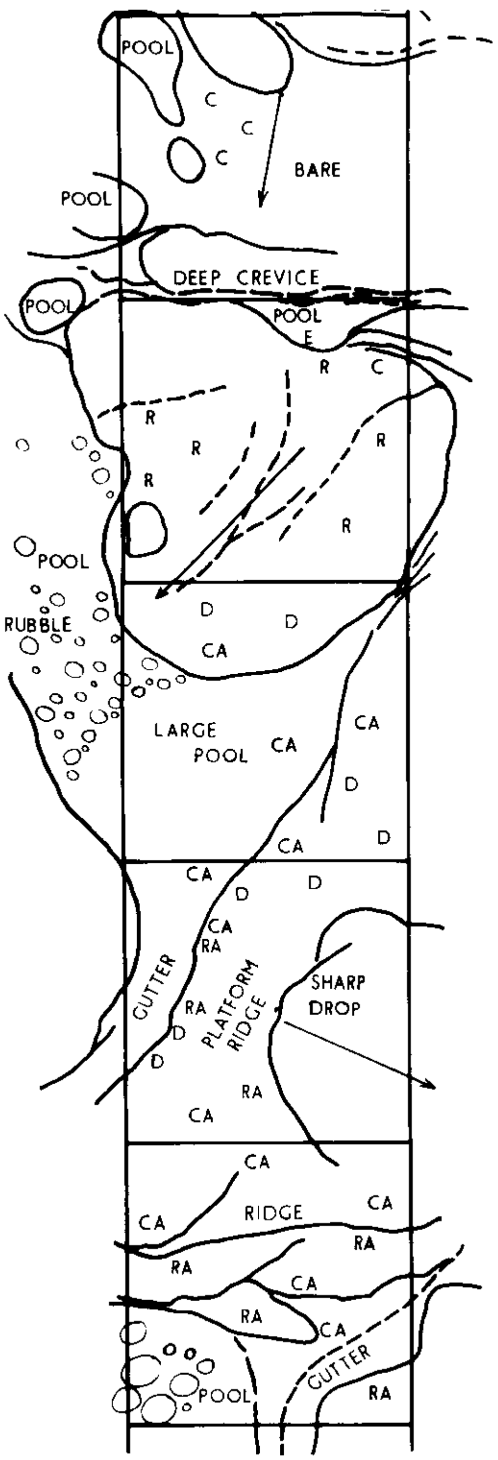
P. MACQUARIENSIS
H. SETULOSUM
P. AURATA
C. (P.) CORUSCANS
HOLOTHUROIDS
ANEMONES
SPIRORBIS AGGREGATUS
STARFISH

16

P. MACQUARIENSIS
H. SETULOSUM
P. AURATA
C. (P.) CORUSCANS
HOLOTHUROIDS
ANEMONES
SPIRORBIS AGGREGATUS
STARFISH

TRANSECT 4


PEG WAS ONE FOOT ABOVE TOP OF SQUARE 1
1
2
3
4
5
CREVICE
BARE BOULDER
BARE BOULDER
DEEP BARE GUTTER
POOL
POOL
POOL
GUTTER
POOL
L
P
U
C
MITES
INSECTS
INSECT LARVAE
MITES
INSECTS
MITES
INSECTS
K. LATERALIS
K. LATERALIS
L. CALIGINOSA
AMPHIPODS
ISOPODS
K. LATERALIS
L. CALIGINOSA
AMPHIPODS
ISOPODS



6

K. LATERALIS
L. CALIGINOSA
P. MACQUARIENSIS
AMPHIPODS
ISOPODS

7

K. LATERALIS
L. CALIGINOSA
P. MACQUARIENSIS
SMALL BIVALVES
AMPHIPODS
ISOPODS

8

P. MACQUARIENSIS
L. CALIGINOSA
H. SETULOSUM
P. AURATA
C.(P.) CORUSCANS
AMPHIPODS
ISOPODS
SPIRORBIS AGGREGATUS
HOLOTHUROIDS
ANEMONES
STARFISH

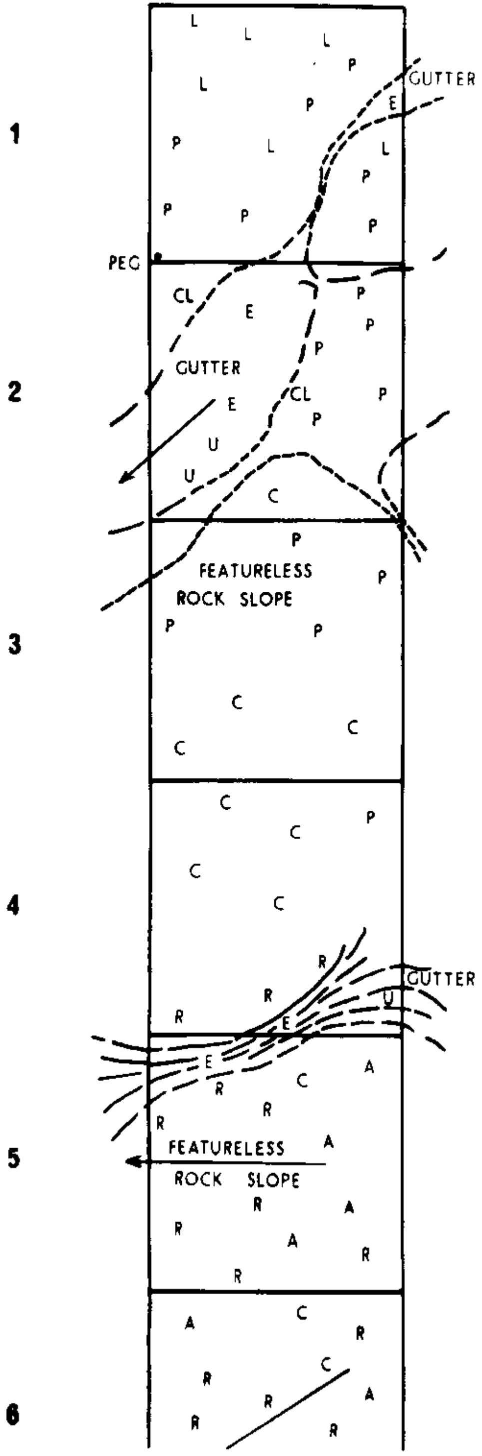
9

P. MACQUARIENSIS
H. SETULOSUM
P. AURATA
C.(P.) CORUSCANS
AMPHIPODS
SPIRORBIS AGGREGATUS
HOLOTHUROIDS
ANEMONES
STARFISH

10

P. MACQUARIENSIS
H. SETULOSUM
P. AURATA
C.(P.) CORUSCANS
M. HAMILTONI
SPIRORBIS AGGREGATUS
HOLOTHUROIDS
ANEMONES
STARFISH

TRANSECT 5



MITES
INSECTS
INSECT LARVAE
OLIGOCHAETES

MITES
INSECTS
INSECT LARVAE

MITES
INSECTS

K. LATERALIS
L. CALIGINOSA
SMALL BIVALVES
AMPHIPODS

K. LATERALIS
L. CALIGINOSA
SMALL BIVALVES
AMPHIPODS

K. LATERALIS
L. CALIGINOSA
AMPHIPODS

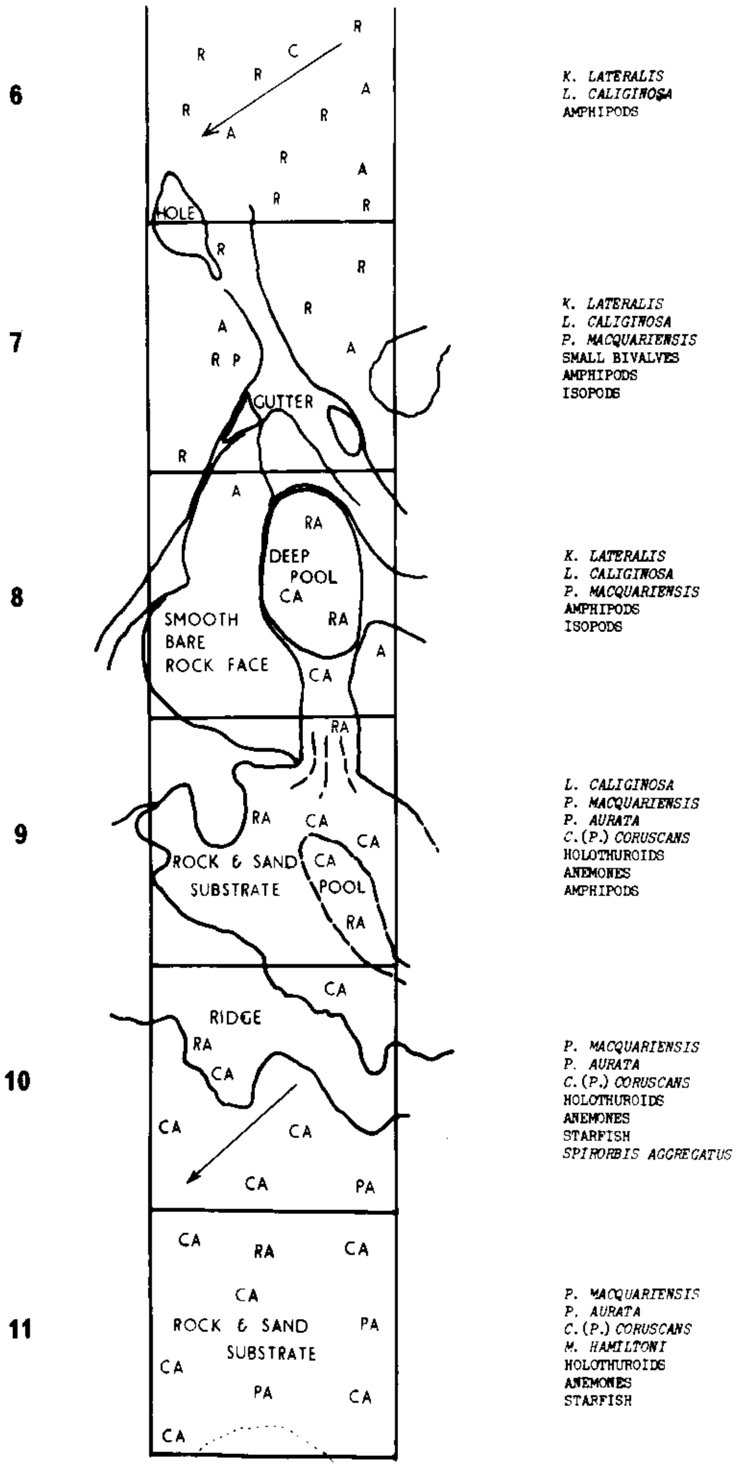
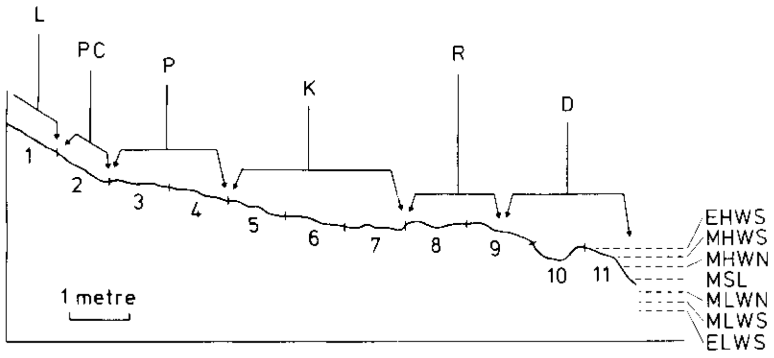


Figure 4

Charts of plane views of Transects 1 to 5. Each square = 1 sq. m. Prevalent algae are indicated by symbols on the charts and common, conspicuous fauna found in the squares are listed to the side.

Key to symbols depicting flora:
L = Lichens
Algae:
P = *Porphyra umbilicus*
CL = *Cladophora* sp.
E = *Enteromorpha* sp.
C = *Chaetangium fastigiatum*
U = *Ulva* sp.
R = *Rhodymenia* sp.
A = *Adenocystis utricularis*
D = *Durvillea antarctica* holdfasts
CA = Encrusting coralline algae (lithothamnions)
RA = Red algae

1.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MLWS
ELWS
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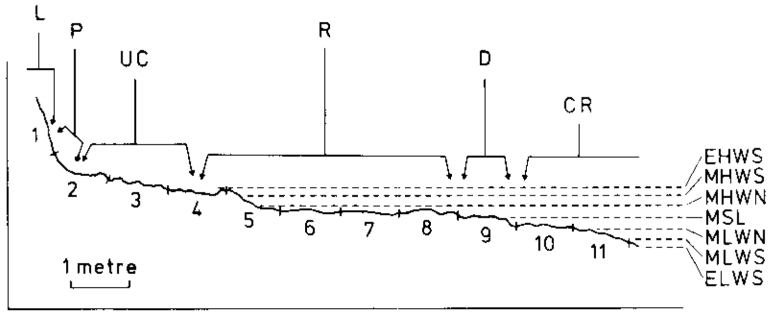
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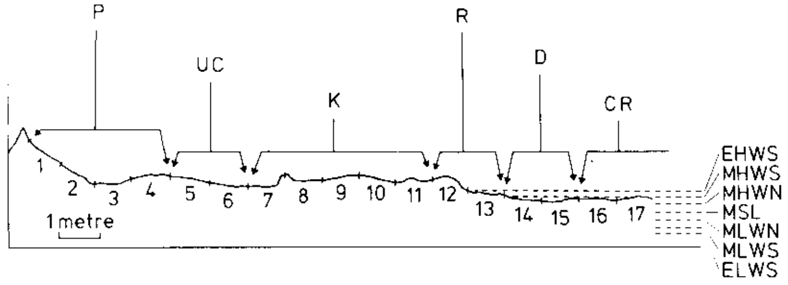
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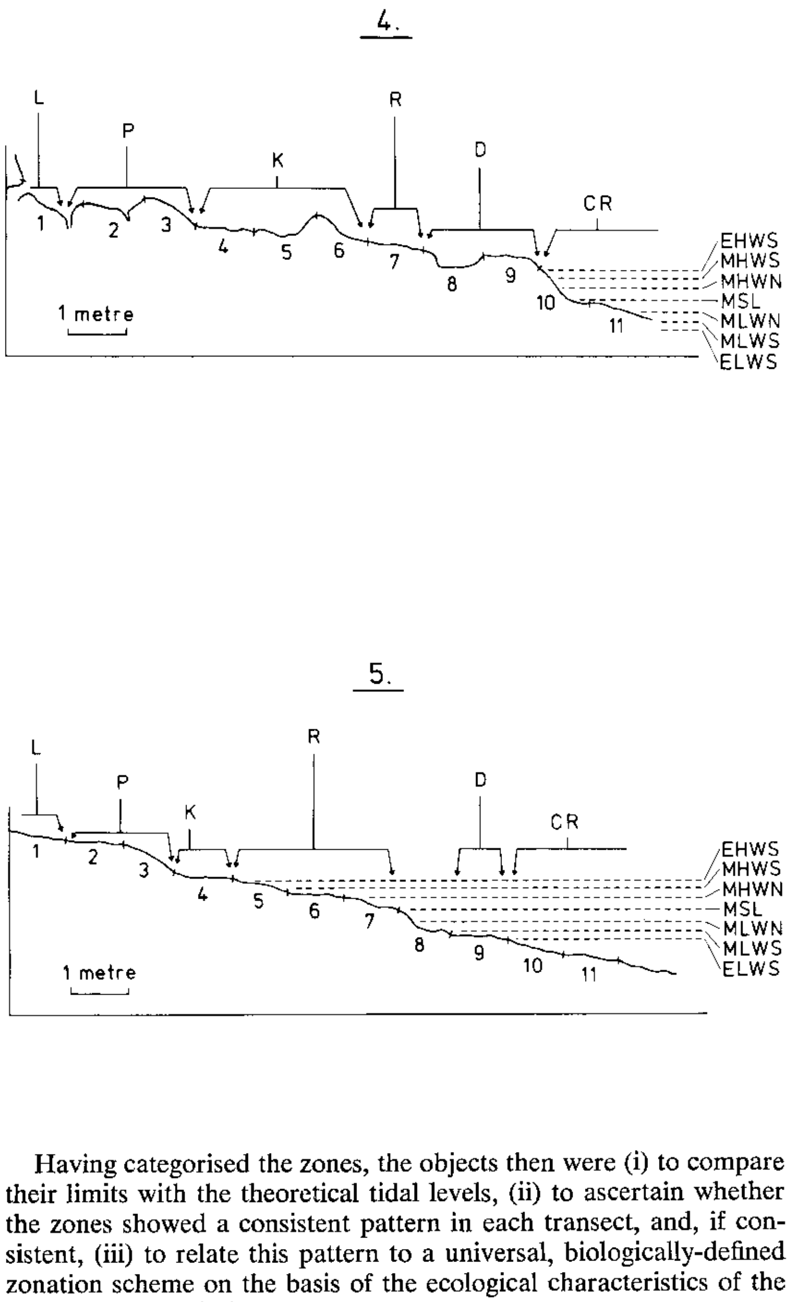

Figure 5

Profiles of the five transects; showing tidal levels and areas of dominant organisms.

Key to dominant organisms:

L = Lichen
PC = *Porphyra - Cladophora*
P = *Porphyra*
UC = *Ulva - Chaetangium*
K = *Kerguelenella lateralis*
R = *Rhodymenia*
D = *Durvillea* holdfasts
C = Coralline algae - Red algae

Having categorised the zones, the objects then were (i) to compare their limits with the theoretical tidal levels, (ii) to ascertain whether the zones showed a consistent pattern in each transect, and, if consistent, (iii) to relate this pattern to a universal, biologically-defined zonation scheme on the basis of the ecological characteristics of the common biota within the zones.

Figure 5 shows the positions of zones along each transect. In Transect 1 the substratum was solid rock. The steep gradient of this transect at sea level and its direct exposure to the path of the sea swells resulted in wetting by frequent surge. Tidal levels alone did not reach above Square 11 even at EHWS. Siphonariids (*K. lateralis*) usually were found in crevices in Squares 3 to 7 and were the dominant organisms from Squares 5 to 7 (Bare Zone).

Plate 1
Lichen Zone. Lichens and mosses.

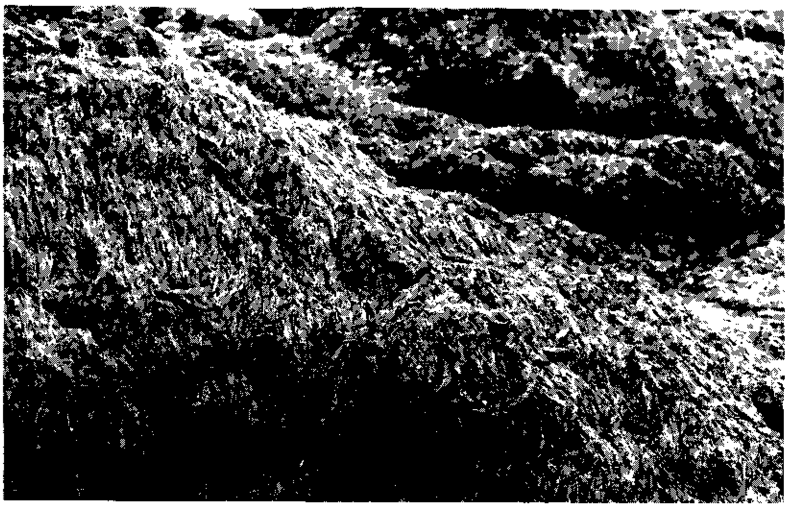

Plate 2
Porphyra Zone. Dense covering of *Porphyra umbilicus.*

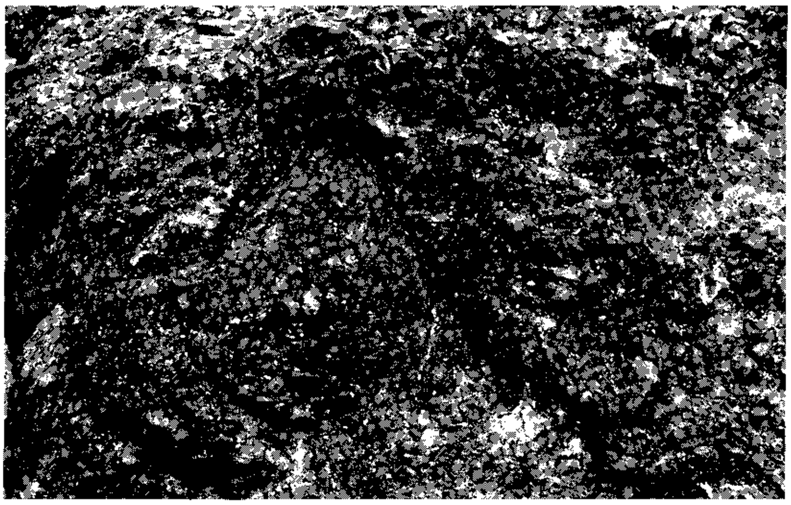

Plate 3
Bare Zone. Bare rock with high density of *Kerguelenella lateralis.*

Plate 4
Upper Red Zone. Covering of *Rhodymenia* sp.

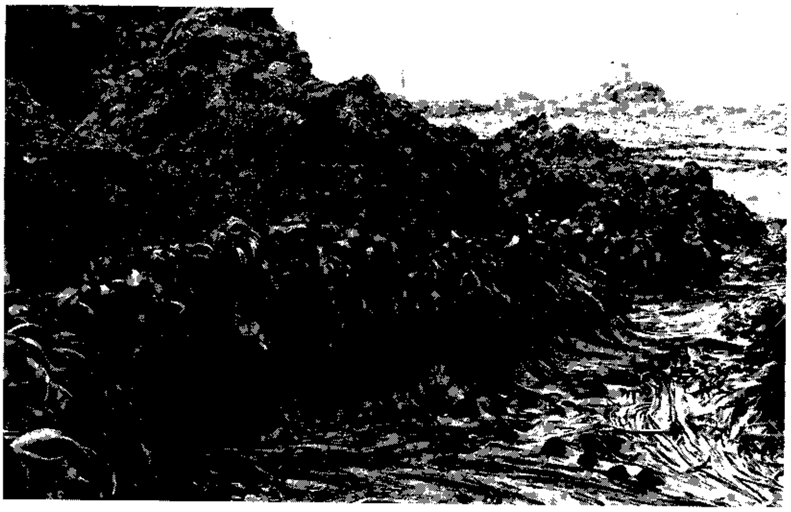

Plate 5
Kelp Zone. Dense growth of *Durvillea antarctica* (photographed at low tide and calm seas).

Plate 6
Lower Red Zone. Rock surface, below the *Durvillea*, encrusted with coralline algae and with small clumps of red algae (photographed at low tide and calm seas).

In Transect 2 the substratum mainly consisted of large, firmly implanted rubble. Because the shore-line was at an obtuse angle to the prevailing swells, the impact of the waves was lessened. EHWS tidal level was at the top of Square 5. *K. lateralis* were lacking in this area where the substratum consisted solely of large rubble and, in such a habitat, siphonariids generally were restricted to the tops of large boulders. In Transect 2, the presence of giant kelp had to be considered in two ways: (i) the effect of fronds from nearby *Durvillea* holdfasts not in transect squares, and (ii) the actual zone where *Durvillea* holdfasts were dominant. The transect was alongside large rock outcrops on which holdfasts were attached, and the upper limit of these holdfasts was at the level of Square 5. Although fronds from these lay over the transect area from Square 5 downwards during low tide and calm seas, *Rhodymenia* was dominant in the actual transect from the bottom half of Square 4 to Square 8. The Kelp Zone, where *Durvillea* holdfasts were dominant on the actual transect, was confined to Square 9.

In Transect 3, the slope was very gentle along a solid rocky substratum. Because the shore-line was at approximately 60° to the prevailing swell, the impact of the waves was reduced. EHWS tidal level was in Square 13. The distribution of both *Chaetangium fastigiatum* and *K. lateralis* was extended greatly, that is, from Squares 4 to 11. Siphonariids were dominant from Squares 7 to 11. In Squares 5 and 6, the rocky surfaces were smoother and lacked crevices. Although *K. lateralis* were present in these latter two squares, *Ulva* and *Chaetangium fastigiatum* were co-dominant.

In Transect 4, the substratum consisted mainly of solid rock. There was a steep gradient at sea level and wetting usually occurred by splash and surge, with the shore-line facing directly into the prevailing swells. The tidal level of EHWS was at the top of Square 10. The top of Square 8 coincided with the upper limit of *Durvillea* holdfasts which dominated Squares 8 and 9, forming the Kelp Zone. However, a large deep pool with a rubble bottom occupied parts of Squares 8 and 9. There were no holdfasts in this pool, which, because the kelp cover had little effect on it, could not be regarded as part of the Kelp Zone. This pool situation apparently was favourable to the limpet *Patinigera macquariensis* as large numbers were found there, an atypical occurrence in the Kelp Zone.

In Transect 5, the slope was gradual over a substratum of solid rock. Although the shore faced directly into the prevailing swells, there was a fringing reef out to sea which greatly reduced wave action. The EHWS level was at Square 5. Removal of *Durvillea* had little effect on the dominant organisms marking the zones and, consequently, little effect on zonal positions. There were changes in the abundance of other common, conspicuous organisms (see later). Further change may have been evident in communities defined in greater detail. In the first four months after the removal of *Durvillea* the only observed effect was on the Kelp and Lower Red Zones where some coralline algae died off and red algae increased; zones above the Kelp Zone were not affected. Before removal, the upper limit of the *Durvillea* holdfasts was at Square 8, but this square mainly comprised a rock surface with scattered stands of the alga *Adenocystis utricularis,* and a pool containing coralline algae and red frond algae.

Durvillea holdfasts had been dominant in Square 9. The removal of *Durvillea* increased the overall number of the limpet *Patinigera macquariensis,* but did not alter the upper limit of its distribution at Square 7. The removal of kelp lowered a density estimate for the chiton *Hemiarthrum setulosum* from common to rare in Squares 10 and 11. These data, and further studies on the removal of *Durvillea* which support the changes in density shown for *P. macquariensis* and *H. setulosum* on Transect 5, are examined elsewhere (Simpson, 1972, 1976).

Observations at bimonthly intervals along the transects showed no seasonal changes in the position of the zones. Although the spatial extent of the zones differed according to conditions along each transect, there was a consistent sequence in the vertical order of zones. Because the ecological characteristics of the *Ulva-Chaetangium* and *Porphyra-Cladophora* sub-zones were very similar to those of the Bare and *Porphyra* Zones respectively, for the purposes of this study the latter two zonal terms also were used to denote those areas where the algal combinations were dominant.

Table 2 lists the conspicuous biota of the six zones, with emphasis on the distribution of molluscs, as determined from the five transects. In all transects, the organisms of each zone were similar, although the proportionate composition varied with the different transects. Kenny *and* Haysom (1962) have compiled detailed lists of the shore biota.

Table 2.
Common biota
of rocky shore zones
of Macquarie Island.

ZONE	FAUNA	FLORA
LICHEN	Mites Beetles Insect larvae Collembola *Tigriopus angulatus* (copepod) Amphipods	*Verrucaria* sp. lichen Other lichens *Hildenbrantia* sp. (alga) *Prasiola* sp. (alga) *Enteromorpha* sp. (alga) *Colobanthius muscoides* (vascular plant) *Cotula plumosa* Mosses

PORPHYRA	Mites Oligochaetes *Kerguelenella lateralis* (siphonariid) *Laevilittorina caliginosa* (littorinid) Small bivalves Amphipods *Exosphaeroma gigas* (isopod) Sedentary polychaetes	*Porphyra umbilicus* (alga) *Enteromorpha* sp. (alga) *Cladophora* sp. (alga) *Ulva* sp. (alga) *Prasiola* sp.
BARE	*Kerguelenella lateralis* *Laevilittorina caliginosa* Small bivalves Amphipods *Exosphaeroma gigas* Sedentary polychaetes	*Chaetangium fastigiatum* *Ulva* sp.
UPPER RED	Amphipods *Exosphaeroma gigas* *Kerguelenella lateralis* *Laevilittorina caliginosa* *Patinigera macquariensis* (limpet)	*Phodymenia* sp. (alga) *Adenocystis utricularis* (alga)
KELP	*Hemiarthrum setulosum* (chiton) *Plaxiphora aurata* (chiton) *Patinigera macquariensis* *Spirorbis aggregatus* (tubicolous polychaete) *Pseudopsolus macquariensis* (holothuroid) Amphipods Anemones	*Durvillea antarctica* (giant kelp) Coralline algae
LOWER RED	*Patinigera macquariensis* *Plaxiphora aurata* *Cantharidus (P.) coruscans* (trochid) *Pseudopsolus macquariensis* *Spirorbis aggregatus* *Anasterias directa* (starfish) *Anasterias mawsoni* (starfish) Anemones	Coralline algae Red algae (several species)

There was no evidence to suggest that the lashing fronds of *Durvillea* were the cause of the relatively barren nature of the Bare Zone, as postulated by Kenny *and* Haysom (1962). In Transect 5, the Bare Zone did not change in either position or species composition of the conspicuous organisms after the removal of *Durvillea* fronds. However, Transect 5 was not a good situation in which to study the effects of *Durvillea* on the Bare Zone since the holdfasts were well away from it; the lower position of the Kelp Zone probably was brought about by the lesser wave action resulting from the fringing reef out to sea (see description of transects).

In other transects (1 to 4) much of the Bare Zone was well away from the influence of the kelp fronds. This also was observed on many parts of the shore-line. However, in other areas of the shore, the Bare Zone was closer to the Kelp Zone and was subjected to considerable contact by fronds thrown about by wave action. *Durvillea* was removed from a strip in five of these areas. Three of these were cleared in May, one in October, and one in February. Observations through to the following March showed that the Bare Zone did not change in position or composition of the conspicuous biota.

There was denser growth of *Chaetangium fastigiatum* in the Bare Zone in the period September-December but the density of *Porphyra umbilicus* (*Porphyra* Zone) and *Rhodymenia* sp. and *Adenocystis utricularis* (Lower Red Zone) also increased in this period, suggesting an overall seasonal increase in growth of littoral algae. The lashing of the Bare Zone by kelp fronds is regarded here as a coincidental rather than a causal occurrence. If anything, the *Durvillea* fronds should have had greater influence on the zone immediately above the Kelp Zone, that is the Upper Red Zone. However, the density of the dominant *Rhodymenia* of the Lower Red Zone did not show any relation to the removal of *Durvillea*. The relatively barren nature of the Bare Zone was apparently due to other factors, such as the absence of dominant sessile animals, for example barnacles and mussels, found on shores at lower latitudes.

It is curious that in the zonal sequence on Marion and Prince Edward Islands, a Bare Zone occurred between the Lichen and *Porphyra* Zones and not between the *Porphyra* and Upper Red Zones (Fuller, 1967).

D. *DISCUSSION*

The use of zonation schemes to describe the shore environment has received attention from many workers. Various interpretations and terminologies have been used and these have been reviewed by Colman (1933), Doty (1957), Stephenson *and* Stephenson (1949, 1972), Southward (1958), Lewis (1961, 1964), and den Hartog (1968).

It has been accepted for some time that attempts to correlate zonation with average tidal levels are unsuitable owing to the influence of many modifying factors, especially the degree of wave action. Stephenson *and* Stephenson (1949) proposed a system defining three basic zones in terms of organisms. Lewis (1961) modified this system and emphasised that the three zones were ecological entities completely defined by biological means, thus rejecting physical definitions of zonation. This biological zonation has since been criticised. Russell (1972) argued that such schemes are largely subjective and sought a pattern by numerical, objective methods. den Hartog (1968) maintained that the formation of the three basic zones was the result of interactions of three major physical factors (air, salinity, light), and of biological stress, at the land-sea interface. He proposed terminology, based on physical factors, equivalent to the "biological" littoral terminology. However, den Hartog's conclusions were theoretical and should be viewed accordingly.

In the present study, zones are defined by biological description. This does not contribute to the understanding of their formation, nor was this the intention. The zones were used simply to form a framework within which to compare distributions of littoral animals as part of ecological studies (Simpson, 1976). Also, it was worthwhile to relate this "local framework of zones" to a universal scheme of zonation so that other workers might place the descriptions readily into perspective with a pattern that is in wide usage: in this case, the scheme of Lewis (1961, 1964). It is appropriate, therefore, to note the way in which Lewis defined his zones.

Lewis defined "littoral" as the zone occupied by marine organisms which were adapted to, or needed alternating exposure to, air and wetting by submersion, splash or spray. The two subdivisions of the littoral — littoral fringe and eulittoral — represented respectively (i) an upper marginal zone in which the organisms were subjected to mainly terrestrial conditions but had greater littoral than terrestrial affinities, and (ii) a lower zone occupied by the majority of littoral organisms. The sub-littoral zone denoted a region occupied, in the main, by fully marine organisms. These three divisions represented three basic ecologically-distinct groupings in the shore environment.

The universality of zones defined by organisms stems not from the world-wide distribution of the same species at precisely the same levels, but from the recurrence, in approximately the same positions relative to each other, of organisms that can be regarded as ecological analogues and which usually are closely related taxonomically. When the typical indicators are absent, investigation of the shore reveals other biological indicators with which to set the boundaries of the three zones. The indicator species used by Lewis to set the zonal boundaries have wide geographic distributions. However, barnacles are not present on Macquarie shores and there are no littorinids in the littoral fringe where lichens, including *Verrucaria* sp., are present.

Kenny *and* Haysom (1962) noted the absence of "balanoid" and "littorinid" zones but, in summary, unfortunately stated this as an absence of barnacles and littorinids *per se* and this was repeated in the review of intertidal ecology of Australasian coasts by Knox (1963). Although a littorinid zone in the area of the littoral fringe certainly was lacking, there were littorinid molluscs on Macquarie rocky shores in the eulittoral and sublittoral zones. However, there was no "littorinid sub-zone" within either of these zones. Barnacles were completely absent from rock surfaces in the littoral area.

Although living stalked barnacles often were found on drifting kelp, settlement would most likely have occurred in warmer waters. In a report on the littoral ecology of the Marion and Prince Edward Islands, Fuller (1967) stated that littorinids were absent. Fuller also made comment on the absence of a "littorinid zone", and it would appear likely that in this report there is a similar confusion between the absence of littorinids and the absence of a littorinid zone.

Because of (i) the absence of the "balanoid" and "littorinid" zones and (ii) the high degree of wave action, Kenny *and* Haysom (1962) stated that it was difficult to correlate the Macquarie zonation with the generalised plan of Stephenson *and* Stephenson (1949). They positioned the zones in relation to "effective tidal heights", following Endean *et al.* (1956), where a subjective adjustment was made to the tidal level according to the tidal data, shore profile, degree of exposure, and the average conditions of wave action. In the present study, the transects down the shores (Figure 5) show the lack of correspondence of zonal boundaries to tidal levels alone. Although "effective tidal heights" would make allowances for other modifying factors, such adjustments of observed data are of questionable value. It is preferable to use organisms to define the zones.

The composition of the common biota in each of the "local" zones as recorded from the transects, could be related to the definitions of ecological affinities that Lewis (1961, 1964) gave to his zones in a universal scheme. Figure 6 shows Macquarie Island's rocky shore zonation correlated with the Lewis scheme. It appeared adequate to use the upper limit of the Lichen Zone to mark the top of the littoral fringe; it represented the upper boundary of an upper marginal zone with mainly terrestrial conditions but with many organisms having littoral affinities (Table 2). Although copepods (*Tigriopus*), amphipods, and *Enteromorpha* alga were found also in pools, many of these pools were too shallow to simulate conditions lower on the shore.

For sub-Antarctic waters, Knox (1960, 1968) placed the Kelp Zone of *Durvillea antarctica* at the bottom of the littoral. In the present study, the actual position of the Kelp Zone at Macquarie Island was closely tied to the degree of wave action in a local area. On first assessment, classifying by the organisms present, the Kelp Zone could be placed in the upper part of the sublittoral zone. However, this warranted further consideration.

The zone of *Durvillea* holdfasts was narrow vertically. (It varied from a single line to a band three metres wide, depending on the angle of slope of the rocky substratum; holdfasts were not found in deep water.) It is important to note that only the area of holdfasts is defined as the Kelp Zone. The holdfasts, with their proximal stipes and fronds, formed a habitat sheltered from the effects of many factors, such as wave action, weather (insolation, heavy rain, wind) and light.

Coralline algae often were found growing on rock surfaces amongst the holdfasts. As previously mentioned, when *Durvillea* was removed in both the winter and summer months, coralline algae died off. The only animals actually censused for changes in density in the areas of *Durvillea* removal were molluscs, the results showing that numbers of the small chiton *Hemiarthrum setulosum* (a species occupying a cryptic habitat in the lower littoral) decreased, while numbers of the limpet *Patinigera macquariensis* (a species capable of living at high densities in the littoral zone) increased. It was also noted that other truly marine species, for example the tube worm *Spirorbis aggregatus*, starfish, holothuroids, either died in or disappeared from areas of *Durvillea* removal. Thus, the very presence of the Durvillea holdfast zone was a biotic factor making this area habitable by truly marine forms.

Wash, from wave action, followed a consistent pattern around rock formations. *Durvillea* holdfasts would align closely with the tops of these patterns, that is, the holdfasts attached in areas that were almost constantly awash. This was a key factor. "Sublittoral", when defined abiotically, is usually regarded as an area that is almost constantly *submerged.*

With reference to the Macquarie Island shore, the difference to the organisms between *awash* and *submerged* is probably that the major part of the underlying fauna of the Kelp Zone cannot live successfully in this zone without the cover of *Durvillea* either when the area is not awash for lengthy periods, because of exposure to the climatic stress, or, paradoxically, when the area is awash from heavy wave action, because of physical stress from direct exposure to the resulting impact and turbulence. The *Durvillea* itself, however, is well adapted for such a region of the shore. Therefore, it appears to be appropriate to regard this zone of *Durvillea* holdfasts *per se* as being at the bottom of the eulittoral zone.

When considering biotic composition, the upper limit of the Lower Red Zone of encrusting coralline and red algae was suitable as marking the upper boundary of the sublittoral zone. The positioning of this zone in relation to the sublittoral agrees with other work (Gauld *and* Buchanan, 1959; Hedgpeth 1969, 1971) which has recognised the zone of encrusting coralline algae marking the uppermost extension of the subtidal zone as a universal and characteristic feature of rocky shores for most parts of the world.

It is interesting to compare this upper boundary of the sublittoral zone, defined here as a biological datum line, with the actual tidal levels on the transects (Figure 5). With smooth seas (rare for Macquarie Island), shore-lines with a high degree of exposure to waves had an upper limit to the encrusting coralline algae zone at about EHWS (Transect 4). This is equivalent to the far left of the diagram (Figure 6) of the universal zonation scheme. Transects 2 and 3 represented the effect of high exposure as shown at some point on the left of the diagram.

Transects 1 and 5 have some anomalies. Transect 2 had a high degree of exposure to wave action. The Kelp Zone was well above EHWS. However, in the actual tidal range, the substrate dropped away very steeply and the Kelp Zone extended down to below MHWN to meet the zone of encrusting coralline algae. The higher zones were extended upwards as expected for a situation at the far

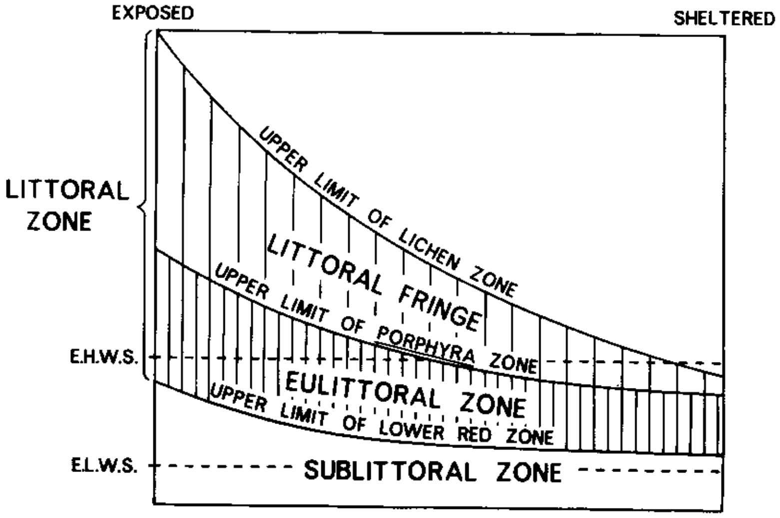

Figure 6
Zonation of rocky shores of Macquarie Island, related to the universal zonation scheme of Lewis (1961, 1964).

left of the diagram (Figure 6). Perhaps a steeply sloping rock face was favourable for the downward extension of *Durvillea.* Transect 5, with its sheltering, fringing reef decreasing the wave action, could be placed to the right in the diagram (Figure 6). However, the upper zones were by no means covered by spring tides on the rare days of smooth seas. There was no doubt that the types of organisms in the *Porphyra* and Bare Zones were occupied in the main by marine organisms adapted to aerial conditions. Apparently, the reduction of the *force* of the wave action had great effect on the lower zones but a lesser effect on the higher zones.

Thus, the "guideline" of tidal range (EHWS-ELWS) shown on the universal, biological zonation scheme (Figure 6) was not valid where the topography, or the adjacent topography, varied greatly from a simple slope. This exemplified the complexity of factors modifying the zonation pattern and emphasised that the total set of conditions controlling zonation is best revealed by the organisms themselves. Strictly, the model of the Lewis scheme (Figure 6) should be applied to areas free of unusual topography, as the changing pattern of the scheme applies only to change in wave action (as indicated on the diagram).

The absence of barnacles required the substitution of an indicator species to denote the "littoral fringe-eulittoral" intersection. Ballantine (1961) noted the prominence of *Porphyra* sp. on very exposed English coasts, and Lewis (1964, p. 204) indicated the possible use of *Porphyra* sp. instead of barnacles as an equivalent indicator species. In the present study, the intersection of the Lichen and *Porphyra* Zones at Macquarie Island was taken as the upper limit of the eulittoral zone, as the organisms found on either side of this division (Table 2) represented groupings that characterised littoral fringe and eulittoral classification as defined previously.

Thus, the local zones can be related to the broader zones of the universal scheme. That is, the Lichen Zone represented the littoral fringe; the *Porphyra,* Bare, Upper Red and Kelp Zones comprised the eulittoral; and the Lower Red Zone was in the sublittoral.

In the universal scheme proposed by Lewis (1964), the boundaries of the zones were marked by the upper limit of actual organisms which dominated particular sub-zones. In the present study, however, it was found that this was invalidated by the occasional occurrence of a few of the indicator species at a level higher than normal, immediately below which the biota belonged to a different ecological area. Therefore the upper limits of the sub-zones as entities have been used as marking the boundaries of the littoral fringe and the eulittoral and sublittoral zones. Because the areas being delineated in this zonation scheme are ecological, it is suggested that the present choice is more exact.

IV. ENVIRONMENTAL FACTORS

A. *MATERIALS AND METHODS*

Wave action, sea temperatures, salinity, pH, phosphate content of sea-water, and chlorophyll estimations in sea-water were recorded throughout the year.

Daily wave action recordings covered estimations of vertical height of waves and time for a set number of waves to break. Wave heights were gauged by eye. These observations probably underestimated the actual heights but the consistency of method allowed comparison of results over the twelve months of observation.

Sea temperatures were taken each day with an accurately calibrated mercury thermometer placed in sea-water scooped up in a bucket. Though water was taken from the shallows, the influence of local heating was minimal owing to the continuous wave action. Salinity measurements were taken with a portable chlorinity-temperature bridge, chlorinity values being converted to salinity using the equation, salinity = 0.03 + (chlorinity x 1.805) (Hamon, 1956). This meter was also used to record water temperatures in the field. Measurements of pH were taken with a portable pH meter with a range 0 to 14 and an accuracy of 0.01 pH. The meter was calibrated with standard solutions prior to each use; temperature compensation was possible by the use of a built-in adjustment.

Phosphate analysis of sea-water was undertaken at intervals of approximately one month from June to February. The method used was that outlined by Strickland *and* Parsons (1960, pp. 41-6). This uses the combination of phosphate and a molybdate reagent to form a phosphomolybdate complex and the reduction of this complex to a highly coloured blue compound. An EEL colorimeter and red filter were used to measure the absorption of the solutions. A calibration curve was drawn using known solutions of potassium di-hydrogen orthophosphate.

Estimations of chlorophyll content of sea-water were used to gauge the amount of phytoplankton pigment which, in turn, gave a correlation with phytoplankton present. Again, the readings were taken at approximately monthly intervals from June to February. The method used was adapted from those outlined in Barnes (1959, pp. 240-42) and Strickland *and* Parsons (1960, pp. 107-112). A sample of sea-water (0.1 to 5 *l*) was first filtered through a metal gauze with a mesh opening of 0.4 mm to remove detritus and large zooplankton. To prevent development of acidity, 0.1 ml magnesium carbonate suspension for each litre of sea-water was added. The water was then run through a Millipore vacuum filter apparatus after which the residue adhered closely to the Millipore filter paper. This was transferred to a desiccator kept in the dark for approximately 90 minutes to remove superficial moisture. The darkness prevented deterioration of pigments. The filter paper was then added to 90% v/v acetone in a graduated centrifuge tube and shaken, during which time the Millipore filter paper dissolved. The extraction of pigments by the acetone was allowed to proceed for 20-24 hours in a dark cool place. Acetone volume was then made up to 10 ml, centrifuged, and the supernatant decanted into a cuvette for measuring the absorption of the colouration caused by pigment extraction. A pure acetone solution was used as a blank.

Absorption of solutions were measured with an EEL colorimeter and purple filter. Readings for sea-water were compared with those for a standard solution which was designated in terms of "Harvey units", one "Harvey unit" being equivalent to 1 ml of a solution of 25 mg K_2CrO_4 and 430 mg of $NiSO_4.6H_2O$ in one litre of distilled water. Comparisons between "Harvey units" and chlorophyll solutions have shown that one unit is equivalent to 0.3 μg chlorophyll as the best estimate (Barnes, 1959).

B. *RESULTS*

Figure 7 shows wave heights for each month of the year on the east and west coasts and Figure 8 shows the time for 19 waves to break on the two coasts. These results were collated from the daily recordings.

The mean heights of the waves on the west coast were consistently greater than those for the east coast. In considering individual months, the difference could be taken as significant in July, September, November, December, and February (95% confidence limits with no overlap of the standard error x 2). The frequency of wave action can be gauged as the reciprocal of the time taken for the set number of waves. Thus, waves generally broke more frequently on the east coast from August to November, more frequently on the west coast from December to February and in May, while other months gave similar figures for both coasts. Statistically, significant differences were shown for December, January, February and September.

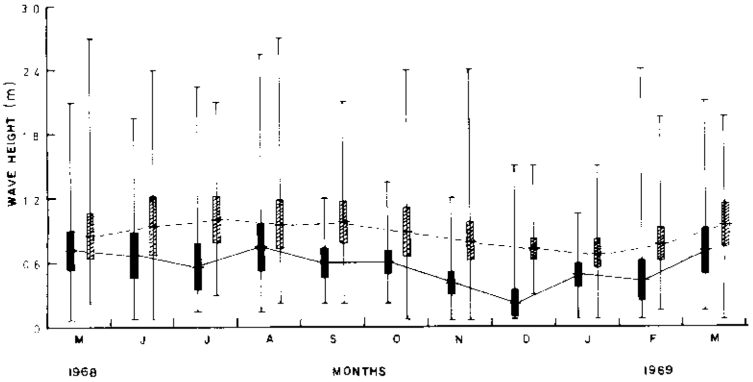

Figure 7
Monthly wave heights from daily recordings from March 1968 to March 1969 for the east and west coasts, showing range, mean, and two standard errors either side of the mean. (Solid bar = east coast, cross-hatched bar = west coast.)

The frequency of wave action coupled with the height of waves is postulated here as pointing to the total effect of turbulence caused by wave action. Thus, on the east coast water turbulence was much less in the summer period (December to February) in relation both to the west coast and to wave action on the east coast itself in other months. The higher frequency of wave action to the east during August to November would bring the overall turbulence comparison between east and west to a more equable level. In other months, the west generally had greater turbulence but the differences were not so marked.

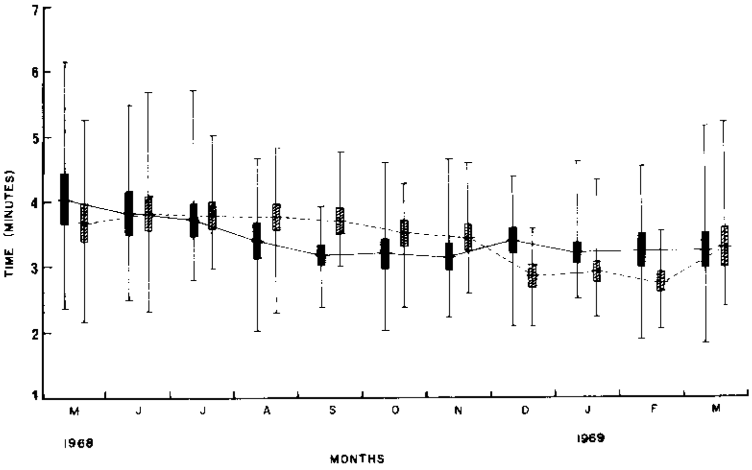

Figure 8
Times for nineteen waves to break on the shore for each month from March 1968 to March 1969, for the east and west coasts, showing range, mean, and two standard errors either side of the mean. (Solid bar = east coast, cross-hatched bar = west coast.)

Records of sea temperatures (listed as monthly means) were given by Loewe (1957) for some previous years. The monthly means for sea temperatures recorded in 1968-69 are compared with these records in Table 3. (Monthly ranges of sea temperatures during 1968-69 are shown also in Figure 9.)

Loewe noted that the period 1951-54 had appreciably higher temperatures than the period 1912-14, particularly during summer. Temperature measurements from these two periods listed in Table 3 were taken at the same time of day and at the same place, that is, the ANARE station at the northern end of the island. Sea temperature records of the present study provided an interesting comparison with the records of the periods listed by Loewe. In 1968-69, mean sea temperatures did not show such wide variations between winter and summer averages as noted in 1951-54. Temperatures during the colder months of 1968 (May to October) were appreciably higher than those in the corresponding months of both periods listed by Loewe. Since, in 1968-69, the place and times of recording were the same as those for 1912-14 and 1951-54, it appeared that Macquarie Island was subjected to sea temperatures more equable than usual during 1968-69.

Table 3.

Sea temperatures (°C), Macquarie Island.

Period	Monthly mean												Annual Mean
	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	
1912-14*	4.72	3.83	3.44	3.28	3.44	3.67	3.89	4.83	4.50	6.33	5.50	5.06	4.50
1951-54*	5.78	4.72	3.78	3.61	3.50	3.78	3.83	5.44	6.72	7.28	7.22	7.22	5.22
1968-69†	5.61	5.72	5.28	4.28	4.67	4.50	4.33	4.56	5.72	6.78	6.67	6.28	5.39

*Converted from °F after Loewe (1957). Recording time = 0900 hours.

†Recording time = 0900-1100 hours.

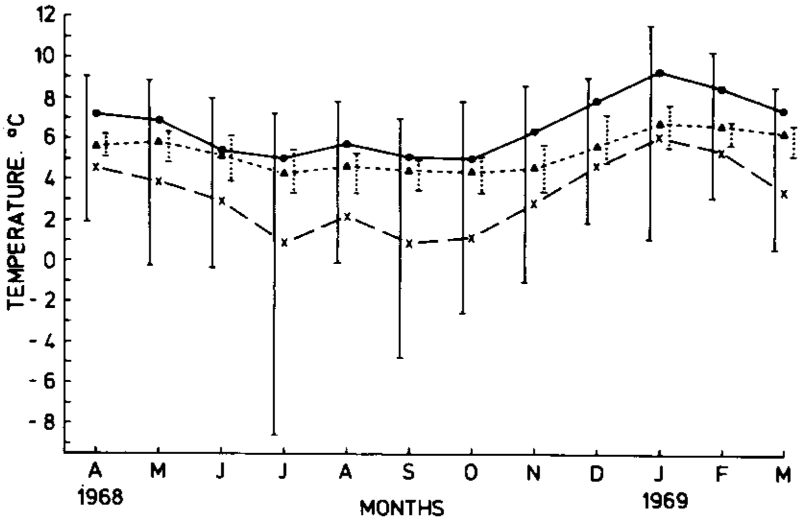

Figure 9

Means for maximum (solid line) and minimum (dashed line) air temperatures and for sea temperatures (dotted line). Solid vertical bar gives range of air temperatures, dotted vertical bar the range of sea temperatures. (Monthly, from April 1968 to March 1969.)

Loewe showed that, as expected for an oceanic climate, there was and air. This also was evident in the present study. Sea temperatures a close connection between the simultaneous temperatures of water for August and October were out of the general trend of the 1968-69 recordings, August being higher and October lower than average. Air temperatures recorded by the meteorological section on the island also showed an increase in August. This can be seen in Figure 9 which combines ranges and means of air and sea temperatures. This unusual rise in temperature may have been due to a temporary southward movement of the Antarctic Convergence, thereby causing warmer water to circulate further south to Macquarie Island.

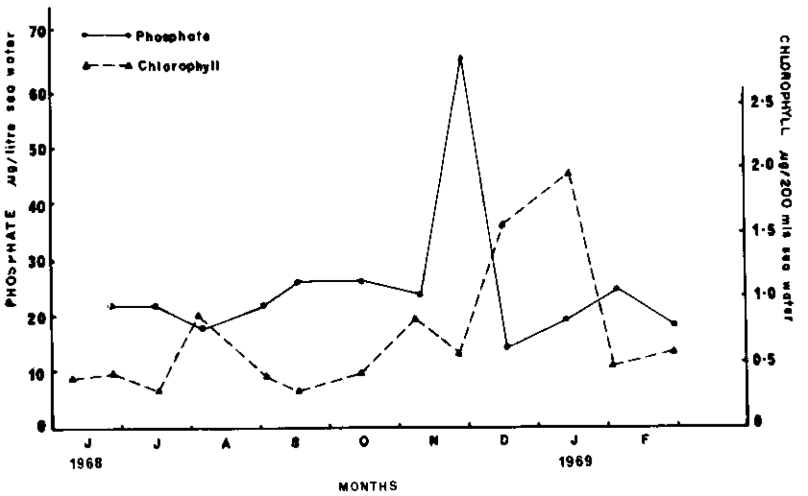

Figure 10

Phosphate and chlorophyll levels in the sea, June 1968 February 1969. (Duplicate samples were taken and, in terms of the scale on this graph, gave the same reading.)

Figure 10 gives phosphate and chlorophyll values obtained from the open sea. Phosphate level in the sea was low generally — around 20-30 µg/l — except for late November when the level rose sharply to 65 µg/l. The cause of this increase could not be determined; certainly there was no increase in wave action during November which might have suggested a stirring-up of deposits. The increase in phosphate showed a close correlation to the upsurge in phytoplankton in December as indicated by the chlorophyll curve. The higher phosphate level would provide extra nutriment favourable to an increase in abundance of phytoplankton. The high phytoplankton level continued to increase through to January, but fell back to the usual level in February.

Salinity and pH readings for the sea were taken at various times throughout the year and, as expected, were consistent. Salinity was between 33‰ and 35‰, and pH between 7.9 and 8.1.

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