A STUDY OF CERTAIN ASPECTS OF THE ECOLOGY OF THE INTERTIDAL ZONE OF THE NEW SOUTH WALES COAST

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(Plates 1-9)

[*Manuscript received February* 10, 1948]

Summary

This paper is the result of an ecological study pursued for several years and extending over the entire length of the New South Wales coast. It is not a systematic investigation of one limited locality, but an attempt to analyse basically a long stretch of the east Australian coast.

A basic and generally clear-cut zonation of plant and animal types has been recognized and described for the intertidal region of the rocky shores and the strip immediately above high-water mark. A series of indicator types is named and discussed with particular reference to the chief animal communities.

1. INTRODUCTION

The zoology of the intertidal zone of the coast of New South Wales (or, indeed, any part of the Australian coast) has received, up to date, very unbalanced attention. Parts of our coast—the ocean and estuarine shores near Sydney—have probably been as carefully "collected over" by systematists as any coast of the world. Other localities on the Australian coast have also been visited by expeditions with the sole aim of making collections, except in the Barrier Reef area where physiological studies of great interest were made. But, on the whole, non-taxonomic studies of the Australian species of marine animals have been rare whether the subject be ecology, behaviour, general life-histories, or even anatomy. Very little is known of the life-histories of the common shore species of echinoderms, molluscs, ascidians, etc., or of their general zoology.

The systematics of the Mollusca of the New South Wales coast has received considerable attention (Hedley, Iredale, Allan, and others) and, thanks to the late H. L. Clark of the United States, the distribution of the echinoderms for all Australia is relatively well known. It is, however, surprising, under the circumstances, that the animal communities of the intertidal zone have not aroused greater interest. The interrelationships of the more common types and the rela-

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tions between them and the environment offer much of great interest, especially at the present time when the results of similar studies in other parts of the world are becoming available.

The absence of such studies is noticeable, more especially since the late Charles Hedley pioneered the way in a stimulating address on "An Ecological Sketch of the Sydney Beaches" in 1915 and Johnston discussed certain ecological aspects of the littoral fauna and flora of Caloundra on the south Queensland coast in 1917. These papers although valuable, are somewhat limited in their ecological treatment. A more detailed study of one particular locality on our coast is that by Pope (1943) which deals with the ocean rock platform of Long Reef.

Hedley (1915) discusses a few of the common species of three different types of locality—the ocean sand beach, the muddy estuary, and the ocean reef—and refers to the fact that there are different zones in the intertidal area, and he frequently indicates how a species prefers a certain kind of niche on the shore. The present paper takes a different view-point. The authors set out with the intention of studying the relationships of the most common shore animals which act as indicators of certain zones between tide marks. By covering the whole of the New South Wales coast, and a stretch approximately 1,000 miles north and south, they planned to determine whether the considerable difference in latitude was reflected on the shores in the distribution of these basic types. It should be emphasized that the northern and southern political boundaries of New South Wales are not natural biological boundaries. The reason for the limits chosen in this paper is that they were the convenient end-points for the first part of a study working out from Sydney. However, there is a little more than this since the northern border of New South Wales is not far from a point where the intertidal fauna of eastern Australia suffers a definite change, and the southern border is not far from a long stretch of sandy coast. To have gone further afield in a southerly direction would practically have meant visiting the southern coast of Victoria which was not possible at the time.

Considerable differences were found in the nature of the fauna in such different types of localities as estuaries, sandy bays, mangrove covered inlets and so on, but the rocky ocean shore has presented a clear sequence of zones which is almost the same from north to south over more than the length of coast especially chosen. This important finding led to the restriction of attention in this paper to the rocky ocean shores.

However, before describing the distribution of the life on our rocky coasts, or any zonation which may be present, it is necessary to supply a few facts in regard to the physiography of the shores studied and to refer to certain physical factors which may be involved.

2. Notes on the Physiography of the Rocky Coast at the Localities selected for Study

The coast of New South Wales is marked by a series of rocky headlands which vary in height and geological formation and often present very steep cliffs to the sea. In places these headlands are close, and small bays with pocket sand beaches are found between them. In other localities the coastline is low plain and there may be long and beautiful sand beaches extending for several miles between one rocky headland and the next. Such a beach is that extending

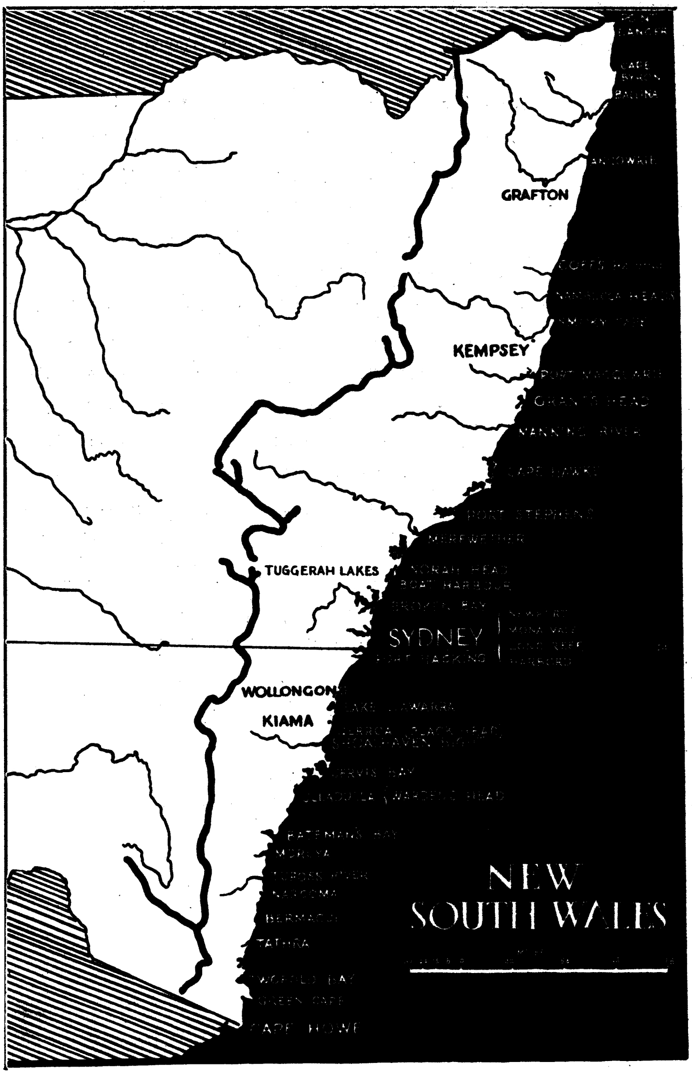

Fig. 1.—Map of the coast of New South Wales showing places mentioned in text.

for eleven miles immediately south of Smoky Cape, or the Seven Mile Beach to the north of the mouth of the Shoalhaven River.

At the foot of very many of the headland cliffs there are highly characteristic rock platforms, many of which are near sea-level, i.e. intertidal (see Plate 1). These rock platforms provide the best conditions for the present study.

They may be seen at Tweed Heads on the Queensland border, at Yamba and Angowrie in the north, and at various places as one passes south. Perhaps the best developed, and certainly the best known (almost famous) are in the vicinity of Sydney and these have been selected for the basic work, but there are other excellent platforms which are very good collecting grounds, such as those at Nambucca Heads and Norah Head (to the north), and at Black Head, Gerroa, and Warden's Head, Ulladulla (south of Sydney).

The rock platforms at Norah Head, Newport, Mona Vale, and Long Reef are broad, fairly flat expanses of rock which fringe the headlands and are left bare as the tide recedes. They are not level. Often they slope seaward and the ocean edge of the platform may be several feet lower than the level on the cliff-side. Sometimes one end of a rock platform is higher than the other. They may rise from the sea by a series of "steps" each several feet high as at Norah Head, Black Head, and also at Harbord and along the eastern edge of Long Reef. At Norah Head the platform margin is 40 ft. above sea-level at the extreme eastern point. At Long Reef again the eastern tip is the highest part and reaches 14-15 ft. but this high area is very small. The surfaces of the platforms are almost always uneven and broken up with hollows and cracks. Both the latter result in the formation of rock pools which are favoured haunts of animal life. These are especially interesting where blocks of rock of small size are resting, either on rock or on pockets of gravel and sand. (By small size, we mean a size reasonable enough to be turned over, but heavy enough, or wedged in some hollow, so as to remain undisturbed by the waves, except during storms or very heavy seas.)

The nature of the animal communities on these rock platforms depends firstly on their levels and secondly on the degree of exposure of the rock surface to the sea. This latter is affected by the orientation of the rocky headland. A point at or very near the margin of the rock platform will be differently affected by the sea from a point at the same tide level, but some distance in from the outer margin. Again, a rock platform margin facing north or south on the sides of a headland jutting out eastward to the sea will usually be less violently attacked by the surf than the extreme seaward point at the eastern extremity. There are other factors concerned in determining the distribution of intertidal life, but tide level and degree of exposure are obvious factors and they draw especial attention to the physiographic character of the rock platforms, and the nature of the rocky shore itself.

It is generally accepted that our coast is a relatively young coast and a coast of submergence. This implies that the coastal margin has been flooded in relatively recent times (geologically speaking) giving rise to estuaries like those of Port Jackson and the Hawkesbury River.

Where high ground was brought to the proximity of the sea the ocean has acted upon it, producing cliffs, cutting in and removing the debris resulting from atmospheric weathering and wave action, and as a result of this we find the steep cliffs of today with the rock platforms at their base. These rock platforms are very characteristic features of the coast of New South Wales.

Geomorphological text-books give typical diagrams of this cutting of rock platforms and these are sometimes pictured with the surfaces near high-tide level. Unfortunately, we meet some argument and a marked divergence in views as to the exact conditions under which our New South Wales rock platforms were, or are, being formed (see Cotton 1947; Gulliver 1898; Hedley 1924; Jardine 1925; Johnson 1919; Jutson 1939; Steers 1929; Wentworth 1938).

The basic idea is that at some particular level the sea has exerted its most effective powers and in combination with weathering has cut back the land, forming a platform and a sea-cliff. There is no doubt that the rock platforms are clear evidence of sea erosion. They are definitely wave-cut. The argument lies in the doubt as to the particular level of the sea when the platform was cut.

Our best developed rock platforms near Sydney are at Long Reef, Mona Vale, and Newport. All these are nearly at the same level and they are very definitely intertidal. The average level is, in fact, approximately mean-tide level (say 3 ft. above zero at Fort Denison) so that the sea pours over them well before the time of high-water, even with neap tides and a calm sea. However, the surface is not in one plane. There is often some slope to the outer margin and there are irregularities and even "steps" in the rocky surface so that usually the part of the platform near the cliff may be several feet above low-water level.

One might quite naturally assume that the sea at its present level is still cutting some of these platforms. This is especially true if one judges from the conditions visible at Mona Vale or Long Reef. At the extreme point of Mona Vale, just north of the bay where the baths are situated, the surface of the platform at the base of the cliff is very clean, and there is a freedom from rock fragments which must frequently fall from the cliff. The shale at, and just above, high-water mark is so soft that fragments can be picked out with the finger-nail. One would conclude that weathered material is continually dropping and is being carried away—the rock platform being cut further into the cliff.

Several geologists and physiographers have assumed that these platforms, including some near high-water level, have been cut with the sea at its present level. Others, however, consider that even such intertidal platforms as those named have been cut at a lower level, and their present position represents a rise in land level or what means the same, a general fall in sea-level. Special reference has indeed been made to Long Reef by upholders of this view (Jardine 1925; Jutson 1939). All these platforms are, however, well exposed to rough seas and this makes matters less easy to decide.

At various places on the exposed margins of the rocky coast the rock platforms stand at considerably higher levels than those just described. Obviously, rock platforms, *with marine remains* at high levels (some have been described on Pacific coasts at heights up to 1,000 ft. and more (see Cotton 1947)) *must* be evidence of a higher stand of the sea. However, all the platforms with which we are concerned are within, or near, present tide levels.

Of the more recent geological works referring to New South Wales rock platforms Jardine (1925) and Jutson (1939) regard the intertidal platforms as exemplified in Long Reef as having been cut by the sea acting under conditions of level such as the present. Others, too, have expressed themselves in support of this for other Pacific intertidal platforms and the view-point is well set out by Jutson. Local geologists, however, favour the other view which is also held by Steers (1929) although he probably only had a brief glimpse of one of the local platforms.

From our own observations we are led to the conclusion that it is characteristic to find one wide rock platform at the foot of the exposed coastal headlands of New South Wales and it ranges from being intertidal to somewhat above high-water mark. These typical platforms whose average height above sea-level varies between narrow limits—usually not more than 6 ft.—give an impression of close similarity. Indeed, a visit on a calm day at the time of low-water might well give the impression that they were all, broadly speaking, at the same level, even though some residues of higher levels are found. We refer now to the rock platforms at Tweed Heads, Yamba, Angowrie, Nambucca Heads, Grant's Head, Norah Head, Boat Harbour, Newport, Mona Vale, Long Reef, Coalcliff, Gerroa, and Ulladulla (Warden's Head). The width of these ranges from approximately 100 ft. (parts of Mona Vale) to 500 ft. (Long Reef and Boat Harbour). From these facts it would be natural to conclude that the platforms named are equivalent, i.e. were formed under similar conditions of sea-level. Now, closer examination reveals unmistakably that the major parts of the different platforms are *not* at the same level. The platforms at Mona Vale and Newport and the greater part of that of Long Reef are not only definitely intertidal, but not higher than mid-tide mark. Indeed, as already noted, there is evidence that the cliff at Mona Vale is being eroded at its base (i.e. at platform level) today, and there is also evidence for similar erosion at Long Reef. A visit to the platforms at Nambucca, Gerroa, and Coalcliff will lead, however, to a very different opinion. This opinion is strengthened by a study of the extensive platforms at Norah Head and much more so by the extraordinary platform at Boat Harbour, near Tuggerah Lakes (the name gives a false impression of the place). All these platforms are wholly, or in part, now definitely above the level which could be the result of wave erosion at present sea-level. We do not want to enter further into the physiographical and geological problems involved.

On the whole we are led to assume that the rock platforms have suffered many vicissitudes since the date of their erosion and that probably most stand at higher levels today. Even those which are now intertidal may have been at higher or lower levels since the date of their first erosion.

The fact that the rock platforms of the coast are not quite at the same level today means more variety for the zoologist and provides an important reason for visiting different places if varied collections are wanted.

SOME NOTES ON THE MAJOR ROCK PLATFORMS WHICH ARE INTERESTING TO THE BIOLOGIST

Almost all of the more extensive rock platforms we have studied present some special features which make them interesting despite the basic similarity in the animal populations, which will be discussed in the chief section of this paper. A brief reference to some selected for special study is desirable. The platforms referred to are taken in order from north to south.

(*a*) *Nambucca Heads*

The major level of this platform lies just above high-water mark. It differs from all others examined in detail in being composed of strongly folded phyllites —metamorphic rocks believed to be of Ordovician age—and veins of quartz are obvious at a high angle to the horiontal (Voisey 1935). Thus the conditions for erosion are very different from those seen near Sydney where soft shales lie with the layers nearly horizontal. The platform is not exactly an extensive one. Its north-south extension is longest. About 150-200 ft. of the width is fairly level and just above high-water level. From this there is a gradual slope seaward of much broken and eroded rock, the extent of this being approximately 100-200 ft. It is impossible to give a closer figure because of the projecting rocks and eroded gullies. The richer collecting surfaces are in the eroded gullies. Rock pools with sponges and anemones are very noticeable. To the north the platform abuts on a sandy beach and between the two are deep eroded clefts with loose rocks which may be turned over. This is a rich collecting ground. Thus a diversity of habitat is provided. It is noteworthy that there are two large pools at intertidal levels which are paved with Zoanthids. Nowhere else on the long coast of New South Wales have we seen these coelenterates in rock pools or in intertidal regions.

(*b*) *Norah Head*

There are several platforms at or near Norah Head. That at the headland proper (and just below the lighthouse) is the one which has been most closely studied. The Norah Head platform lies in the Narrabeen Series. The surface dips slightly from a line joining the lighthouse to the extreme tip of the point of the platform. Thus, at the exposed point the height of the platform surface is at least 35 ft. above low-tide level, whilst about 200-250 yards south of this point the platform surface has become intertidal. The platform is fairly wide—approximately 500 ft. from cliff to seaward edge. There is a break in the platform to form a little bay with a sandy beach, approximately 300 yards south of the lighthouse. A path leads down from above at this point.

From what has been said it will be realized that the Norah Head platforms provide many varying conditions for collecting and observation. In fact, this is one of the best collecting grounds on the coast. On the extreme seaward margin at the highest point there are vertical rock surfaces exposed to heavy seas and surf presenting the types characteristic of such surf zones. At the sides of the little bay there are much more sheltered surfaces, and sand and gravel and rock pools. But the feature giving a character to this platform, and seen nowhere else, is the nature of the rock which is largely conglomerate. This seems to have especially favoured the cutting of deep rock pools, many of which are open (by narrow underground passages or cracks) to the sea. In consequence they contain rich growths of kelp and animals of the littoral-sublittoral fringe, and quite large fish may be trapped.

The Norah Head platform will probably turn out to be as rich in species as the famous Long Reef, near Sydney, owing to the diversity of the conditions present. As noted before, Norah Head is a platform which seems to indicate that geological changes in level, etc., have taken place since it was formed by coast erosion.

(c) *Boat Harbour (south of Tuggerah Lakes Entrance)*

In at least two respects this is one of the most extraordinary rock platforms of the New South Wales coast. It is an extensive platform of rocks of the Narrabeen Series, practically 500 ft. wide and extending north and south for almost a mile. One of the first points to be noted is that there is no vertical cliff at the landward side. Instead, the high ground rises almost gently from the rock platform and is clothed with grass, shrubs, and trees. There is no doubt that the conditions of tide level here are not those which would favour the erosion of this rock platform today. The surface near the outer margin of the platform is approximately 9 ft. above zero tide level and the rock is sandstone. The land side of the platform is lower and so water tends to collect there. It should be noted, however, that there is little or no headland jutting out where this platform protects the coastline, and the seaward margin of the platform runs nearly north and south. This provides conditions of exposure rather different from those of the long margins bounding bays at Mona Vale, Long Reef, Gerroa, etc.

The fact which makes the Boat Harbour platform extraordinary, however, is the presence of mangroves which are to be found on the land side at the foot of the high ground and facing the ocean. Nowhere else on the exposed seaward face of the New South Wales coast on a rock platform have we seen mangroves. It is impossible at present to offer any exact explanation, except that it is very unusual to find a typical platform such as this without a rocky, near-vertical cliff on the land side. And in most cases any deposition of mud or soil on the platform would be impossible. This is, however, permitted here, and there is a marked seepage of fresh-water at the foot of the hill. The conditions show clearly that there is no erosion on this side. The whole place provides definite evidence in favour of change of sea level, although it may be only a matter of two or three feet.

The result of the presence of mangroves is that very unusual biological groupings exist about them, and here, in close proximity, we find ocean face conditions, together with some of those of estuaries. Side by side one may collect ocean-shore and estuarine species proper to this tide level.

Apart from the above, this rock platform presents another feature which has not been seen anywhere else. The upper surface near the seaward margin bears well-weathered, but distinct, hollows such as those made by the sea urchin, *Heliocidaris*. Sea urchin holes occur at relatively high levels in some other places where deep permanent pools are found near the platform margin, but those at Boat Harbour are higher still and out of water, well in from the margin, uninhabited and weather worn. Is this a clear proof of a moderately recent change in level?

(*d*) *Newport*

The platform at the southern end of Newport Beach is composed of horizontal shales and sandstones of the Narrabeen Series. It is noteworthy as being one of the lowest lying rock platforms on the coast and is covered by the sea until the tide has ebbed to about mid-tide. Even so it is not quite level and the southern part is uncovered long before the northern end is out of the water. Much of the latter lies in the *Galeolaria* zone (see page 196) and the platform surface here provides a very rich collecting ground because of the large number of shallow rock pools with suitably sized stones. There is also a very wide exposure of the lowest tide levels providing one of the best exposures of the kelp zone. All this is partly due to the low level of the rock platform surface, but it is also the result of the configuration of the coast. A detached area of rock platform projects sharply eastward as a very low promontory, in fact, an island, except at very low water. This forms a bastion providing shelter for the shore platform.

(*e*) *Mona Vale*

The rock platform referred to under this title is that which extends round the foot of the headland north of the baths. Part of it lies immediately below the extreme tip of the headland. North and south of this the platform curves round (more particularly on the southern side) to form the margin of the adjacent bays.

It is a narrow rock platform, approximately only about 85-100 ft. across from cliff to sea at its narrow end, and 165 ft. wide nearer the Mona Vale sandy beach.

The most interesting places here are at the extreme point, and along the southern margin of the platform which actually runs in a west-east direction and is the first area reached when approached from Mona Vale. Almost the whole surface of the platform which is of chocolate Narrabeen shale is intertidal and it seems to be still extending inward at the extreme eastern point where the cliff is suffering erosion.

By reason of the kind of shelter provided by the direction of the southern margin (east and west) and the presence of submerged reefs in the bay, this platform provides one of the most extensive beds of *Pyura* to be seen near Sydney.

At extreme low-water mark (spring tides) there are glimpses of a secondary platform and the whole is covered with an extensive growth of kelp. This is also an exceptionally good region for the boring sea urchin which is present in thousands in hollows of the rock.

(*f*) *Long Reef, Collaroy*

This is the best known of all our rock platforms. The geology and physiography have been described by Jardine (1925) and Jutson (1939). Pope (1943) has given an account of the ecology of the best known area, that near the fishermen's settlement on the northern shore.

The platform of Long Reef is a very extensive one. It is found on both the southern and northern sides of the triangular peninsula, and then protrudes seawards from the eastern end for a considerable distance. Actually a rocky reef continues in roughly the same direction but below the surface of the sea and is a recognized danger to shipping. Further description is unnecessary here, except to point out that the rich north-western area is probably one of the most sheltered of all on our ocean coast. This is supported by the fact that small fishing boats are regularly launched from the shore. Another fact of importance is that the extreme eastern point, which is far less frequently examined by naturalists, is exposed and subjected to very different sea conditions from those existing on the sheltered western margin. The zonation is distinctly modified by these sea conditions as discussed on page 197.

(*g*) *Black Head, Gerroa*

The rock platform at Gerroa round the headland which marks the northern extremity of Shoalhaven Bight is probably one of the most extensive of the southern platforms. There is a very long margin of rock here, and once again the variety of ecological conditions can be emphasized. Most of the rock consists of fossiliferous mudstones of Upper Permian age, and as one traverses the surface one passes numerous fossil Brachiopods.

Most of the platform at Gerroa is just above high-water level and the sea is presumably at a lower level now than when the platform was eroded. The platform at Warden's Head, Ulladulla, stands at approximately the same level and occurs in similar beds. The geology of these platforms has been discussed by Brown (1925, 1928, 1930).

Black Head, itself, is a very exposed promontory and the rock conditions present are also wild looking. Here the animal types which are dependent on a splash zone are found at very high levels indeed. The long stretch of platform from this point south-westward along the bay provides a gradual change, with the introduction of features characteristic of shelter until the limit is reached where the change takes place to sand at the northern end of the Seven Mile Beach.

At this end one notices in particular the repression of *Galeolaria,* the luxuriant nature of the kelp growths, and the great width and obvious nature of the *Chamaesipho* band of barnacles (see Plate 7).

3. Tides and Physio-Chemical Conditions of Ocean Water bathing the New South Wales Coast

The rocky ocean shores we are considering all face the ocean and are very free from contamination of any kind from the land. There is singularly little effect due to the rivers.

The salinity and the temperature conditions immediately along the shore may be regarded as generally approximating those recorded during several years a few miles out to sea off Sydney. This is suggested on the basis of the turbulent conditions so often existing on the shores and on a few readings which have been made from the rocks.

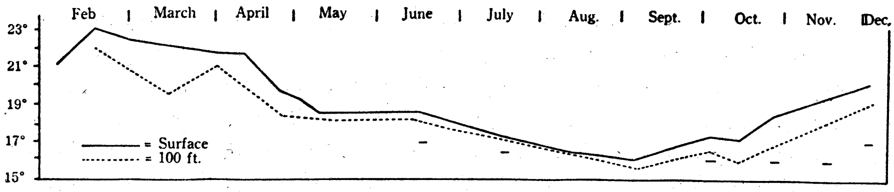

Fig. 2.—Annual range of sea temperatures in °C., from observations made off Sydney by W. J. Dakin.

The graph (Fig. 2) indicates the average range of sea temperatures about four miles off the land in the latitude of Sydney. Through the kindness of Mr. D. Rochford, of the C.S.I.R. Division of Fisheries, we have been able to obtain a few figures for some other places on the coast taken from the research vessel, *Warreen.* From these it would appear that at a station three miles off Cape Byron in the north, the temperature ranged from 20.2°C. in August 1940 to 22.5° in January 1941, and 22.6° in January 1942. The temperatures at our most southerly latitudes are still not known. The striking feature of the Cape Byron temperatures recorded in 1940, 1941, and 1942, is that the *winter* temperature was 20.2°C. compared with temperatures of 13.6° to 16.0°C. which are usual off Sydney.

There has been no organization for prolonged and accurate temperature records at places distant from Sydney on the coast. Nor are there records which will allow close comparisons of rock pool and ocean water. In these there will be much variation during the day, and the height of the pools above low-water level plays a marked part.

Thus, in July 1947, the low temperature of 9°C. was recorded for a rock pool at one of the higher levels of the intertidal zone of the rocky coast. This was the temperature at 8 a.m. and reflected the low night temperatures, but even lower temperatures are probably reached. At the time other rock pools in the vicinity, but from which the sea had receded not so long before, gave 13°C. as did also the water in a large swimming bath which had just been flooded by the tide.

In the summer the temperature varies in the opposite direction and we find rock pools in the intertidal area with temperatures up to 30.5°C. This is excluding pools high up, but nevertheless filled with salt-water, which are only filled by spray or at high-water spring tides.

The extreme tidal range for Sydney Harbour at Fort Denison is given as 6ft. 7 in. This is a harbour station. Unfortunately, at the present time, accurate information on the tidal range at other parts of New South Wales, and particularly on the sea coast itself, is lacking (see Halligan 1928). But the observations available show that there is little difference, if any, between the northern and southern limits of New South Wales, and the figures given above may be taken, in general, as approximately correct for the open coast.

For many reasons the rock pools present conditions of life which contrast strongly with those of the shores at similar levels. By and large, a rock pool may be regarded as a modified sample of the life of a lower level—perhaps the lowest of tide levels. But even near the lowest tide levels there are some organisms which seem to prefer the changing conditions of the shore and a period, even if short, of aerial exposure, and so are not found in rock pools. A rock pool tends to favour organisms which need permanent submersion. This is particularly well demonstrated by the occurrence of the alga, *Hormosira Banksii* (Turn.) Decne. *Hormosira* covers some rock platforms (e.g. parts of the Long Reef platform, see Plate 2) which, by reason of their level and configuration, remain distinctly wet between successive tides. In other places, however, the only wet intertidal spots are shore pools. Under such circumstances one finds the *Hormosira* always forming a fringe round the margins of the pool, but not on the general rock surface (see Plate 2). It may extend only a very few inches under water; below this it cuts out, and the sides and bottom of the pools, under permanent water, will often be richly covered with other algae such as species of *Corallina, Sargassum lophocarpum* J. Ag., *Ecklonia radiata* (Turn.) J. Ag., *Padina pavonia* (Linn.) Lamour, and *Pocockiella* (*Gymnosorus*) *variegatus* (Lamour) J. Ag. (see May 1938, 1939) according to locality or intertidal level.

The higher pools of the shore will be subjected to considerable changes in temperature and light and also in salinity, contrasted with those of the lower levels which are freely filled by the sea.

The highest rock pools filled only by spray or exceptional tides are different again. They are subjected not only to extreme changes of temperature, but to extreme changes in salinity. This is very marked on our coast where long periods without rain may be terminated by great downfalls which flood these pools with fresh-water.

The rock pools differ considerably in nature apart from the difference due to level or distance from margin of platform. One marked difference is to be correlated with their size and depth. On most rock platforms one meets everywhere with little shallow collections of water, perhaps only one inch or two inches in depth. These are places where certain animals tend to congregate when the tide recedes. The water in such puddles and in slightly bigger ones, must get very hot in summer, or even dry out between tides. The large and deep pools will obviously present a different community. Even in the lowest zones, however, there may be a difference between a pool which is completely cut off from the sea for a period and one which has some deep connection so that there is always contact with the ocean. In these latter one may find the large kelps and fine growths of sponge which are characteristic of the lowest zones and open water.

General Tidal and Wave Effects on Zonation—Splash Zone

It is a well-known and generally recognized fact that the intertidal region of the seashore can be divided into a series of horizontal zones, each of which has its characteristic forms of life. The intertidal animals and plants vary considerably in the requirements necessary for a favourable existence. Some cannot flourish if exposed to the air and sun for more than a very short time and then only on rare occasions. Others prefer to be high up, even reaching places beyond the range of the tide. Between these two types there are many grades and specialities.

There is, however, one particular set of conditions which shows itself more than usually vividly on the New South Wales ocean shore. It is the effect of spray and splash on the exposed coast. Compared with some of the world's coastlines which have been closely studied, the rocky ocean coast of New South Wales would appear to suffer rougher seas for longer periods (see Plate 3). There is no statistical evidence for this. One can, however, not only deduce it from the descriptions of other ecological work, but from our experience at sea, off the coast, during many years of plankton research. The old-time whalers complained of our rough seas. The purse seiners of the Californian coast use fishing techniques regularly which require calm conditions and seem to be of doubtful value here.

This feature is important because the headlands, in particular, present rocky shore contours where, owing to frequent heavy seas, the spray and water splashes keep moist regions which are well above normal high-water mark. Splash zones have been described on other world coasts, but we wish to stress not only the clear effect of splash in pushing some zones to greater heights than usual (and raising intertidal conditions above normal high-water mark), but also the differentiating effects. It is, for example, surprising to find that certain animal associations retain their usual zonation and levels despite the surging water on the wildest sea margins. They demonstrate in the clearest way how some animal species have their shore levels linked physiologically with the tides. On the other hand, some shore forms are affected markedly by the moisture of the spray or water in the condition of foaming seas, and are sensitive to factors which might occur at many tidal levels. To illustrate what is meant, the barnacle, *Tetraclita purpurascens,* may be taken as an extreme case. It requires moist and shady conditions and is usually found on the shaded surfaces of some vertical or horizontal crack in the rocks. These conditions being given, however, it may be found at almost any level on the seashore from low- to high-tide mark. On the other hand, the ascidian, *Pyura praeputialis,* holds to its very low-water level, scarcely ever being more than 18 inches to two feet above the lowest low-tide mark. The situation becomes still more striking when one observes the barnacle, *Tetraclita rosea,* which loves a vicious lashing by the sea and is therefore generally found near the platform margin. Thus, provided the exposure is sufficient it may actually invade the level characteristic of the Littorinid mollusc, *Melaraphe,* which can exist in the highest zones above tide levels altogether. This latter organism is indeed influenced especially by tide levels, the former by rough wave action and constant splashing or surging.

Keeping in mind these special requirements of intertidal organisms, we shall find that it is possible to select one group of attached animals each of which always keeps to its "proper" levels and thus conveniently serves as an indicator for the zonation of our shores. Fortunately, the most striking of these present this constancy to their particular tide levels, notwithstanding the locality or the varying conditions on the coast. We shall first take these basic or fundamental forms as they appear on a coastal margin, such as that near Black Head, Gerroa, where all zones are present and where the rock slopes at a suitable angle to the lowest of low-tide levels.

We shall compare this with other suitable places and finally refer to positions where intertidal rock platforms are developed at various levels.

GENERAL BIOLOGICAL SECTION

4. The Basic Zonation of the New South Wales Rocky Ocean Coast*

THE CHIEF ZONES

The northern and southern margins of Black Head, Gerroa, provide excellent localities for an introduction to the study of zonation of our rocky coast. At Black Head a very extensive rock platform is developed, but in general, except where much broken up, its chief and most extensive level stands near high-water mark. Except at its extreme eastern tip, the outer or seaward margins of this platform

* It should be noted that this attempt to formulate a basic zonation for the coast of New South Wales is the result of very many visits extending over a period of years to the more central rock platforms. Numerous visits have also been made to practically every rock platform of any size on the entire coast of New South Wales from Queensland to Victoria. Owing, however, to the great distances and difficulties of travel in some areas, it will be appreciated why the more central parts of the coast have received most attention and the work applies to these in particular.

slope to the water at a convenient angle down to the lowest of spring tide levels where there is visible and readily attainable the very lowest of the intertidal zones.

The conditions met with on this platform can be "checked" at numerous other headlands, and a very good place near Sydney is the headland to the north of Harbord. The main difference between the two places is that the Hawkesbury Sandstone formation exposed at Harbord favours weathering along certain joint planes and so instead of a fairly gradual slope of the outer margin to the lowest tide levels, there are what may be called a series of big steps, and the faces of these steps exposed to the sea are vertical. The same zones are to be seen both at Black Head and Harbord, but the conditions at the former make it easier and safer to examine them, especially the lower tide levels.

At Harbord most of the platform seems to be exposed and curiously subject to heavy surf. Thus the vertical faces we have mentioned receive the full force of the surf, and, in consequence, one finds a highly developed splash zone (see Plates 3 and 7). The same applies at Gerroa, too, in a restricted area near the tip of Black Head, but for the most part the margins of this headland away from the extreme tip are more sheltered and extend a long distance, and clear-cut variations in topography are thus easily available for comparison.

The sequence of associations at these and other localities to be mentioned, remains fundamentally the same despite variations in the degree of exposure. This is one of the most interesting findings. Differences in degree of development of this or that association may and do occur and provide interesting lines of inquiry since the reasons for a poor or good development are by no means obvious.

The animals and plants chosen as key indicators for zonation are few in number. They are the common creatures whose number and position of growth is such as to give character to the shore. In general, they are fixed creatures growing on the exposed rock surfaces, for these are the best for this purpose, although there are some exceptions in the form of one or two species of molluscs such as chitons, limpets, and other gastropods which might almost be called semi-attached for their movements are circumscribed even when the tide is in, and they remain practically fixed when it is out.

The zonation is first referred to tide levels which are determinable fixed marks. We intend to call the intertidal region of the shore the *Littoral,* for that is the usage made famous by the classic work of the earliest shore ecologists and especially by the British naturalist, Edwin Forbes. Accordingly, the littoral belt means the band of shore marked above by the normal high-water line of spring tide in calm water. Its lowest boundary is marked or defined with greater difficulty, especially on the coast of New South Wales where the water is practically never calm. Gislén (1930) takes the low-water mark of neap tide as his boundary. There seems to be more reason for taking low-water of spring tides and this we would regard as the lower limit. However, this need not be discussed here for we have approached this difficulty in another way which is dealt with below.

The *Sublittoral* region is the area which follows on from the lower boundary of the littoral and is thus normally covered *at all times* by the sea. Its lower limit does not concern us at all since only the upper fringe can be reached from the shore (except by diving).

The *Supralittoral* is the region *above* high-water spring tide levels which has been invaded by only a few typically marine animals, chiefly gastropods. The species are Littorinids, and one might call this the Littorinid zone, the conditions presented being thus similar to those found at this shore level almost all over the world, although in different countries different Littorinid species are found occupying the corresponding places at this level. A point about which to be careful in connection with the supralittoral is the modification of much of this area which may occur when it comes to be near the extreme margin of an exposed coast. In such positions what should be the supralittoral level can be so wet with spray and even with heavy surges of sea-water that it has a special character. The conditions approximate to those of intertidal levels. An interesting feature under such conditions is the presence, not only of some marine forms which are usually associated with lower tide levels, but of a mixture of the typical supralittoral Littorinid types with lower intertidal forms—their occurrence together being determined by the spray, splash, and tides.

The Littoral-Sublittoral Fringe.—The uppermost belt or zone of the sublittoral is very characteristically marked by certain large, "brown" seaweeds (Phaeophyceae). *Phyllospora comosa* (Labill.) Ag. and *Ecklonia radiata* (Turn.) J. Ag. are two of the dominant forms and correspond to the *Laminaria* of other parts of the world's coasts. The line of division between this algal zone and the next zone above is indeed, one of the sharpest "cut-offs" on the shore, and in view of the surging sea this is really noteworthy. The upper part of this algal zone is visible fairly frequently because the large weeds are supported by the water and the upper parts of their fronds often just break the surface.

However, on rare occasions, a zero low tide (or better still, a minus tide) will coincide with a very calm sea. On such occasions it is possible to find *Phyllospora* with intermingled corallines covering extensive areas which are completely exposed. These weeds, therefore, certainly invade the intertidal belt, especially in sheltered places. The photographs (see Plates 3 and 4) were taken on such days. However, under average conditions this zone is normally submerged even at low tides. One might almost say that physiologically it was below the intertidal part of the shore. Yet on calm days it is clearly seen that its upper boundary definitely extends above the mark of low-water spring tides.

Because of all this, and in particular, because a most characteristic animal zone of the shore, marked by the ascidian, *Pyura praeputialis,** is found at the margin of the littoral and sublittoral areas, and extends not only well above the estimated zero tide level, but also below it, we are calling this strip of shore along the margins of the littoral and sublittoral zones the *Littoral-Sublittoral Fringe.*

This important belt is probably much the same as that described by Stephenson (1939) as the Sublittoral Fringe in his excellent South African work, and by Pope (1943) in her paper on Long Reef. Stephenson states that it is submerged at low-water of *neap* tides and that the sublittoral *proper* (on the west coast of South Africa) is occupied by a rich growth of large algae including a giant species of *Ecklonia,* and *Laminaria.* He also states that in many places the sublittoral fringe is occupied by a giant simple ascidian (*Pyura stolonifera*). All this is remarkably like the Australian conditions on the coast of New South Wales. If one defined the littoral zone as only extending to the low-water mark of *neap* tides, then the term Sublittoral Fringe might have *raison d'être* but Stephenson has not actually defined his Littoral. In view of the uncertainty and difficulty in fixing a rigid boundary at this level, coupled with the fact that the *Pyura* occupies a strip or zone which is definitely partly intertidal and partly subtidal, we prefer the expression Littoral-Sublittoral Fringe—even though it be more cumbrous. This usage is supported by observations on the tide levels occupied by the larger brown algae.

We shall now commence with a description of the lowest shore levels.

(*a*) *The Littoral-Sublittoral Fringe*

I. *The Kelp Zone*

It is noteworthy that in several places in New South Wales there is a rather level area of rock surface providing an extreme margin to rock platforms and falling exactly in this fringe. In places indeed, it may be called a secondary rock platform at this low level. One sees it at Newport, Mona Vale, Long Reef, Black Head, and Warden's Head, to mention only a few localities.

The lowest zone of the fringe is usually occupied by the large brown algae, *Ecklonia radiata* (Turn.) J. Ag. and *Phyllospora comosa* (Labill.) Ag., the latter only at places south of Grant's Head (lat. 31.30°S.). Near the southern end of the New South Wales coast a bigger kelp, the Bull Kelp, *Sarcophycus potatorum,* joins the *Ecklonia-Phyllospora* association, see page 202. *Ecklonia* is present from

* This common Ascidian has been known in recent years as *Pyura praeputialis* (Heller). There is a possibility that one of the other generic names, *Cynthia* Heller, or *Cynthiopsis* Michaelsen, which have been used for it may have to take the place of *Pyura* Molina and even the long-used specific name may go. But we have kept to the more familiar usage, especially as there is a comparable *Pyura* zone on South African and New Zealand shores, and our species may very well be the same as that of South Africa.

north to south but is poorly developed in the extreme north. Growing between the larger algae are clumps of corallines and possibly some *Sargassum*. Where there is a low level rock platform one may find the ascidian, *Pyura*, growing amidst the algae named, but the closest and thickest growths of *Pyura*, the *Pyura* zone proper, occur immediately above the richer algal layers marked by the big, brown weeds which clearly occupy the lowest zone ever exposed on the New South Wales shores by normal tides.

In some places the *Phyllospora–Ecklonia* association shades upwards into low growths of other brown algae—in particular, a stunted *Sargassum* and *Padina pavonia* (Linn.) Lamour. This occurs especially where there is shelter from the surf, and at Mona Vale the succession is *Ecklonia, Phyllospora*, stunted *Sargassum*, and *Padina pavonia*, in that order from below upwards.

In places, too, where the growth of *Phyllospora* is luxuriant, odd specimens may be found well above the usual level amidst the *Pyura*. This is still within the fringe. One species of *Corallina* seems to range upwards from the *Phyllospora-Ecklonia* horizon, becoming more and more stunted on the way. Whether the same or not, this stunted *Corallina* often forms extensive coverings on the rock platform at mid-tide levels (see page 221).

A much more significant difference in the algal formations of the fringe lies in the nature of the occurrence of the red alga *Pterocladia capillacea* (Gmel.) Born. and Thur. On some of the most exposed headlands, especially if the rock descends vertically or with a very steep slope to depths well below tide levels, the conditions for the growth of the large brown weeds, *Phyllospora* and *Ecklonia*, are less favourable. At such places—and especially where the surf is most violent—the littoral-sublittoral fringe is marked by a growth of *Pterocladia capillacea*. Some *Pyura* may be interspersed with it and here and there the *Pyura* prevails. It is not easy to explain the varying and relative abundance of this red alga and the ascidian at different places. *Pterocladia* is not so sharply limited in its upper growth level as *Pyura*. Like some of the barnacles it flourishes at higher levels but only where there is surf and splash, and for this reason it is not so satisfactory as an indicator of zonation. Its characteristic feature is its love of the pounding surf and the most exposed of all rock surfaces. It does not seem to extend much, if at all, below the zero tide level.

II. *The Pyura Zone*

The characteristic animal of the littoral-sublittoral fringe is, as noted above, the ascidian, *Pyura praeputialis* (Heller). Remarkable growths of this occur at some places and a very definite *Pyura* zone is one of the most characteristic intertidal features on the New South Wales coast. Its upper limit is most regular at a height of approximately 18 to 21 inches above zero tide level. The exact requirements of this creature seem to be fixed firstly, and above all, by the tide level. Neither exposure nor shelter seems to affect this preferred level very much.

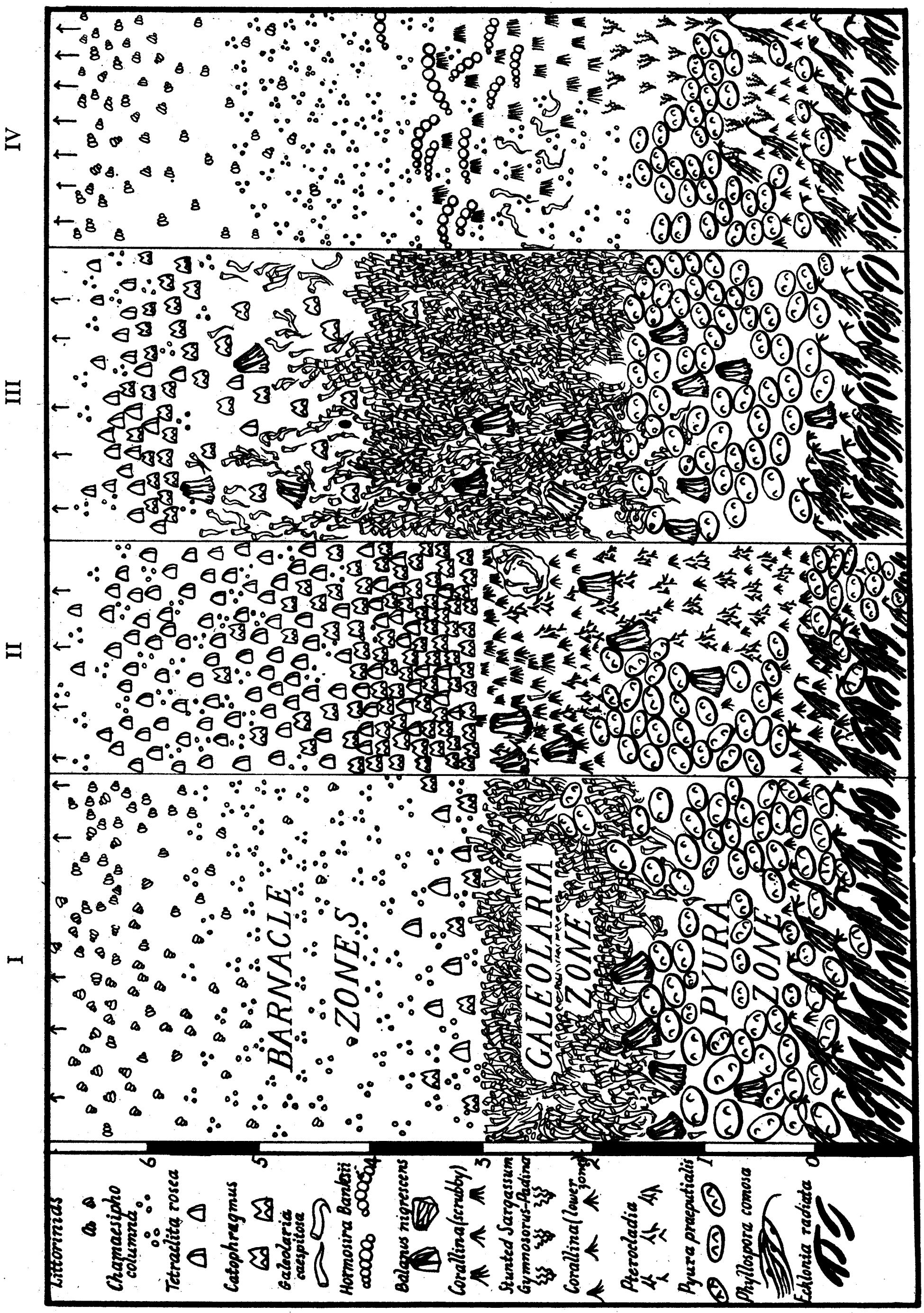

Fig. 3.—See explanation on opposite page.

Apart from the matter of sea-level, it will grow not only where there is considerable disturbance in the water, but also in estuarine entrances (usually, however, opposite the opening). On the whole we would say that it likes rough ocean water on the open coast. Some of the finest growths we have seen occur on level surfaces just sheltered from the fiercest sea attack. This can be seen immediately north and south of some of the headlands along the sides of the bays, Mona Vale and Warden's Head providing two excellent samples.

The photographs (see Plates 4 and 5) illustrate these remarkable growths of *Pyura* on our coast. It is not surprising that this animal obtained a native name, Cunjevoi, shortened to Cungy by the rock fishermen who have destroyed tons of it by using it as bait.

An interesting feature about this ascidian is that it is represented by an almost identical form growing at the same level and forming similar encrustations on the seashores of both New Zealand and South Africa. Oliver (1923), for New Zealand, states that it is dominant "in a few localities." He states that he has not been able to find the name of the species and it is to be noted that he gives its height as 6-8 cm. which is much smaller than our *Pyura.*

The South African species is given as *Pyura stolonifera* and is also described as a type marking the lowest intertidal levels. Stephenson states that the *Pyura* community reaches its apotheosis on the south coast of South Africa. "On a very large number of exposed reefs in the fringe" (our littoral-sublittoral fringe) "this leathery ascidian conceals the rock in incredible numbers, closely packed; it must cover, altogether, many inches of rock." This resemblance to our condition is exceptionally interesting. We can add, however, that the Australian species seems to occupy even a greater length of coastline. On the East Australian coast alone, it is found along 1,000 miles of coast, between the parallels of latitude 28°S. and 38°S. So far as New South Wales is concerned it is impossible to say whether it is less developed in either the north or the south after examining the rich beds at Yamba in the north and Eden in the south. Harvey Johnston (1917) records it at Caloundra, Queensland, although he states that it is not so common there as at Tweed Heads on the New South Wales border.

Explanation of Fig. 3.—Basic zonation of shore and some variations. The scale is approximate and only applies to levels measured vertically above zero tide mark. Vertical measurements are given in feet, zero being the low-water spring tide level at Fort Denison, Sydney Harbour.

Column I. Average conditions facing ocean, reasonable shelter. Typical basic type.

Column II. Very exposed ocean face, swell reaching near vertical or vertical face of rock.

Column III. More exceptional conditions with considerable exposure but with reefs breaking the swell. (Long Reef, extreme point.)

Column IV. Rock platform and margin in very sheltered locality, and often near sandy beach, e.g. rock platform at Black Head at westward limit, and Norah Head.

In Column II the surf barnacles are greatly developed and the barnacle zones extend high above normal limits (splash zones). In III the *Galeolaria* zone is extended upwards and continued by barnacles. In IV the *Galeolaria* is poorly developed and *Chamaesipho* extends in a wide band between the *Pyura* and the supralittoral, or the *Galeolaria* is replaced by algae (extreme right).

The *Pyura* association shelters a number of different animal species. These are listed in the next section which deals in greater detail with some of the shore associations. Attention might be drawn here to the moderately large sea urchin, *Heliocidaris erythrogramma,* which in places occupies rounded hollows in the rock surfaces on which the *Pyura* grows and may almost honeycomb it. It should also be noted that in certain exposed places a very large rock barnacle, *Balanus nigrescens,* occurs not only amidst the Cunjevoi, but above it.

Further details of its occurrence are, however, given later for its presence evidently demands splash. At the top of its range it cannot be said to be abundant and even where there is splash its occurrence is often rather capricious.

(*b*) *The Mid- and Upper-littoral*

III. *The Galeolaria Zone*

Immediately above the *Pyura* zone, and therefore beginning just about the upper margin of the littoral-sublittoral fringe, is an association of an entirely different kind. This is the *Galeolaria* association. It is as remarkable as *Pyura* in the sharpness of its limits, but this sharpness must be coupled with a certain important proviso concerning the nature of its growth, as follows.

Galeolaria caespitosa Lam., a polychaete worm living in a secreted tube of lime, may be found alive as isolated individuals well separated from one another, at almost any intertidal level on the shore, provided the spot is sufficiently moist, but *Galeolaria* also occurs in a very different condition as a very crowded encrustation in which masses of tubes are closely packed and intertwined. In places such a crust may reach a thickness of eight inches and look like coral. In fact, growing in this way it is often popularly called "Sydney coral." This is the condition in which *Galeolaria* forms a highly characteristic belt along our shores, and even where only an inch or less thick this crowded encrusting state can be easily recognized as a clear-cut shore feature (see Plates 5 and 6).

Galeolaria in the form of this close-growing encrustation occupies a sharply limited zone just above the *Pyura.* On a vertical face the width of this zone as a band is usually only about 18 inches and at most two feet. Its upper margin is, in fact, at about the three-foot tide level. On a suitable slope the width will naturally be greater. At Harbord and above all at Merewether, south of Newcastle, and at other places, rock platforms may be found the heights of which just coincide with the *Galeolaria* level. At these places very extensive growths indeed may be found and many square feet of the rock platform will be covered, the growth being especially thick on the corners and edges of rocks (see Plate 5).

The sharp vertical limit of the *Galeolaria* is well illustrated in the photograph of the conditions at Black Head, Gerroa (see Plate 6). The existence of such a margin at a place where the sea breaks violently for most of the time is a very remarkable phenomenon and one almost impossible of adequate explanation at present.

It will be seen that *Galeolaria* in its thick, crusty form occupies the middle zone of the intertidal region. On a vertical face there will roughly be only six feet marking the total rise and fall of exceptional spring tides. The lowest limit of the *Galeolaria* encrusting zone may be approximately about 18 inches to two feet above tidal zero mark of Fort Denison and the upper limit as stated comes near the three-feet tide level.

The upper limit is extraordinarily regular in its occurrence and in most places varying conditions of exposure and shade will scarcely shift it more than an inch or two.

But in very exceptional places this limitation of the *Galeolaria* to a belt 18 inches to two feet wide is changed. We have illustrated such a condition in column III of our typical zonation in the diagram (Fig. 3). It is not easy to define the conditions which bring this about. Our best example is a very restricted area on the extreme tip of Long Reef. Now this is an exceedingly exposed point and as a rule extreme exposure restricts *Galeolaria*. There is, however, one feature of note at this locality. The vertical faces of the rock platform (average height at this point 10-12 ft. above zero tide level) do not pass down to deep water, but to a considerable area of reef or secondary platform which is at about zero tide level. Thus we have a very exposed coast where, however, the swell is broken at periods round low-water by a reef of considerable extent. Thus, broken surf must reach the *Galeolaria* face where ordinarily, in such a position, solid waves would break against it. Here the *Galeolaria* crust extends up to a height of approximately 5 ft. 6 in. above zero tide level. Similar vertical extensions have been noted elsewhere where the same conditions exist.

In the *Galeolaria* band the close growth of limy worm tubes seems not altogether favourable as a surface for creeping sedentary univalves such as limpets etc. (which enjoy the spaces between *Pyura*) and at first sight it would appear as if nothing else but *Galeolaria* occurred. (This is not the case at Nambucca Heads where in places the *Galeolaria* surface is dotted over by the chiton, *Liolophura gaimardi.*) Careful examination of the crust shows, however, that this is very far from the truth and that actually *in* the mass, and *between* the tubes, there is a rich association of small animals, five species at least of which are so closely linked up with the *Galeolaria* (and in many ways noteworthy) as to require special mention.

They are the barnacle, *Ibla quadrivalvis,* the pulmonate, *Onchidium patelloides,* the little bivalve, *Lasaea australis,* an unknown species of a polyclad or turbellarian, and, strangest of all, a spider, *Desis crosslandi.*

A number of other organisms are found in interesting ecological relationship with *Galeolaria.* Reference will be made to all these, with *Galeolaria,* in the next section, where further details of the associations are given.

The *Galeolaria* zone has been noted as far north as Moreton Bay and we have followed it south to the Victorian border where it is still very much in evidence.

Formations of tube-worms have been recorded from other of the world's coasts at about the same level as that at which the *Galeolaria* occurs here, but this characteristic and common member of the family Serpulidae does not seem to be represented in this particular way by any close ally on the South African shores, although in places, at about the same level, there are great expanses of the sandy tubes of another polychaete genus (*Gunnarea*). And the shore of New Zealand is not very different, for Oliver (1923) specifically mentions that the *Galeolaria caespitosa* association of Australia might well be regarded as represented on New Zealand shores by the sandy worm tubes of *Hermella*. There is a tube-worm related to *Galeolaria* forming masses of calcareous tubes in restricted localities on the New Zealand shores (and at about the same tide level) but it is in the muddy waters of Auckland Harbour. This is the worm, *Vermilia carinifera*. It seems to be very much larger than *G. caespitosa* (3-5 cm. in length) and the tubes larger still.

Up to this point we have been dealing with the lower and middle zones of the shore and this has, of necessity, forced our attention to positions on or very close to the outermost margins of the coast and rock platforms. The next zones upwards may present different appearances here and there in consequence of the varying possibilities in the nature of exposure of this part of the shore. The variations are, however, clear and simple, and largely concerned with one animal group—that of the barnacles. Several species are characteristic indicator types of the zones immediately above the *Galeolaria*.

IV. *The Barnacle Zones*

The upper zones of the intertidal region of the coast are typically barnacle zones, although the greatest development of these lies immediately above the *Galeolaria*.

It is essential at the outset to stress again two possible types of locality (the tide level being the same), the exposed locality on the outer tips of headlands with splashing surf and the more sheltered parts of headlands which usually face north or south.

On sheltered margins the *Galeolaria* is usually followed upwards by a zone (often a wide one if the shore presents a gentle slope) marked by a small barnacle, *Chamaesipho columna*. This is, in fact, the smallest of our barnacles of the ocean rocky shore. It may cover the rocks with a close mat in which one individual touches others on all sides. We have counted approximately 3,000 in a square foot and there might easily be more. It is one of the characteristic South-West Pacific animal species and is found on New Zealand shores in a similar position. *Chamaesipho* seems to fade out along the extreme northern part of the coast, north of or about Ballina, and we have information that it is missing in southern Queensland. Except for this change *Chamaesipho* is characteristic of the New South Wales coastline.

A very true and exceptionally clear-cut picture of the general position of *Chamaesipho columna* is exhibited by the rocks on the south side of Black Head forming the northern end of Shoalhaven Bight. Here the *Chamaesipho* forms a whitish band which may be 30 ft. wide owing to the gentle slope, and which can be seen from the cliffs as it extends along the shore for a mile or more (see Plate 7). Near the village of Gerroa the *Galeolaria* zone is practically missing and its place is taken by *Chamaesipho.* Where the rock rises almost vertically from the Cunjevoi zone one can measure the barnacle's vertical extension. At one place this reached approximately five feet above low-water mark, that is, nearly to high-water limits. There are other localities which are unfavourable for *Galeolaria,* and the *Chamaesipho* may be seen invading this zone. Apart from the disappearance noted in the extreme north, *Chamaesipho* is probably the ubiquitous fixed animal of our rocky shores for the platform surfaces often lie somewhere in this zone, and although at exposed places, the lower part of the zone is taken over and occupied by the surf barnacles next to be mentioned, closer examination will probably show *Chamaesipho* amongst them.

On the coasts where an intertidal rock platform is developed at a suitable level, as at Long Reef and especially at Mona Vale, the width of the surface on which *Chamaesipho* is well established becomes much greater. The species is obviously capable of withstanding considerable variations in the duration of exposure and submergence. Typically the zone may be stated as approximately that between high- and low-water mark of *neap* tides.

On *surfaces* where the *Chamaesipho* is less crowded one meets with the limpet, *Cellana,* and other gastropods. Within its geographical range *Sypharochiton* also occurs here. The common associated forms are, however, listed in the following section.

At high levels where the upper boundary of *Chamaesipho* is approached one often finds another barnacle species intermingled with it. This is *Chthamalus antennatus.* At the highest intertidal levels the barnacle zone is represented exclusively by this latter species and in places it develops into a close barnacle community in which each specimen touches its neighbours. Such a condition may be seen at Yamba on the far north coast, or at Harbord, Newport, and many other places, usually in restricted areas. The growth of *Chthamalus* is favoured by spray, but its occurrence is such as to make it a valuable indicator type for zoning purposes.

We have taken *Chamaesipho columna* and *Chthamalus antennatus* first because their positions on the shore are distinctly indicative of certain tide levels which scarcely applies to the three rather more "exciting" barnacle species to which we now draw attention.

At places where the ocean surf beats with all its force, the lowest part of the barnacle zone is occupied by a combined association of *Tetraclita rosea* and *Catophragmus polymerus. Catophragmus* is actually known locally as the "surf barnacle," but it is not easy to see why *Tetraclita rosea* should not receive the same appellation since it, too, loves the break of heavy surf.

The association of the two barnacles is, however, not one of two equal partners. Usually just above the *Galeolaria* zone (and in those places where there is danger to life unless the sea is very calm) one finds a closely packed crust of these two largish barnacle species. *Catophragmus* is probably always the more abundant here, if conditions are sufficiently wild, so much so, that one may at first be tempted to think that only this species is present. Closer examination will probably reveal some *Tetraclita rosea.* This thick, mixed band may extend vertically for about three feet where there is a vertical face on which waves break (and it is only in such vertical or near vertical places on a very exposed margin that one will find the best closely packed "crusts," more especially a crowding of *Catophragmus* which prefers a vertical surface). Above this the *Catophragmus* quickly become fewer and fewer in relation to the *Tetraclita rosea,* and at the same time *Chamaesipho* begins to appear.

Tetraclita rosea may, however, form a close community for several feet more. (Note: This obviously brings it above high-water mark, but in those places where *T. rosea* is found in numbers, we are really faced with physiological rather than actual tide levels, and the conditions normal to lower zones may be pushed high up the cliffs.) Since the rise and fall of the tide on the New South Wales coast averages less than five feet it will, of course, be realized from the above that the presence of *T. rosea* and *Catophragmus polymerus* is not a matter of tide levels at all.

T. rosea is a moderately large, rough-looking barnacle with a characteristic pink colour, and when rock surfaces are crowded with this species the colouring effect is very conspicuous.

One might almost say that any place where these two barnacles occur can be a dangerous position for rock fishermen, meaning that, with a rising tide and rough sea, they are always within the reach of breaking waves.

The sea coast at Harbord presents an exceptionally favoured place for the examination of *Tetraclita rosea* and *Catophragmus polymerus* because it is a particularly exposed headland and in places there are inclined rock surfaces up which the waves run easily. Here we have found *T. rosea* at a height of nine feet above low-water level, and, at one place, as much as 68 ft. horizontally inwards from the outer margin of the shore (see Plates 7 and 8). With regard to the geographical range of these two species similar fine growths can be found in the north at Cape Byron and also at Point Danger on the Queensland border. *Catophragmus* has also been recorded by us up to Moreton Bay. Both species are still present at the southern end of our coast, but it should be noted that *T. rosea* is not nearly so common in the south (see page 204).

Thus, to sum up, one finds the sequence, *Galeolaria, Catophragmus-Tetraclita, Tetraclita, Chamaesipho-Chthamalus* (passing from low to higher levels) in fairly exposed places, and *Galeolaria, Chamaesipho, Chthamalus* on more sheltered rock shore margins. Exceptionally, the *Galeolaria* may be missing altogether.

Before passing to the supralittoral it is necessary to mention a more restricted association which in certain limited localities may also occupy the surface of the rock in close numbers. It is a limpet community, but is almost as definite as that of the barnacles for the members are certainly fixed when the tide is out, and they probably only move a few inches (and return) when covered, which will only be at spring tides. The species is *Notoacmaea petterdi* and where found in a crowded condition its occurrence is characteristic. The requirements for this seem to be (1) a vertical surface, (2) a high level near the upper limits of the intertidal zone, and (3) a certain amount of moisture in the air which implies a position not too far horizontally from the outer edge of a rock platform. Its tide level is then as indicated above, at the uppermost margin of the littoral zone (indeed, in special places it would appear to be well above all tide levels).

Despite what is stated above, *Notoacmaea* may also occur on non-vertical, even horizontal surfaces, and with the greatest diversity at almost all levels. But where the above conditions are present one may find definite bands of *Notoacmaea* and we recorded them at Yamba in the north, at many places in the latitude of Sydney, and in the far south of the New South Wales coast at Eden.

(c) *The Supralittoral*

V. *The Littorinid Zone*

The highest zones of the rocky ocean shore, and we refer here to those well above all tide levels, are naturally not richly frequented by species of marine life. One might add that this should not be surprising since the surface of the dry rock reaches very high temperatures under our blazing summer sun. Under these circumstances it is very interesting to find that two species of Gastropoda are numerous in this zone. They are *Melaraphe unifasciata* and *Nodilittorina tuberculata*. *Nodilittorina* is found higher than *Melaraphe* (in fact it has been recorded from 40 ft. above sea-level). It is *the* characteristic species of the supralittoral. *Melaraphe unifasciata* also extends downwards into the intertidal zones and juvenile forms are frequently found together with the barnacle, *Chamaesipho,* and even down with *Pyura praeputialis.*

The little *Melaraphe* is interesting in that it illustrates, in conjunction with the barnacle, *Tetraclita rosea,* two different types of reaction to tide and splash. As we have noted, *Melaraphe* is adapted to the supralittoral levels where it may be seen exposed for long periods to a hot sun and dry air. *T. rosea* likes rough sea water and much splash. On exposed headlands where waves break higher than the mid-tidal zone for much of the year one may meet *Melaraphe* and *T. rosea* side by side under the wet conditions favourable, indeed essential, to *T. rosea.*

5. The Geographical Range of the Basic Associations

It has been stated in the previous section that very little geographical change occurs in the basic zonation of the rocky ocean shore between the Queensland and Victorian boundaries.*

Differences no doubt occur in the presence or abundance of some of the many shore species which have been collected in this long range. Quite a number of such have been noted, but they are amongst the less common species. Probably many are still to be discovered. To establish certainty of real presences or absences of the rarer forms would require very extensive collecting indeed at different localities and at all times of the year in each locality, for we have found that many animals of the rock platforms are seasonal and migrate.

There are, however, about half a dozen striking changes in the range of the common members of the basic associations and these deserve very special mention, especially since the number is so small. The species concerned are:

Algae

Phyllospora comosa (a large kelp-zone species)

Sarcophycus potatorum (Bull Kelp)

Mollusca

Loricata—
Sypharochiton septentriones
Liolophura gaimardi
Onithochiton quercinus

Gastropoda—
Cominella alveolata
Pelecypoda—
Brachydontes rostratus

Crustacea

Chamaesipho columna

Tetraclita rosea

Phyllospora comosa (Labill.) Ag.—This alga, as will have been noted, is described as forming, with *Ecklonia*, a very distinctive and sharply marked association in the lowest intertidal zone and below it. These large brown weeds are equivalent to the *Laminaria* of rocky shores of other parts of the world. It is all the more significant to notice, therefore, that *Phyllospora* "cuts out" rather sharply somewhere in the neighbourhood of Grant's Head (lat. 31°30′S.). Nowhere north of this do we find the characteristic pastures of *Phyllospora* which are so obvious in the south.

Sarcophycus potatorum (Labill.) Kuetz.—This is almost as noteworthy as *Phyllospora* in its occurrence, except that it is much more restricted "in mileage" along our coast. This is one of the giant kelps. It is a southern form and occurs in the lowest zone characterized by *Phyllospora* and *Ecklonia*. It "cuts out,"

* A reference to Johnston (1917) will show that many animal species listed by us are present at Caloundra, Queensland.

however, north of Bermagui (lat. 36°30′S.) and is only found south of that latitude. The presence of this large seaweed on our extreme southern coast is quite a feature in the seascape at low-water spring tides.

Sypharochiton septentriones (Ashby).—This is one of the three chiton species which live clearly exposed to view on the rock surfaces (albeit in small moist depressions or cracks). It is found over a rather wide band of shore from the *Galeolaria* zone upwards so long as slight moisture is available. (Perfectly sculptured juveniles appear amongst the *Pyura.*) Somewhere about the latitude of Grant's Head or Trial Bay, *Sypharochiton septentriones* "cuts out," but curiously enough its place is taken by a species of a different genus, *Liolophura gaimardi* (Blainville), which occurs from that point northwards and then along the Queensland coast.* This latter species is probably more usually found in the lower parts of the *Chamaesipho* zone or even in the *Galeolaria* zone. (It was very common in the *Galeolaria* zone at Nambucca Heads.)

Strangely enough *Sypharochiton* also disappears again in the extreme south, and certainly is not common south of Bermagui. As an easily seen and common shore creature its geographical range is thus limited to the central parts of the coast. Of the two other chiton species of the exposed rock surfaces, *Poneroplax paeteliana* (Thiele) is plentiful along the entire coast, but *Onithochiton quercinus* (Gould) is absent from the extreme south, its range ending between Narooma and Bermagui. It inhabits the lower zones of the shore and is almost always found below the *Galeolaria.*

Brachydontes rostratus Dunker.—This mussel is clearly a southern form and it occurs in very large numbers covering the shore in "sheets," on parts of the Victorian coast. In southern New South Wales it is restricted to cracks in the rocks where considerable numbers may be found crowded together.

It has not been found by us north of Tuross Heads (lat. 36°10′S.), but occurs from there southwards.

Cominella alveolata Kien.—This is a gastropod of the family Buccinidae and the species is apparently absent from the entire stretch of the New South Wales coast except the extreme southern end. Thus it plays little or no part in our general zonation. But it suddenly turns up in numbers at Twofold Bay and is an interesting case since the species is known along the southern coast of Australia and is common at Kangaroo Island, near Adelaide.

C. alveolata is found at about the same level as that of the gastropod *Morula marginalba,* in the *Chamaesipho* zone of the shore. Both are present at Twofold Bay.

* This statement applies only to the open ocean coast.

Chamaesipho columna.—The disappearance of this small barnacle in the extreme north of New South Wales is perhaps the most striking change amongst the zonation indicators. Everywhere else it is a very common and characteristic feature of the upper half of the littoral (see page 198).

Tetraclita rosea Darwin.—This surf barnacle which plays the prominent part described in the text along most of the New South Wales coast, becomes considerably reduced in numbers in the extreme south, so that whilst present in the same situations in conjunction with *Catophragmus*, its partnership in this association (see page 200) is very seriously reduced.

It would be legitimate to refer the geographical boundaries of all the above species to sea temperature changes along the coast. As already noted, the change is gradual and the number of common species affected is very small.

6. The Common Animals associated with the Basic Zones of the New South Wales Rocky Ocean Shore

In this section we shall list the common shore animals which are found more or less closely linked with the associations previously enumerated and where necessary further notes in regard to the biology of selected species are added. A brief reference only is made to the more important algae.

It should be obvious that the greatest number of species, and, indeed, the greatest number of individuals in the different shore zones, tend to be found where, owing to the occurrence of nearly horizontal platforms or gentle declivities, the zones, and more especially the lower zones, cover a greater area. Horizontal platforms provide every kind of niche beloved by the shore animals for, owing to cracks and hollows, they provide pools of all sorts and sizes, shallow and deep, together with overhanging ledges, stones, and overhanging rocks with beautifully sheltered holes and crannies beneath them. Even a rough weathered surface provides useful depressions which retain sea-water, or provide shade, or both.

We shall follow the same sequence as in the preceding section and commence with the lowest region taking first a platform in the littoral-sublittoral fringe.

(a) *The Littoral-Sublittoral Fringe*

A warning might be given here in regard to the littoral-sublittoral fringe to the effect that our lists apply mainly to places just away from the most exposed points of the coast. One can see the algae, *Pterocladia*, *Ecklonia*, and the corallines, and the ascidian, *Pyura*, at such points at low spring tides on calm days, but real collecting at these exposed places is rarely possible. The necessary protection to allow of collecting may be provided by a detached rock acting as a breakwater, or a mere bend or break in the platform margins.

I. *The Kelp Zone*

The littoral-sublittoral fringe is characterized, as we have seen, by the large brown weeds, *Phyllospora comosa* (Labill.) Ag. and *Ecklonia radiata* (Turn.) J. Ag. (especially at the lowest levels), together with corallines and smaller brown weeds. Owing to the absence of *Phyllospora* north of Grant's Head and the gradual fading out of *Ecklonia* in the extreme north, the conditions of the fringe are different north of Byron Bay. The fringe is then characterized by the abundance of *Corallina.*

In the most exposed places of all, and usually where the platform presents a vertical face to the ocean, the red alga, *Pterocladia capillacea* (Gmel.) Born. and Thur., may be abundant.

In some localities there may be platforms of softer or deeply eroded rock with countless semi-spherical hollows each containing a large specimen of the echinoderm, *Heliocidaris erythrogramma* (see Plate 8). Exactly similar formations have been found in widely distributed and distant parts of the world but with different sea urchin species burrowing in the rock and apparently making the holes (in which they fit fairly closely) by means of their spines or teeth or both. *H. erythrogramma* occurs from Queensland to South and Western Australia. In places in this zone one also finds odd specimens of a related species, *H. tuberculata.* A few may always be found at Mona Vale in the summer but for some reason or other they were far more numerous at South-West Rocks, Trial Bay, in September 1946 than anywhere else. Empty sea urchin holes are sometimes lined with thin layers of an algal nature, often with cushions of a green, velvet-like *Codium,* or the calcareous encrusting algae, *Lithothamnion* or *Melobesia.* They become shelters for small anemones and sponges (the latter being species which we have not been able to identify as yet). Between the sea urchin holes or the *Pyura* clumps and at a level above that preferred by the largest brown weeds, there will probably be masses of corallines (*Corallina* spp. and *Amphiroa anceps* (Lamk.) Decne.) and the rock surface itself is typically pink in colour with encrusting calcareous algae.

II. *The Pyura Zone*

The *Pyura* association needs particular attention. It usually attains a height of 18 inches to two feet above zero low-tide level. *Pyura* has been stated by Hedley to demand rough seas. This is not quite correct, but it is not altogether simple to define the limiting conditions. *Pyura* likes unadulterated ocean water for its best development and a considerable amount of movement in the water is desirable, but not an extreme amount. In fact, in the most exposed places *Pyura* does not extend upwards so far as in more sheltered localities. (An altogether exceptional height is nearly 4 ft. above zero tide level. This was seen in a few places in Twofold Bay at the extreme southern end of the New South Wales coast.) It is also found in the estuaries and almost land-locked bays like Jervis Bay, but usually in such places it is best developed where it faces the estuarine opening to the ocean.

COMMON ANIMALS CLOSELY ASSOCIATED WITH PYURA

Porifera

Purple and orange encrusting sponges—
probably a *Haliclona* sp.

Coelenterata

Hydroida—
Sertularia elongata Lamx.
S. operculata Linn.

Worms

Polychaeta—
Galeolaria caespitosa Lamarck
Salmacina australis Haswell
Lepidonotus argus (Qtrfg.)
Lysidice collaris Grube
Nereis zonata Malmgren var. *pessica* Fauvel
Pseudonereis masalacensis Fauvel
Perinereis novae-hollandiae Kinberg

Nemertinea—
Small, greenish-grey nemertian (unidentified), very common

Crustacea

Cirripedia—
Balanus imperator Darwin
B. nigrescens Lamarck
B. algicola Pilsbry
Elminius simplex Darwin
Tetraclita rosea Darwin
T. purpurascens (Wood)

Amphipoda—
Leucothoe commensalis Haswell (inside *Pyura*) and other unidentified species

Tanaidacea—
Unidentified sp. (very common)

Brachyura—
Pilumnus vestitus Haswell

Mollusca

Loricata—
Poneroplax paeteliana (Thiele)
Onithochiton quercinus (Gould) (except in extreme south where it is missing)
Craspedoplax variabilis var. *cambrica* Ired. & Hull
Meturoplax retrojecta (Pilsbry)

Gastropoda—
Patelloidea alticostata Angas
Montfortula conoidea (Reeve)
Dicathais orbita (Gmel.)

Pelecypoda—
Lasaea australis Lam.

Echinodermata

Echinoidea—
Heliocidaris erythrogramma (Val.)
Centrostephanus rodgersii (Agassiz)

Chordata

Ascidiacea—
Amaroucium sp.
Boltenia (*Pyura*) *pachydermatina* Herdman

The very nature of *Pyura praeputialis* with its strong, rough, and leathery coat favours the attachment of a number of organisms. Still others seek the shelter found between adjacent individuals. One expects, therefore, to find an association of species, adapted to the physio-chemical conditions as well as to each other. In addition to the following list of animals, the algae *Ulva lactuca* Linn., *Colpomenia sinuosa* (Roth.) Derb. and Sol., *Dictyota dichotoma* (Huds.) Lamour, *Pocockiella* (*Gymnosorus*) *variegatus* (Lamour) J. Ag., and a short reddish alga which covers the whole surface, are found adhering to the tests of the *Pyura*.

Often found crawling over and among the tests of *Pyura* is the smallish slit limpet, *Montfortula conoidea*. This shell is found typically in rather moist sheltered situations where it browses on the algae. It is not, however, confined to the littoral-sublittoral fringe alone, being found in higher zones, especially in rock pools and crevices and among the short, tufty, stunted *Corallina* of the mid- and upper-littoral parts of the reef.

We have shown that it is possible to distinguish two roughly marked zones in the littoral-sublittoral fringe. Lowest of all is that characterized by the big brown weeds (with *Pyura*, *Heliocidaris*, and an undergrowth of the smaller red weeds making up the common types to a greater or lesser degree according to amount of exposure and nature of rock). Above this zone we still find that the *Pyura*, *Heliocidaris*, and the corallines are continued with an admixture of the smaller brown weeds such as *Sargassum* spp., *Padina pavonia* (Linn.) Lamour, and *Colpemenia sinuosa* (Roth.) Derb. and Sol.

The very large barnacle, *Balanus nigrescens*, occurs in groups or as scattered, isolated specimens in both the kelp and *Pyura* zones. It is best observed, and reaches its largest size, in the *Pyura* zone and even above this.

On an exposed part of the ocean coast at Nambucca Heads, the algal zoning in the sublittoral fringe was as follows: *Ecklonia*,‡ *Ecklonia* interspersed with brilliantly red corallines, then *Sargassum*, then stunted *Sargassum*. Next came a low scrubby coralline encrustation, the branches of which feel gritty and come away in particles. It is a very common condition of the higher growths of *Corallina*. This algal sequence is very characteristic of the outer margins of the Long Reef platform and many others. Above the sublittoral fringe the alga, *Hormosira Banksii* (Turn.) Decne. appeared. The *Galeolaria* zone came approximately between the stunted *Sargassum* level and the *Hormosira* level.

LIST OF COMMON ANIMAL SPECIES OF THE LITTORAL-SUBLITTORAL FRINGE

(*Additional to those of the* Pyura *Association mentioned above*†)

Those marked with an asterisk occur also in higher zones.

Porifera

Tethya (*Donatia*) *corticata* Lend.
(There are also about six common encrusting sponges in this zone which have not been identifiable as yet)

‡ *Phyllospora* is, of course, absent at this latitude.

† It will be obvious that each species occupies its own characteristic habitat on the platforms. Some only occur where there are collections of sand or gravel, others are under stones, in pools, in crevices, or on the bare rock.

Coelenterata

Hydroida—
Halocordyle disticha var. *australis* (*Pennaria australis*)
Myriothela australis Briggs
Tubularia gracilis V. Lend.
Obelia australis V. Lend.
Silicularia campanularia V. Lend.
Sertularia spp.
Plumularia spp.
Aglaophenia spp.

Madreporaria—
Cylicia quinaria Tenn. Woods

Actiniaria—
Actinia tenebrosa Farq.*
(best developed at higher levels)
Anthopleura (*Oulactis*) *muscosa* (Drayt.)*
Bunodactis (*Phymactis*) *veratra* (Drayt.)*
Anthothoe albocincta (Hutt.)
Phlyctenanthus australis Carlg.

Corallimorphidae—
Corynactus australis Hadd. & Duerden

Worms

Gephyrea—
Physcosoma japonica (Grube)*

Polychaeta—
Sabellastarte indica Sav.*
Identhyrsus pennatus (Peters)*
Spirorbis sp.
Galeolaria hystrix Mörch.*
Diopatra dentata Kinberg*
(limited to places where sand is present in cracks of the rock platforms)
Eunice aphroditois (Pallas)
Nereis pelagica Linn. loc. var.
Platynereis dumerilii (Aud. & M. Edwards)
Pseudonereis anomala Grav.
Syllis closterobranchia Schmarda var. *kinbergiana* Augener
Syllis zonata Haswell
Eusyllis (near *kerguelensis* McIntosh)
Audouinia anchylochaeta (Schmarda)
Lepidonotus melanogrammus Haswell*
L. bowerbankii Baird*

Turbellaria—
Leptoplana australis Laidlaw
Diplosolenia Johnstoni Haswell

Bryozoa

Retepora sp.
Beania magellanica Busk
Membranipora membranacea Linn.
Watersipora cucullata (Busk)
Cantenicellid sp.
Cryptozoon sp.

Mollusca

Loricata—
Ischnoradsia australis (Sowerby)*
Cryptoplax mystica Ired. & Hull
Haploplax smaragdina (Angas)*
Callistelasma antiqua (Reeve)*
Rhyssoplax jugosa (Gould)*

Gastropoda—
Cellana tramoserica (Chemnitz)*
Patellanax squamifera (Reeve)*
P. perplexa (Pilsbry)
Haliotis ruber (Leach)
Scutus antipodes Montfort
Tugalia parmophoidea Q. & G.
Eligidion audax Ired.
Sophismalepas (*Lucapinella*) *nigrita* (Sowerby)*
Bankivia (*Cantharidus*) *fasciatus* (Menke)
Bellastraea sirius (Gould) (olim *Astraea tentoriiformis* Jonas)*
Ninella torquata (Gmelin) (olim *Turbo stamineus*)*
Turbo militaris Reeve
Ravitrona (*Cypraea*) *caputserpentis* (Linné)*
Charonia rubicunda (Perry)
Cymatilesta spengleri (Perry)

Gastropoda (*continued*)–
Mayena australasia (Perry)
Monoplex australasiae (Perry)
Nassarius particeps (Hedley)*
Morula (*Drupa*) *marginalba* (Blainville)*
Floraconus papilliferus (Sowerby)*
Umbraculum botanicum Hedley*
Flabellina janthina Angas*
F. ornata Angas*
Aeolis (*Coryphella*) *macleayi* (Angas)*
Chromodoris (*Glossodoris*) *bennetti* (Angas)*
Casella atromarginata (Cuvier)*
Ellsiphon scabra (Reeve)*

Pelecypoda–
Mytilus obscurus Dunk.*
Trichomya (*Brachydontes*) *hirsutus* (Lamarck)*
Codakia rugifera (Reeve) (only where there is deep sand)
Arca pistachia Lam.*
Austrolima nimbifer Ired. (olim *Lima multicostata* Sowerby)
Lasaea australis Lamarck*
Venerupis crenata Lamarck

Crustacea

Decapoda–
Caridea–
Rhynchocinetes rugulosus (Stimpson)
Leander serenus Heller

Brachyura–
Plagusia capensis de Haan*
P. glabra Dana*
Pachygrapsus transversus Gibbes
Halicarcinus varius (Dana)
Naxia tumida (Dana)
Pilumnus rufopunctatus (Stimp.)
Eriphia norfolcensis McCull.

Anomura–
Eupagurus lacertosus Hend.*

Amphipoda–
Isopoda–

Insecta

Clunio pacificus Edw.

Echinodermata

Asteroidea–
Patiriella calcar (Lam.)*
P. gunnii (Gray)*
Allostichaster polyplax (M. & T.)*
Coscinasterias calamaria (Gray)*
Uniophora granifera (Lamarck)
Asterina inopinata Livingstone*

Ophiuroidea–
Ophionereis schayeri (M. & T.)*
Ophiocoma pulchra (H. L. Clark)*
Ophiarachnella ramsayi (Bell)*
Placophiothrix spongicola (Stimp.)*
Ophiactis savignyi (M. & T.)*

Echinoidea–
Heliocidaris tuberculata (Lamarck)
Holopneustes pycnotylus H. L. Clark (usually in fronds of the kelp; seasonal)
Tripneustes gratilla (Linné) (seasonal)
Phyllacanthus parvispinus Tenn. Woods

Crinoidea–
Cenolia trichoptera (Müller)

Holothuroidea–
Stichopus mollis (Hutton)

Chordata

Ascidiacea–
Cynthia sp.*
Botrylloides sp.

Enteropneusta–
Balanoglossus australiensis (Hill)

Of the types named above, the following are worthy of a further note. Some of the large gastropods are common members of the littoral-sublittoral zones. Characteristic on very exposed rocks is the "cart-rut" shell, *Dicathais orbita.* It is amazing how this creature stands up to the waves and seems to prefer the surf-beaten headlands. It may be seen laying its eggs in July and August. At the same levels one finds *Haliotis ruber,* but only where there is shelter, and particularly in somewhat sheltered pools or hollows or under ledges where the sea has eaten into the edges of rock platforms. Large specimens may be found on exposed surfaces at very low levels, especially on the sides of crevices, and small ones may be found under stones in rock pools. At the same low levels are very large tritons (*Cymatilesta spengleri* and *Charonia rubicunda*) and the black Fissurelid, *Scutus antipodes.* The tritons may crawl about in exposed places, but *Scutus* likes a deep pool to which the sea has entrance, yet where there is perfect protection, and often still water when the tide is out. The large turban shell, *Ninella torquata,* is also found here. Along the northern part of the coast, north of Nambucca, another large turban shell, *Turbo militaris,* appears. Occasional specimens turn up as far south as Long Reef.

At the upper margin of the littoral-sublittoral fringe and where the *Pyura* zone passes into the *Galeolaria* zone one finds (especially on horizontal platforms) two large chitons, *Poneroplax paeteliana* and *Onithochiton quercinus,* which are to be seen fully exposed on the surface (except in extreme south where *O. quercinus* is missing). Less frequently, some specimens of *Poneroplax* may be found at higher levels than this, but in pools in a wild splash zone. Most of our chiton species hide away under stones, but this does not apply to the two species just named, nor to *Sypharochiton* or *Liolophura* which prefer higher levels. Thus, three easily visible chiton species (for up to date we have not found *Sypharochiton* and *Liolophura* together at one place) occupy well-defined zones on the shore.

One should mention at this point the most striking of all our worms—the giant tube-worm, *Sabellastarte indica.* The finest collection—hundreds of expanded heads looking like a flower bed—was seen in this zone below the *Galeolaria* at Merewether just south of Newcastle, but this worm often occurs in permanent rock pools at high intertidal levels on rock platforms, *provided* the pools are near a splash zone and kept filled with ever changing sea-water.

Sabellastarte indica is the polychaete which Haswell described in error as *Spirographis australiensis,* and up to the present date, this worm, known to all students, has been called by that name, although several authors, writing on collections of polychaetes from other places, have questioned Haswell's diagnosis (Augener 1914-1930; Fauvel 1917). We have been able to obtain very fine specimens of this glorious tube-worm and have seen hundreds *in situ* all along the New South Wales coast. The species has also been examined in the preserved state. There can be no question about its being *Sabellastarte indica,* which has actually been recorded by overseas collectors from several places in the neighbourhood of Sydney.

At about the level of the *Pyura* zone or the lower part of the *Galeolaria* zone (where a horizontal surface exists at this level), one often meets isolated specimens of a polychaete which constructs a thick and very hard, irregular tube of cemented sand. The worm is the species *Idanthyrsus pennatus.* At Norah Head a mass of these tube-worms was found at one place. At Nambucca Heads, further north, several masses were found at a level definitely below the *Galeolaria* and thus in the fringe zone. At Angowrie, still further north, however, a very great development of this mass formation occurred. Here, below the *Galeolaria,* almost all the great blocks of rock which form the southern margin of the bay are cemented together by *Idanthyrsus* tubes.

As already noted, the characteristic barnacle of the littoral-sublittoral fringe is the very large *Balanus nigrescens.* This species likes plenty of surging water, and is influenced by the presence of breaking sea and spray so that it may occur at higher levels if special conditions combine to favour it. The highest occurrence we have seen was at a spot where a narrow crevice about six inches wide formed a funnel up which the sea rushed at every breaking wave. Obviously *B. nigrescens* will not be found far away from the edge of a rock platform.

It is not our intention in this paper to give lists of *all* the species found in the different zones. Of special note, however, in the littoral-sublittoral fringe are the encrusting sponges and two small anemones which are particularly characteristic. The sponges are, unfortunately, not identifiable with certainty. The commonest one is of a heliotrope colour (probably *Haliclona* sp.), and other common forms include a *Chondrilla*-like species and several irregular encrusting forms of bright colours. A *Tethya, Tethya corticata* Lend. (=*T. diplodetma* Schmidt), is also common.

The anemones need special mention. One small orange-coloured species, *Corynactus australis,* the club-shaped tentacles of which end in little whitish knobs, occurs in thousands, with the individuals touching each other and covering the rocks. It is found round about zero tide mark and is rarely uncovered by the sea. It prefers some shelter, however, and is usually seen under ledges, on the sides of some gutter, rock pool open to the sea, or other big crevice formed by the action of the waves. This is a highly characteristic species of the littoral-sublittoral fringe and should attract the attention of anyone making a thorough examination of the shores at extreme low-water. Up to date it has not been recorded as playing a distinctive part on our shores. The common anemones, *Actinia tenebrosa, Anthopleura muscosa,* and *Bunodactis veratra,* may all be found in the littoral-sublittoral fringe, but they are more frequent in other zones.

(*b*) *Mid- and Upper-Littoral*

III. *The Galeolaria Zone*

It must be emphasised again that in speaking of a *Galeolaria* zone we are referring to the zone marked by *Galeolaria caespitosa* in a closely packed, encrusting condition, just above the *Pyura* zone. As is usual with porous material the encrustation provides a home for other organisms, and as we have already noted, the whole mass becomes a fascinating ecological formation in which certain arthropods, molluscs, and worms live in a balanced community.

Actually the level of the *Galeolaria* zone is, for every-day collecting, the most luxuriant of all, but this applies only where a horizontal rock platform surface occurs at this level. The reason, of course, is that the still richer lower levels require the rarer coincidence of the lowest tides and favourable weather for their examination. Naturally, where the *Galeolaria* encrustation is presented on a vertical or near vertical face, there is a much more restricted fauna consisting almost solely of the species enclosed within it, together with a few chitons and gastropods.

The *Galeolaria* association exemplifies many of the most interesting problems of intertidal ecology which are unsolved. There is first the problem of the factors causing its sharp limitation in the encrusting condition. A considerable amount of observation around the coast is necessary to appreciate the conditions involved and the factors which favour a full expression of its growth. *Galeolaria* may be found living over a wide series of shore zones. Isolated individuals may be seen many feet above the level of what we have called the *Galeolaria* zone and many yards away from the seaward margin of a rock platform, but under these conditions they are always distinctly separate and scattered and are in places which remain wet with sea-water when the tide recedes. The most surprising occurrence of this kind was a single, isolated specimen alive in a very small rock pool high up (approximately 12 ft. above its usual level) on the shore at Harbord. The pool was, however, in a splash zone where it might be kept reasonably saline, despite rain.

We have already stressed the fact that as a rule the *Galeolaria* encrustation forms a band, with the upper limit about mid-tide level and the lower limit abutting against the *Pyura*. This condition is not only widespread, but also may be seen at places as different as estuary mouths and open ocean rock faces. Yet there are apparently at least two other variations in type of occurrence. One of these, seen clearly at the extreme tip of Long Reef, has been described on page 197. It is a variation in which the upper limit of the *Galeolaria* is considerably raised and the growths are vigorous. On the other hand, there are places on the extreme exposed coast where heavy wave action seems too much for *Galeolaria* and a growth of algae such as *Pterocladia* and corallines takes its place. Finally, there are a few localities, sometimes extremely sheltered, and often where the rocky coast abuts on sand beaches, where *Galeolaria* is again repressed and one either finds the rock surfaces invaded by the small barnacle, *Chamaesipho* (usually so abundant in the zone immediately above the *Galeolaria*), or occupied by a close growth of the scrubby *Corallina, Padina, Gymnosorus,* and stunted *Sargassum* (see Fig. 3, Column IV).

Many years ago Hedley referred to the *Galeolaria* as occurring both on surf-swept headlands and on wharf piles in sheltered water, but said it was intolerant of sand or mud. He also recognized that in places its crust might be six to eight inches thick and specially mentions Wyargine Point at the entrance of Middle Harbour for this condition.

We have seen far greater developments than this at Grant's Head, but nowhere on the coast of New South Wales does *Galeolaria* flourish so well as at Merewether, just south of Newcastle.

Investigation of the Merewether formation with comparisons and close observations at other places suggests the following conclusions:

Galeolaria caespitosa likes continuous moisture and, in particular, requires to be submerged for a considerable period each day. It thrives best in ocean water but not where heaviest wave action is prevalent. It does not mind broken surf and in very exposed places an outer rampart of fallen and half-submerged rocks is quite enough to provide excellent conditions for its growth on the lee or semi-lee sides. These are the conditions at Merewether where the growth is thickest just away from the most exposed margins of the rock platform.

The fine growths at Merewether and other places are not far from a sandy part of the shore. The proximity of sand is thus not an obstacle to its growth.

Even the saline calm water of Sydney Harbour in Rose Bay and below the zoological gardens is still favourable to considerable growths, but a short distance above the Spit Bridge in Middle Harbour it is very poorly represented, whilst the long seven mile arm of the Hawkesbury estuary–Pittwater–seems almost poisonous to it, compared with the certainly polluted water of Sydney Harbour. The water of Pittwater is probably less saline in wet weather, but the more obvious difference is that the water of the Hawkesbury entrance and Pittwater contains much fine mud suspended in it.

The exceptional extent of its growth at Merewether is difficult to explain and we have no clear proof available of any causal factors. Merewether ocean beach is, however, near Newcastle, and a prominent stormwater (street drainage) channel opens on the shore nearby. Wyargine Point makes an interesting comparison for it is directly opposite the ocean entrance to Sydney Harbour and at one side of Balmoral Beach. It receives surf, yet is moderately well sheltered, and it is also in proximity to some drainage water. On the whole, however, we are intrigued at the subtle reaction to some chemical or physical feature in the environment.

One might possibly expect sharp tidal limits where *Galeolaria* is found growing on a wharf pile or on rocks in a somewhat sheltered harbour situation. One can also conceive of a certain degree of exposure to the air being fatal, so that the upper limit could be directly related to tidal levels. But the problem is made much more puzzling by the sharp limit seen even where the sea surges up and down almost continually over the rocks on the ocean coast (see Plate 6). Varying degrees of exposure do not affect the levels very much. And this applies similarly to the sharp "cut-offs" of the large brown seaweeds and to *Pyura*.

The only explanation we can offer at present is the following: We suggest that *Galeolaria caespitosa* is, in general, adapted to a fairly prolonged period of submergence under water. Let us ignore the average days of surf and swell with spray, and consider only the exceptional days with no swell. On these occasions the limiting factor for the upper "cut-off" could very well be tide level. In support of the contention that it may be these exceptional conditions which are limiting factors we might point to the fact that on one occasion only during the year 1945-6 there was a particular kind of blinding white band along part of the very exposed coast of New South Wales between lowest tide levels and mean-tide level. Examination showed that it was due to dead seaweeds, bleached white in the sun. These were chiefly corallines and *Ulva* which normally live satisfactorily in this region because of spray and surf. At this date, however, a series of low spring tides had coincided with an extremely calm ocean and cloudless days, and the result was fatal. (One might note here that it is not the summer temperature which limits the southward extension of coral reefs, but the winter temperature.) Incidentally, the upper limit of thick *Galeolaria* encrustment coincides almost with the lowest level of high water at neap tides.

ANIMALS CLOSELY ASSOCIATED WITH GALEOLARIA ENCRUSTATIONS

Species marked with an asterisk are also found at other levels.

Coelenterata

Actiniaria—
Actinia tenebrosa Farq.*

Worms

Gephyrea—
Physcosoma japonica (Grube)*

Turbellaria—
A Leptoplanid worm (sp. not yet determined; very common everywhere *Galeolaria* examined)

Polychaeta—
Phyllodoce sp.
Nereis sp.

Nemertinea—
Sp. undetermined.

Arthropoda

Arachnida—
Desis crosslandi Pocock

Crustacea—
Ibla quadrivalvis Cuvier*

Pycnogonids—

Mollusca

Loricata—
Meturoplax retrojecta Pilsbry*

Gastropoda—
Onchidium patelloides Q. & G.*

Pelecypoda—
Lasaea australis Lamarck*
Brachydontes hirsutus (Lamarck)*
Mytilus obscurus Dunk.*

It should be stressed that in the list above only those animals found very closely associated with the thick encrustations, often only discovered by breaking off clumps of tubes, have been given. Migratory species such as gastropod molluscs, crabs, etc., which may be found at one place or occasion and not at another, are all noted in the next list.

Of the animals listed above, a special note is desirable in so far as the following species are concerned: *Desis crosslandi, Onchidium patelloides, Lasaea australis,* and *Ibla quadrivalvis.* The spider, *Desis crosslandi,* has only been found by us in *Galeolaria* encrustations. The other three species, although occurring elsewhere on the shore, are particularly at home in the *Galeolaria* and are abundant at least from Merewether to Ulladulla.

The Marine Spider, *Desis crosslandi* Pocock

This spider occurs with a web nest between the intertwined *Galeolaria* tubes and so is almost completely buried in the encrustation. The genus is surely outstanding, especially in view of the rarity of members of the group Insecta and of spiders in the sea. Several species of *Desis* are known (Pocock 1902), and despite the fact that they have been found in widely separated parts of the world, the shore zone in which they have been taken presents considerable similarity in tide-level. Thus *Desis martensi* Koch from the Java Seas occurs in coral or reefs at places "only temporarily uncovered by the sea." One of the first systematists to describe a specimen doubted the possibility of spiders living such a submarine life, and thought they had been floated in an accidental manner from the land. But to get at these spiders the coral has to be broken up, and the same thing applies exactly to *Desis crosslandi* from the *Galeolaria.* Strangely enough, this species is recorded from the Barrier Reef and also from Zanzibar. Another species, *Desis marinus,* has been recorded for Port Jackson and this also occurs on the shores of New Zealand. The Port Jackson specimens are stated by Whitelegge to be "a very common species of spider found under stones at low-water mark." Of the New Zealand specimens it is said that "all the spiders of this kind which we have found have had nests in holes" (*Lithodomus* holes in the rock) "and always under water at all times of the tide" (Robson 1877).

No reference has been made before to the occurrence of *Desis* in *Galeolaria* encrustations and yet we have never found the spiders elsewhere. This is the first record for *Desis crosslandi* from the coast of New South Wales.

Still another species of *Desis, D. Kenyonae,* has been collected and described from east Australian shores—from Westernport in Victoria. Mrs. Kenyon, the discoverer of the Victorian specimens, says she found a specimen under a sea-worm shell which seemed attached to the rock by web and it appears to have been partly submerged under a stone. *D. crosslandi* is reported from the Barrier Reef merely as occurring in holes and crevices of the under-side of stones *which are completely submerged at high water.*

It will be noted, therefore, that here we have a spider living in an encrustation at a fairly low level on the open ocean coasts. It is difficult to see how it could ever reach the surface when submerged and it is in a position where often the surf beats on its borrowed worm-tube bastions. It would appear that the whole manner of its behaviour is still a problem of a most interesting kind. Whatever may be said about the occurrence in holes under stones it is particularly worthy of note that a South African species, *D. tubicola,* is, like ours, actually found amidst masses of worm tubes—in this case, sandy worm tubes. The description of its occurrence is worth recording in full because what is said applies so closely to our local species. The reference is from Pocock's paper (1902).

"Mr. Nendick Abraham's account of the habits of this spider is reprinted from the 'Bulletin of the Liverpool Museum.' After describing his first discovery of the animal in the tube-masses of *Tubicola,* the writer proceeds: 'This formation (the *Tubicola*-masses) is invariably covered by the sea at high tide, and much of it even at low tide . . . Sometimes I have found five or six spiders in one piece of material weighing five or six pounds. Now, what is curious is that these spiders cannot swim or dive, and when placed on the surface of the water appear to be quite helpless, or nearly so . . . I eventually succeeded in securing several nearly perfect examples (of their dwellings). I then saw that the spider does not, as a rule, make its home in the empty tubes of the worms, but . . . in the spaces left between the tubes. The dwelling consists of a delicate silken chamber with the opening seaward. It is so frail and delicate that the least rough handling destroys it. Yet in this frail home of silk, hidden away in some little space in the masses of tubes built by marine worms, these spiders live and thrive, . . . the waves breaking over them all day long . . . I have watched the tubes when the tide was low in the hope of seeing a spider crawling or running about, but I have never yet seen one. They live out of sight deep down amongst the worm tubes. How they catch their food, what their food is, and how they keep the sea from drowning them, are questions I have not yet demonstrated, though I have tried again and again to keep them in my marine aquaria. Shortly after introducing one, I have often found it floating helplessly on the water, apparently half dead, and I have had it lifted out of the water and placed on the rockwork, when it soon became active and ran about very quickly, when it appeared to be just like an ordinary spider.'"

Incidentally, when species of *Desis* were first discovered, stress was laid on the fact that they were known from South Africa and Australia with a gap in between. The original finding of *D. crosslandi* at Zanzibar was noteworthy in that it helped to bridge the gap. We now record the same species from the south-east coast of Australia.

Ibla quadrivalvis Cuvier

Ibla is an Indo-Pacific Cirripede genus of the family Scalpellidae, a group of the stalked barnacles which is found attached to rocks or to animals in the littoral. It is a small form only about 20-30 mm. in height including the peduncle. The genus is a small one with few species but it has been of great interest anatomically and physiologically since Darwin wrote of it. The valves are only four in number and horny, the peduncle is clothed with horny spines which look like coarse hair. The particular interest of the genus, however, is the presence of separate sexes, the males being very small, living inside the mantle cavity of a female or hermaphrodite form practically as parasites. The condition was described by Darwin who actually dissected the tiny complementary males only about one-sixth of an inch long. His specimens came from Kangaroo Island, South Australia, and the description is testimony to his powers of observation. Later the structure of the parasitic males of our species was described in detail by Gruvel in 1904. The *Galeolaria* association provides an almost certain place of finding specimens of *Ibla* in our intertidal zone, but *Ibla* also occurs attached to the lower sides of rocks.

Onchidium patelloides Q. & G.

The discovery of this little marine pulmonate between *Galeolaria* tubes was another very striking incident of this research. The entire group of the Onchidia is particularly interesting and its occurrence had aroused our especial attention in ecological researches on New South Wales beaches before discovering the habits of the species now in question. There are several Australian species, and their common habitat is the shore of estuaries—particularly the muddy shore of mangrove swamps. During these investigations we found that the species, *O. patelloides,* favoured the open ocean coasts. One could not always count on finding it, but on occasions it was quite common on the rock platform at Long Reef. It was next discovered by one of us on the southern coast of Victoria, near Lorne, and so the species has a wide range on the south-east coast of Australia. It came quite as a surprise, however, to find that an *Onchidium* was a regular and common inhabitant of the *Galeolaria* encrustation. The specimens occur amongst the tubes and the flattened shape is evidently very suitable for the home it has found. Most Onchidia seem to feed when the tide recedes and retire to holes when the ground is flooded. Possibly *O. patelloides* does the same, but it is doubtful if it wanders far away from the *Galeolaria,* and it is not usually seen unless a piece is broken off and carefully examined.

Lasaea australis Lamarck

This member of the community is a small bivalve and it may occur in hundreds between the *Galeolaria* tubes. The species is very well known (perhaps best under the generic name of *Kellia* Turton 1822, although *Lasaea australis* was the original name of Lamarck). It occurs all along the south coast of Australia as well as up the western and eastern coasts and it has a habit of fixing itself in crevices and between barnacles. We find it particularly common amidst the corallines of the littoral-sublittoral fringe. The *Galeolaria* encrustation appears to be a second highly favoured place. The shell is only about 6 mm. in length. The genus is noteworthy because of its incubatory habits, the developing eggs being retained in the interlamellar gill spaces until the young are far advanced.

OTHER SPECIES OF THE GALEOLARIA ZONE

(Additional to those already listed in the Galeolaria encrustations)

As already stated the rock platform pools and crevices at the level of the *Galeolaria* zone are probably the most favourable collecting grounds of all. The following list indicates other animal species which are common at this level. Some of these may be seen on the rock surfaces. Most occur under stones. Actually, it is rare to find a suitable stone on a rock platform which is not resting in a depression with a little water. In other words, an upturned stone not only reveals a fauna which seeks shade and is definitely negatively phototropic but one which might be correlated also with the necessity for some submergence in water between tides. This must be kept in mind since it complicates matters. The list, however, refers more particularly to animals which are only in very small and shallow collections of water under stones and not to deep rock pools unless specially stated.

Species marked with an asterisk are found at other levels.

Coelenterata

Actiniaria—
Anthopleura muscosa (Drayt.)*
Bunodactis veratra (Drayt.)*
Phlyctenactis tuberculosa (Q. & G.)*
Phlyctenanthus australis Carlg.*

Worms

Polychaeta—
Salmacina australis Haswell*
Serpula sp.
Spirorbis sp.*
Sabellastarte indica Sav.*
Galeolaria hystrix Mörch*
Diopatra dentata Kinberg*
Eunice aphroditois (Pallas)*
E. antennata (Sav.)
E. siciliensis Grube
Syllis variegata Grube
Nereis pelagica Linn. loc. var.
Lepidonotus melanogrammus Haswell*
L. bowerbankii Baird*
L. argus (Qtrfgs.)
Eurythoe complanata (Pallas)
Idanthyrsus pennatus (Peters)*

Turbellaria—
Leptoplana australis Laidlaw*
Diplosolenia Johnstoni Haswell
Thysanozoon sp.
Tripylocelis typica Hasw.

Nemertinea—
Gorgonorhynchus repens Dakin
Several unknown spp. are common

Mollusca

Loricata—†
Ischnoradsia australis (Sowerby)*
Haploplax smaragdina (Angas)*
H. lentiginosa (Sowerby)
Ischnochiton elongatus (Reeve)
I. versicolor (Sowerby)
Callistelasma antiqua (Reeve)*
(particularly where there is mud)
Rhyssoplax jugosa (Gould)*
Cryptoplax mystica Ired. & Hull*
Poneroplax paeteliana (Thiele)*
Sypharochiton septentriones (Ashby)*
Liolophura gaimardi (Blainville)*
Onithochiton quercinus (Gould)*

† With the exception of the last four species all these chitons are found on the *under*-sides of stones.

Mollusca (*continued*)

Gastropoda—

Cellana tramoserica (Chemnitz)*
Patellanax squamifera (Reeve)*
Scutus antipodes Montfort*
Sophismalepas (*Lucapinella*) *nigrita* (Sowerby)*
Montfortula conoidea (Reeve)*
Austrocochlea obtusa (Dillwyn)*
A. concamerata (Wood)*
Stomatella imbricata Lam.*
Gena impertusa Burrows*
Bellastraea sirius (Gould)*
Subninella undulatus (Mart.)*
Ninella torquata (Gmelin)*
Melanerita melanotragus (Smith)*
Melaraphe unifasciata (Gray)*
Bembicium melanostoma (Gmelin)*
Bittium lacertinum Gould*
Ravitrona (*Cypraea*) *caputserpentis* (Linn.)*
Ellatrivia merces Ired.*
Vicimitra contermina Ired.
Nassarius particeps (Hedley)*
Dicathais orbita (Gmelin)
Bedeva (*Xymene*) *hanleyi* (Angas)*
Morula marginalba (Blainville)*
Agnewia tritoniformis (Blainville)
Floraconus papilliferus (Sowerby)*
Bullinula lineata Brazier (seasonal)
Dolabrifera brazieri Sowerby
Tethys angasi (Sowerby)
T. norfolkensis (Sowerby)*
Umbraculum botanicum Hedley
Pleurobranchus punctatus Q. & G.*
Flabellina janthina Angas*
F. ornata Angas*
Aeolis (*Coryphella*) *macleayi* (Angas)*
Chromodoris (*Glossodoris*) *bennetti* (Angas)*
Casella atromarginata (Cuvier)*
Dendrodoris davisi Allan
Ellsiphon scabra (Reeve)*
Talisiphon virgulata (Hedley)*
Onchidium patelloides Q. & G.

Pelecypoda—

Arca pistachia Lam.*
Anomia descripta Ired.*
Marikellia solida (Angas)
Venerupis crenata Lamarck*

Cephalopoda—

Octopus cyaneus Gray*
O. maculosus Hoyle*

Crustacea

Decapoda—

Caridea—

Crangon strenuus (Dana)
Alope australis (Baker)
Leander serenus Heller

Brachyura—

Naxia tumida (Dana)*
Pilumnus rufopunctatus Stimp.*
Ozius truncatus M. Edw.*
Leptograpsus variegatus Fabr.*
Pachygrapsus transversus Gibbes*
Plagusia capensis de Haan*
P. glabra Dana*

Anomura—

Eupagurus sinuatus Stimp.
E. lacertosus Hend.*
Paguristes squamosus McCull.
Clibanarius taeniatus M. Edw.

Amphipoda—

Isopoda—

Cirripedia—

Tetraclita purpurascens (Wood)*
Chamaesipho columna (Spengler)*
Tetraclita rosea Darwin*
Catophragmus polymerus Darwin
Balanus imperator Darwin*
Elminius simplex Darwin*

Echinodermata

Asteroidea–
Patiriella exigua (Lamarck)*
P. calcar (Lamarck)*
P. gunnii (Gray)*
Asterina inopinata Livingstone*
Allostichaster polyplax (Müll & Tros.)*
Coscinasterias calamaria (Gray)*

Ophiuroidea–
Ophiocoma pulchra H.L.C.*
Ophionereis schayeri (Müll. & Tros.)*
Ophiarachnella ramsayi (Bell)*
Placophiothrix spongicola (Stimp.)*

Echinoidea–
Heliocidaris erythrogramma (Val.)*
Tripneustes gratilla (Linn.)*

Holothuroidea–
Leptosynapta dolabrifera (Stimp.)*
Pentacta australis (Ludwig.)*

Chordata

Ascidiacea–
Cynthia sp.*
Sidneioides tamaramae Kest.
Other compound ascidians

Enteropneusta–
Balanoglossus australiensis (Hill)

IV. *The Barnacle Zone*

The succession of the indicator barnacles and the factors which modify the succession in rough, exposed, or calm and sheltered localities have already been described.

In this section it is proposed to consider some aspects of the general ecology of the whole strip of intertidal shore above the *Galeolaria* zone. Referred as near as can be to tide levels, this means approximately the upper half of the intertidal belt of the shore, and its lower limit may well be the lowest level touched at high-water of neap tides.

The greater part of the area of most of the New South Wales rock platforms falls into this zone, and consequently it is an area of shore which is familiar to the general public. It is characterized, except north of Ballina, by the presence of the small barnacle, *Chamaesipho columna*. The upper limit may be indicated by a change from this to *Chthamalus*, but the growth of *Chthamalus* is restricted and varies considerably even within its narrow limits. In many places close encrustations of *Chthamalus* are rare, in a few localities one can find large areas closely covered. An excellent example of this was found at Yamba, and it may also be seen at other places on the coast.

The surfaces of rock platforms lying at the lower levels of the *Chamaesipho* zone often present rich growths of *Hormosira Banksii*, which may also invade the area occupied by the *Galeolaria* encrustations. This is a brown alga which is a characteristic species of the South-West Pacific and only seems known from New Zealand and Australia. It is one of the most striking algae of the New South Wales intertidal zones, and in places may be thick enough to form what has been called a Hormosiretum. We have never found growths as rich, however, as the coverings of *Fucus* on British coasts. *Hormosira* evidently likes to be moist and yet to be exposed for a short time either to air or the unfiltered rays of the sun. Its habitat clearly reflects these requirements, for where a platform surface is somewhat convex and tends to dry up soon after the tide recedes, it will be found only as thick fringes round shore pools. Here, however, it still reveals its character as a mid-littoral form because it fails to grow in permanent shore pools below a depth of six or more inches. It just forms a curious thick fringe round the margin—its "beads" making contact with the air whilst the tide is out (see Plate 2).

Also, in places where water tends to collect, in juxtaposition with the *Hormosira,* are close mats of *Corallina.* Now *Corallina* is characteristic of the kelp zone and the littoral-sublittoral fringe. It is therefore of particular interest to note that this *Corallina* which is at a higher level is very different in appearance. It is dull and dirty looking in colour and forms low, scrubby growths which look like the surface of an old and much worn nail-brush. It feels coarse and brittle and particles break off. One might have expected this stunted *Corallina* to be a different species from any in the lower shore zones, especially as it is usually found quite separated from those zones. Up to date we have been given to understand that it is the same species at both levels, and in places a continuous series does seem to exist between that of the high zone and that of the kelp beds.

On well-exposed margins of platforms in this zone are moderate growths of *Ulva.* Away from this, and near the land side on the highest rock surfaces of the intertidal zone, the whole surface may be covered with a dazzlingly brilliant green growth of *Enteromorpha.* This is especially the case where an oozing or small drainage of fresh-water seeps from the land. Other surface algae of the higher parts of the platforms are *Bangia* and *Ectocarpus.* There are, it should be noted, very rich and varied growths of algae in the deeper and more extensive rock pools of the lowest parts of the zone.

The characteristic surface-loving chiton, *Sypharochiton septentriones,* marks the *Chamaesipho* zone but only along the central stretch of the coast. Specimens are practically always found in little shallow depressions of the rock surface and so very frequently have no shade from the vertical sun, although presumably they obtain moisture and a somewhat sheltered spot in this way. Reference has already been made to the interesting geographical distribution of this species.

Glancing over the often broad area of level rock, much of which is covered by *Chamaesipho,* one notices that up to a certain distance from the seaward margin considerable areas of the flat rock surface (wherever a slight concavity results in shallow collections of water remaining between tides) bear regularly scattered individuals of *Galeolaria.* And, also distributed over the whole area are numerous limpets, of which *Cellana tramoserica* is most conspicuous, together with the pulmonate *Ellsiphon scabra,* which simulates a limpet in appearance.

The other, more obvious and exposed animals are six or seven species of gastropods, very large numbers of which occur browsing on the algal scum of the rock surface. There is a very clear succession in the distribution of these air-loving species as one passes from the seaward margin towards the land. Lowest are *Austrocochlea concamerata* and *A. obtusa,* along with the carnivorous *Morula marginalba.* Then come *Melanerita melanotragus, Bembicium melanostoma,* and uppermost, the little blue *Melaraphe unifasciata.* These last two are Littorinids.

As the sea-water recedes from the surfaces of the rock platforms it is interesting to watch the species which are relatively quick movers. They gradually move to the wetter places and to shade. Most characteristic, however, is the tendency of the species on higher areas to go into a "huddle." One meets collections of *Melanerita* and *Bembicium* each consisting of dozens of individuals. Most striking, however, in this respect is *Melaraphe* which is usually present in thousands. It collects or huddles in groups wherever there is a corner, a hollow, or even the slightest ridge on the rock surface.

In some places where there are collections of small stones and boulders, one gastropod species may occur in pockets beneath them literally in hundreds. This is *Hinea brasiliana.* Possibly it is one of the most common univalves of the shore, yet along many rock platforms it may never appear conspicuously.

Scattered about at this upper margin of the littoral are specimens of the rock oyster, *Saxostrea commercialis,* but the specimens are small compared with those of the estuaries. The oysters mark a high zone of the intertidal shore and their zoning is fairly sharp, a character which is brought out very conspicuously in the estuaries. The photograph (Plate 9) shows the oyster's relationship to *Hormosira* in this respect.

A very different habit is that of the other common barnacle of the rocky shores—*Tetraclita purpurascens.* This species seems entirely unaffected by tide levels. Its needs are moisture and shade, and if a corner under an overhanging rock or crack provides the favourable conditions, one may meet collections of *T. purpurascens* at practically any level on the shore from the *Pyura* zone to the supralittoral.

In cracks and channels running across the level parts of rock platforms where sea-water remains, one finds the three anemones, *Actinia tenebrosa, Anthopleura muscosa,* and *Bunodactis veratra.* They are actually found in all zone levels. The red species, *Actinia tenebrosa,* is, however, most at home in the highest intertidal zones and one frequently finds collections of individuals left far away above low-tide level on the sides of a platform boulder. Here, in the retracted state, they wait for a return of the tide.

One other species of the highest parts of the intertidal zone may be specially mentioned as one of the types which may be seen fully exposed. This is the little sea-star, *Patiriella exigua,* which thus differs entirely from its two relatives, *P. calcar* and *P. gunnii,* which prefer rock pools of the lower zones.

MOST COMMON SPECIES OF THE ROCK SURFACES IN THE BARNACLE ZONE

Coelenterata

Actiniaria—
Actinia tenebrosa Farq.
On surface rocks
Bunodactis veratra (Drayt.)
Anthopleura muscosa (Drayt.)
On surface, but usually in cracks with a little residual water

Worms

Polychaeta—
Diopatra dentata Kinberg
Usually exposed, but in cracks with water and sand
Galeolaria caespitosa Lam.
Isolated tubes in moist places
Idanthyrsus pennatus (Peters)
Few isolated specimens in wet places

Mollusca

Loricata—
Sypharochiton septentriones (Ashby)

Gastropoda—
Notoacmaea petterdi (Tenn. Woods)
Melaraphe unifasciata (Gray)
Cellana tramoserica (Chemnitz)
Montfortula conoidea (Reeve)
Melanerita melanotragus (Smith)
Austrocochlea obtusa (Dillwyn)
A. concamerata (Wood)
Bembicium melanostoma (Gmelin)
Bellastrea sirius (Gould)
In shallow pools
Subninella undulatus (Mart.)
In pools
Dolabrifera brazieri Sowerby
Over a wide area of surface, and in pools and under stones, but seasonal and wandering over platform in breeding season (October-March)
Ellsiphon scabra (Reeve)
Talisiphon virgulata (Hedley)

Pelecypoda—
Saxostrea commercialis Ired. & Rough.

Crustacea

Chamaesipho columna (Spengler)
Except in the far north
Tetraclita rosea Darwin
Isolated specimens in wet places. In splash and very wet places it may be very thick (except in the far south)
Tetraclita purpurascens (Wood)
At all levels in shade and moist cracks
Chthamalus antennatus Darwin
Only at highest levels

Echinodermata

Patiriella exigua (Lamarck)
In any shallow pools or small cracks

MOST COMMON SPECIES OF THE BARNACLE ZONE WHICH ARE USUALLY HIDDEN UNDER STONES

Since the whole vertical width of this zone may be only a matter of inches, one may find the same organisms scattered over quite a wide area of platform if the level happens to fall in this zone. Actually this is frequently the case. Excellent examples are the major part of Long Reef platform, at least half of the Newport platform, and the parts of the Norah Head platform which are awash at high tide.

Worms

Polychaeta—
Spirorbis sp.

Turbellaria—
Leptoplana sp.

Mollusca

Loricata—
Haploplax lentiginosa (Sowerby)
Ischnochiton elongatus (Sowerby)
I. versicolor (Sowerby)
Ischnoradsia australis (Sowerby)

Gastropoda—
Gena impertusa Burrows
Bedeva hanleyi (Angas)
Scutus antipodes Montfort
Small specimens and under stones
Hinea brasiliana Lam.

Crustacea

Decapoda—
Leander serenus Heller
Naxia tumida (Dana)
Ozius truncatus M. Edw.
Leptograpsus variegatus Fabr.
Pachygrapsus transversus Gibbes

Echinodermata

Asteroidea—
Patiriella exigua (Lamarck)
Often exposed but always in pools
P. calcar (Lamarck)
At lower levels
Coscinasterias calamaria (Gray)

Ophiuroidea—
Ophionereis schayeri (Müll. & Tros.)
Placophiothrix spongicola (Stimp.)

Holothuroidea—
Leptosynapta dolabrifera (Stimp.)

(c) *The Supralittoral*

V. *Littorinid Zone*

As in other parts of the world, the highest parts of the shore, those above all ordinary tide levels, are characterized by the presence of Littorinids. There are two species of these, *Melaraphe unifasciata* and *Nodilittorina tuberculata.* They may be found on dry rock on which a blazing summer sun pours its rays. *Nodilittorina* is the perfect type of this zone and the highest marine mollusc of the shore. As already noted it has been seen 40 ft. above tide levels and marked specimens have not moved down from this level through periods of several months. At places where there is average shelter the supralittoral with its characteristic mollusc, *Nodilittorina,* will be found at a level of about 6 ft. (approximately just above high-water spring tides) and so one may see *Nodilittorina* on the tops of the very large isolated boulders which are frequent on some platforms. Where there is much splash the lower limit of the *Nodilittorina* will be definitely much higher. *Melaraphe unifasciata,* which is not, however, found so high as

Nodilittorina, is, as already described, a common individual in lower zones, more particularly the higher intertidal levels. Thus, of our three common Littorinids, *Bembicium, Melaraphe,* and *Nodilittorina,* the first is restricted to the upper parts of the barnacle zone (upper intertidal); *Melaraphe* occurs at the same levels, but also higher (and in the juvenile condition lower); and *Nodilittorina* is best adapted to the conditions of dry land. Other common species of these high zones of the shore are given in the attached list.

COMMON ANIMALS OF THE SUPRALITTORAL

Species marked with an asterisk also occur in lower zones.

Mollusca

Gastropoda—
Nodilittorina tuberculata (Menke)
Melaraphe unifasciata (Gray)*
Melanerita melanotragus (Smith)*
Notoacmaea petterdi (Tenn. Woods)*

Arthropoda

Crustacea

Amphipoda—
Talorchestia novae-hollandiae Stebbing and other species

Decapoda—
Cyclograpsus audouinii (M. Edw.)
Leptograpsus variegatus (Fabr.)*

Insecta

Rock pools well up in the supralittoral containing water which ranges from fresh rain water to water of a high salinity due to wave splash and subsequent evaporation are often crowded with the larvae of the mosquito *Aëdes* (*Pseudoskusea*) *concolor* Taylor.

It should be pointed out that many zoology students, in their urgency to reach the lower zones, often fail to realize the high level which may be attained by some of the species of lower zones which habitually collect under stones in shallow pools.

The most striking zonation is naturally presented by those forms which are fixed or semi-fixed and must face the extreme conditions of the shore. Animals which favour and can find even shallow pools and sheltering stones may obtain satisfactory conditions (at least for a time) at almost any level.

Thus, careful collections made over long periods may result in the discovery of many species having cryptic habits at many very different levels on the shore.

7. Conclusions

We have shown how, along the entire rocky coast of New South Wales (and the limits can almost certainly be extended southwards into Victoria and north across the Queensland border) there is a fundamental basic zonation of typical indicator animal species. This zonation is described in the text.

Of the common animal species of the shore zones only a few do not extend throughout this stretch of coast. This is a strong confirmation of the conclusions reached by the systematists working on individual groups (chiefly with collections of echinoderms (Lyman Clark 1946) and molluscs (Hedley 1904; Iredale and others)). On their work, the Peronian province of the Australian coast extends from about 26°S. (Queensland coast) to eastern Victoria.

This basic zonation has been described first for an average condition of exposure. In places where conditions of extreme exposure prevail or where specially sheltered rock margins occur, the basic zonation is slightly modified, but any change is usually an easily recognized variation in which rough surf and splash extend some of the zones vertically, or shelter may favour or repress certain species. The typical zonation is not obscured in such places.

Stephenson (1936-1947), in his excellent reports on the zonation of the South African coast, states that a comparison with Ricketts and Calvin's semi-popular work (1939) on the intertidal shores of California reveals "much that is reminiscent of South Africa." We find much that is reminiscent not only of South Africa and California, but of other temperate coasts. We have, in fact, noted as an exceedingly interesting feature of our zonation studies, the repetition of seashore pictures of other and distant world shores. One might suggest that such broad and interesting resemblances have often been lost in the accumulation of specific names and studies which draw attention to the geographical range of particular species and emphasize the discontinuities of distribution.

For example, we may take the presence of Littorinids on the highest zones of the shore. Actually, the relation of Littorinids to upper zones of rocky coasts is one of these general features which has attracted notice already. The linking of Littorinid species with special zones has received special attention in England, but the presence of Littorinids high in the supralittoral has been noted from Japan, America, and Africa, as well as Sydney. At the other extreme level of the intertidal area we find the kelp, here as elsewhere, marking the lowest levels with the genera *Ecklonia* and *Phyllospora*-species which play the part of *Ecklonia* and *Laminaria,* etc., on South African and other coasts. We have not seen in the northern hemisphere anything like our beds of *Pyura,* but these closely resemble those of South Africa and New Zealand and probably South America, even though the species are recorded as different.

On our exposed rocky shores at low-tide levels we find rock honeycombed with hemispherical hollows containing the purple sea urchin, *Heliocidaris erythrogramma.* We can read an almost identical description of the purple *Strongylocentrotus purpuratus* on the Californian coast. But the same story has been told about rock-boring sea urchins in the surf zone of Europe, and the genera are not so distant from each other; in fact, the names *Strongylocentrotus, Heliocidaris, Echinus,* and *Echinometra* have often been interchanged in taxonomic history.

Species of the mollusc, *Thais,* are listed for South Africa and the Pacific coast of America at the same low-tide levels as those frequented by *Dicathais* here.

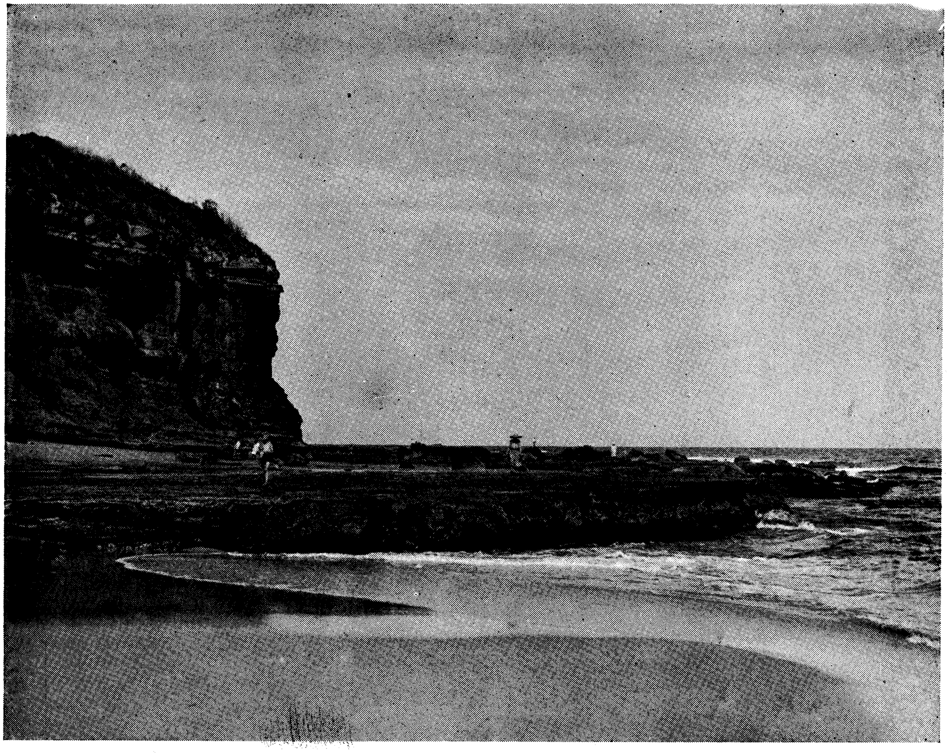

Fig. 1

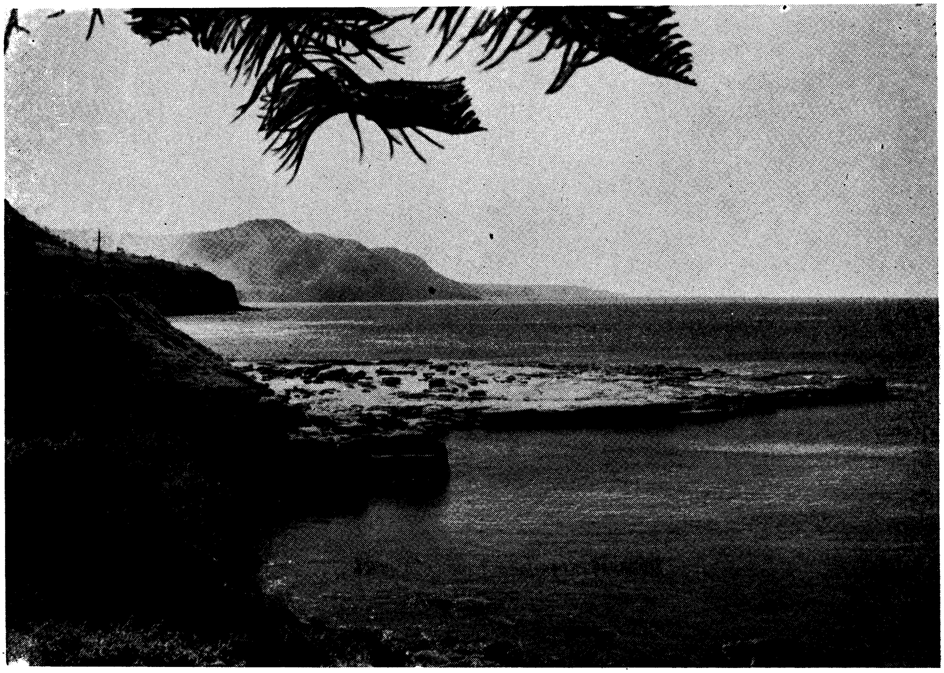

Fig. 2

DAKIN, BENNETT, and POPE.—A STUDY OF CERTAIN ASPECTS OF THE ECOLOGY OF THE INTERTIDAL ZONE OF THE NEW SOUTH WALES COAST

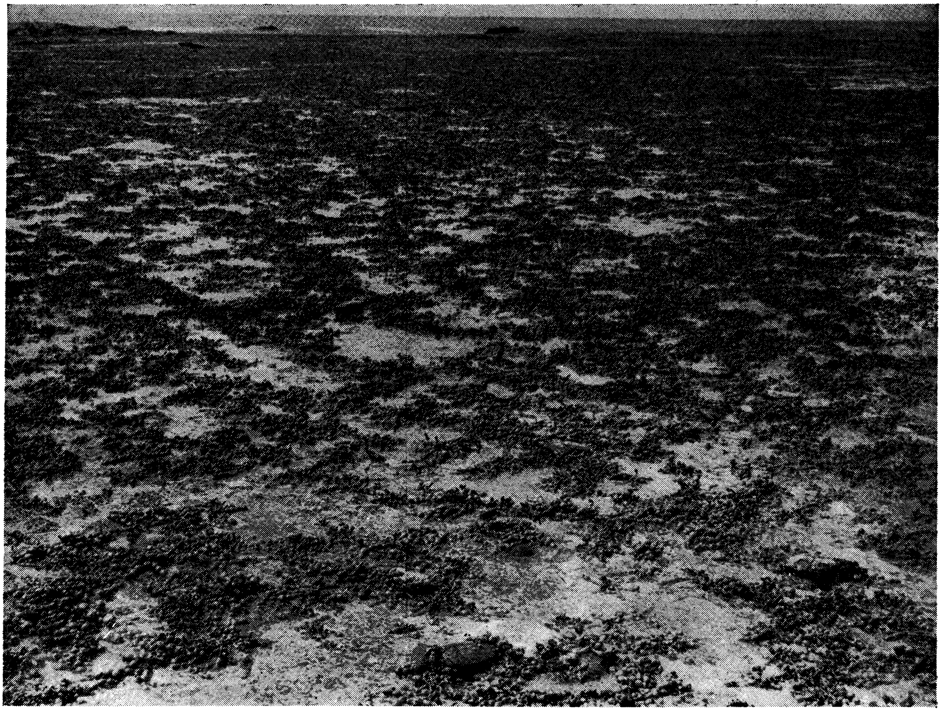

Fig. 1

Fig. 2

DAKIN, BENNETT, and POPE.—A STUDY OF CERTAIN ASPECTS OF THE ECOLOGY OF THE INTERTIDAL ZONE OF THE NEW SOUTH WALES COAST

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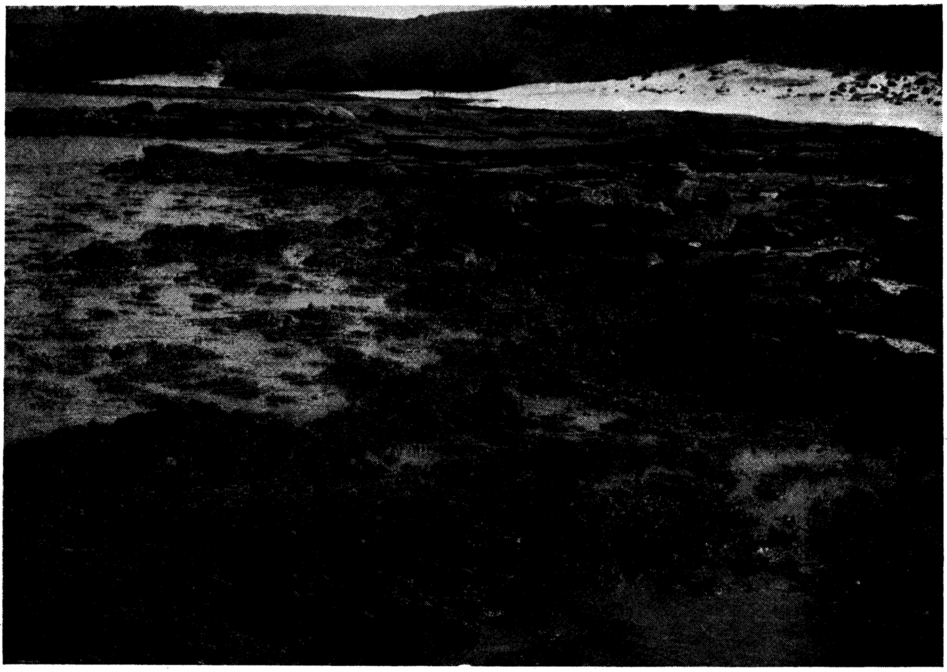

Fig. 2

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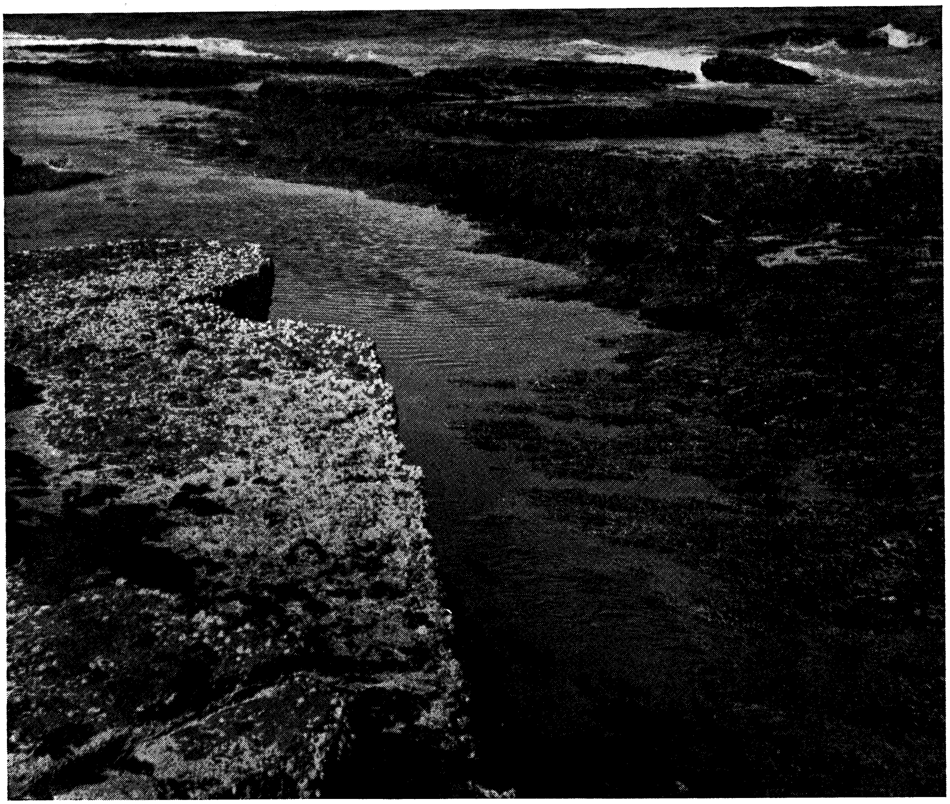

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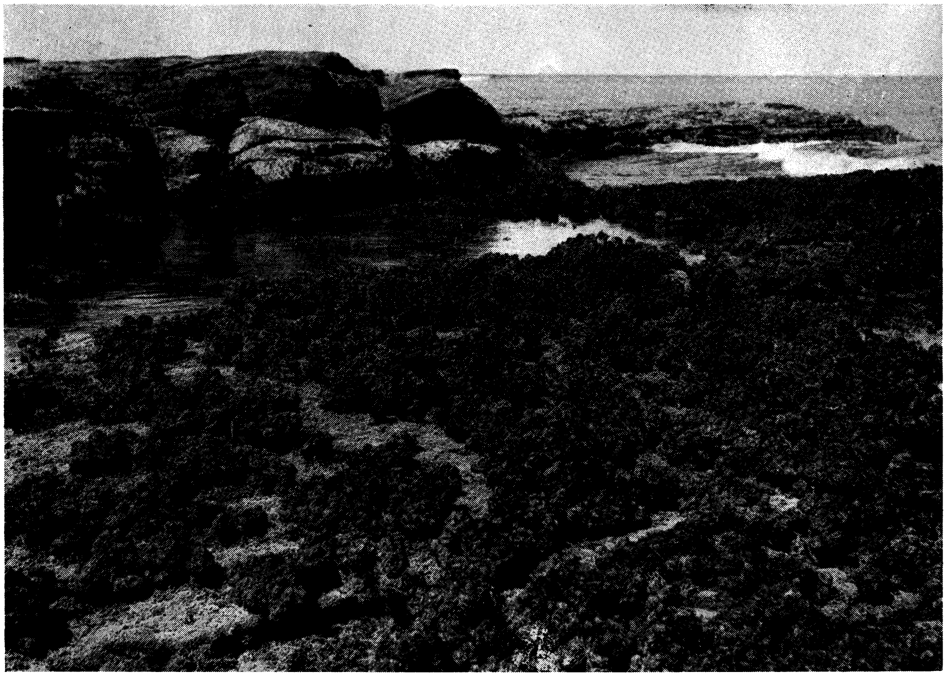

Fig. 1

Fig. 2

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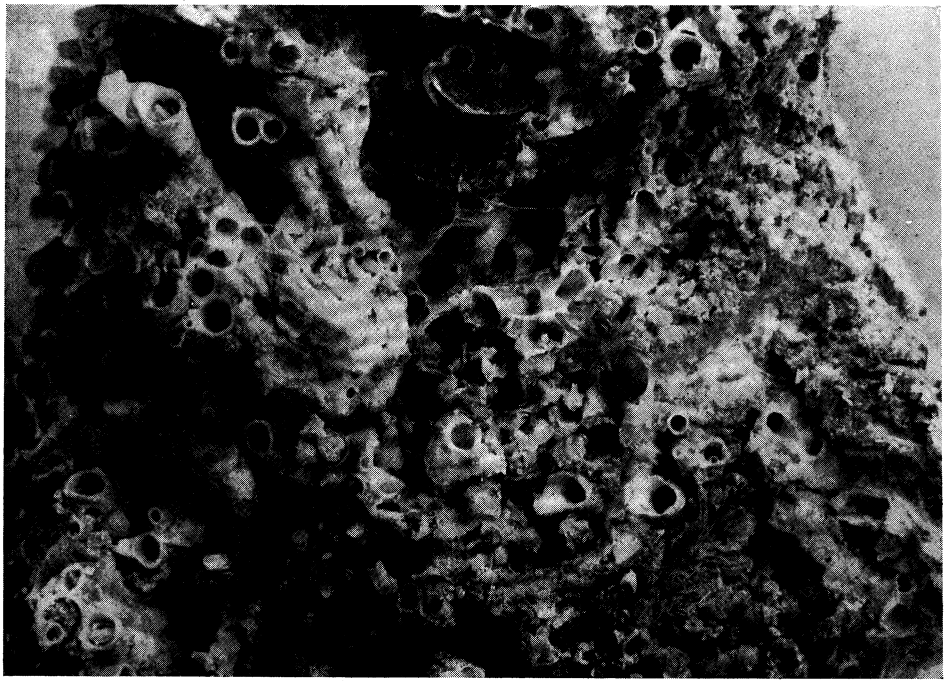

Fig. 2

DAKIN, BENNETT, and POPE.—A STUDY OF CERTAIN ASPECTS OF THE ECOLOGY OF THE INTERTIDAL ZONE OF THE NEW SOUTH WALES COAST

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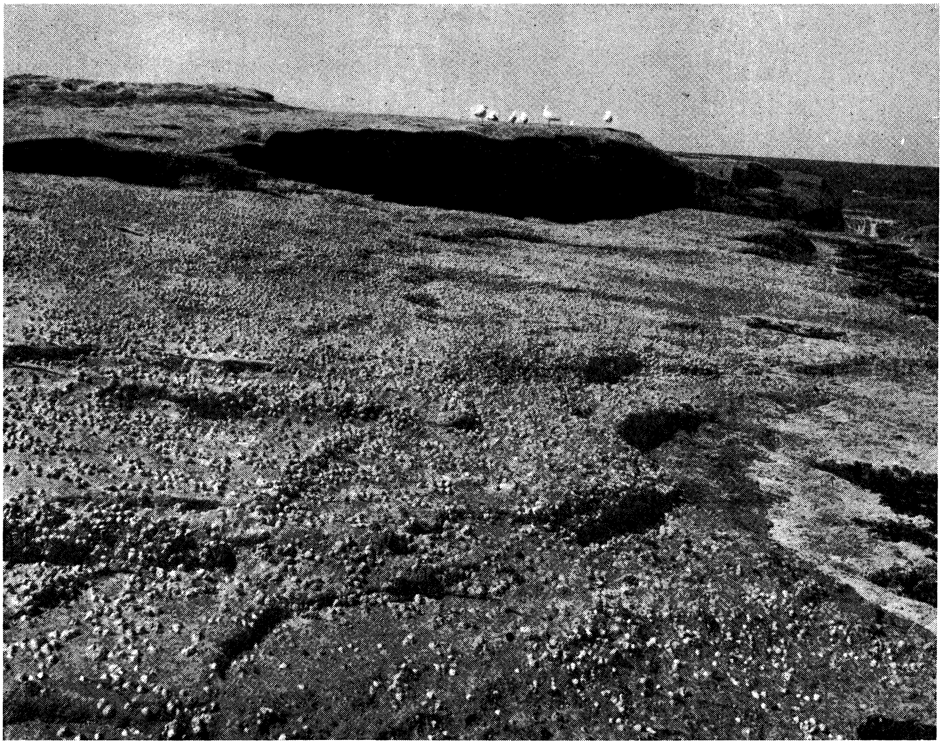

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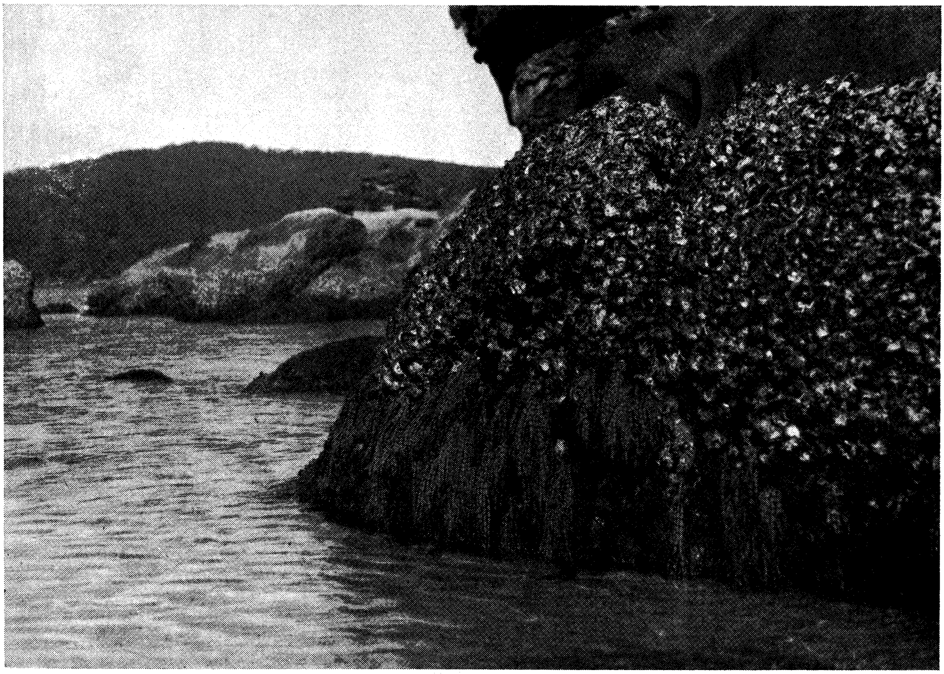

Fig. 1

Fig. 2

DAKIN, BENNETT, and POPE.—A STUDY OF CERTAIN ASPECTS OF THE ECOLOGY OF THE INTERTIDAL ZONE OF THE NEW SOUTH WALES COAST

The barnacle zones of the shores are well known and although the species are different and at times very characteristic of certain definite geographical regions, yet somewhat similar forms live under similar conditions on shores far apart. In fact, Ricketts and Calvin (1939) figure a *Tetraclita rubescens*—a dull brick-red barnacle—as occupying the middle shore zone and being a surf swept animal. We have our pink *Tetraclita rosea* in similar positions.

One of the most surprising examples is the spider of the surf zone, *Desis*. Species occur on shores from South Africa to Victoria and a series of these is found under the same puzzling conditions on each coast.

One could extend the list easily. We would therefore draw attention to the occupation of similar ecological niches on distant shores by similar types and stress the similarity in the basic zonation of shores separated by oceans and continents.

Much emphasis has been placed on the sublittoral and littoral area as a "cradle of evolution" and perhaps on a landward migration of species from the sea. One must never forget the geographical distribution of shore species *along* the world's coasts. And one might venture to stress the view that through the vicissitudes of phylogenetic history the genus or family is often closely anchored to a specially favoured ecological niche, notwithstanding the workings of geographical distribution and isolation.

Shore faunas have extended themselves along the world's coasts even if carried as larval stages by sea currents. Isolation has worked in some cases to produce highly local species. Naturally, in isolated regions, there may be specialities and in some cases entirely different types may be evolved to fit into ecological niches occupied otherwise elsewhere. One sees this on land in studies of the world's floras. But the striking general resemblances remain.

The sensitivity of a seaweed like *Sarcophycus*, which seems to distinguish a difference between the outer ocean coast and the adjacent and apparently almost equally exposed rocks in the wide open Twofold Bay is remarkable. There are many animal cases of the same nature, some examples of which have been indicated.

There are some fascinating physiological and biochemical problems to be solved before the adaptations of seashore animals to their special zones are even partly understood (see Colman 1933, 1941; Stephenson *et al.* 1943). But this is very much in the realm of pure science and the answers are not likely to be forthcoming in the near future with other fields of research offering so much that is essential and remunerative today.

8. Acknowledgments

This research was made possible by funds from the Commonwealth Research Grant and the financial help is gratefully acknowledged.

Thanks are due to several members of the staff of the Australian Museum, particularly to Miss J. Allan, Messrs. Rainbow, McNeill, Musgrave, and Iredale. The investigation has been greatly facilitated by the fine collections and Library of the Australian Museum.

We also wish to thank Dr. A. B. Hastings of the British Museum (Natural History) for identifications of Bryozoa and Mrs. Valerie Jones of the National Herbarium and C.S.I.R. for her assistance in the determination of the algae.

9. References*

* The literature noted below is referred to in the text. A very long list of taxonomic papers could be drawn up, since much systematic investigation has been called for in the research. Only a few references to papers of special taxonomic significance have, however, been included, since the aim of the investigation has not been systematic.

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Explanation of Plates 1-9*

(All photographs, with the exception of Plate 6, Fig. 2, by W. J. Dakin.)

* All photographs of rock platforms were taken at low-water spring tide.

Plate 1

Fig. 1.—Typical intertidal rock platform. (Southern side of Mona Vale Headland.)

Fig. 2.—Rock platform, Coalcliff. Most of surface above high-water mark.

Plate 2

Fig. 1.—*Hormosira Banksii* growth on part of Long Reef platform.

Fig. 2.—Characteristic growth of *Hormosira* around rim of rock pool.

Plate 3

Fig. 1.—Exposed rock platform at Harbord, Sydney, on day with calm sea, but moderate swell.

Fig. 2.—View along littoral-sublittoral fringe at extreme low water, showing algae *Phyllospora comosa* and *Ecklonia radiata,* with *Pyura praeputialis.* (Warden's Head, Ulladulla.)

Plate 4

Fig. 1.—Kelp zone at extreme eastern edge of Long Reef.

Fig. 2.—Zonation with barnacle, *Galeolaria, Pyura,* and kelp zones showing. (Long Reef, extreme eastern margin.)

Plate 5

Fig. 1.—*Pyura* zone. Extensive beds of this ascidian exposed at low water. (Warden's Head, Ulladulla.)

Fig. 2.—Exceptional development of encrustations of polychaete worm, *Galeolaria caespitosa* Lam. (Merewether, N.S.W.)

Plate 6

Fig. 1.—Example of sharp limits to zones. Margin of *Galeolaria* and barnacle zones on vertical wall of rock at Black Head, Gerroa. Barnacles are *Catophragmus polymerus* and *Tetraclita rosea.*

Fig. 2.—*Galeolaria* tubes separated to show sea spider, *Desis crosslandi* and web. Enlarged x 5. (Photo: Gwen Burns.)

Plate 7

Fig. 1.—Barnacle zone—*Chamaesipho columna* band along southern shore of Black Head, Gerroa.

Fig. 2.—A vertical face on rock platform, Harbord, showing surf barnacle zone (*Catophragmus* and *Tetraclita*) above *Galeolaria* zone.

Plate 8

Fig. 1.—Exposed slope on Harbord rock platform. In such splashed positions the surf barnacle zone is broadened. (Barnacles seen are *Tetraclita* with *Catophragmus.*)

Fig. 2.—The burrowing echinoderm, *Heliocidaris erythrogramma,* in typical hollows at low tide levels.

Plate 9

Fig. 1.—Zonation up the Hawkesbury River Estuary. The commercial oyster (*Saxostrea commercialis*) is seen above the alga *Hormosira* and below this is a band of mussels.

Fig. 2.—A "carpet" formed by the alga *Corallina* with evenly distributed anemones (*Anthopleura muscosa* (Drayt.)).