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Transportation patterns of Aboriginal artefacts in the Shark Bay area, Western Australia

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Abstract

Artefact material at Aboriginal sites in the Shark Bay area is derived from various rock units exposed along the course of the Murchison River, as well as from local sources. The probable transportation pattern was from the Badgeradda area south-westward along the Murchison River at least as far west as the Ajana area, and then northward to Shark Bay. The maximum established transport distance is about 400 km for grindstones derived from the Badgeradda area. Coastal sites were occupied during the late Holocene, but one inland site may have been occupied prior to 6000 B.P., as a likely source of some artefact material is thought to be under the sea.

Introduction

During geological mapping in the Shark Bay area a number of previously unrecorded Aboriginal sites were briefly studied. All sites were marked by the presence of extraneous rocks as well as by shell fragments, and most of these artefacts were clearly worked. Apart from the recognition of grindstones, distinct flake tools and baler-shell scoops, no attempts were made to identify other tool types. The stone artefacts consist mostly of distinctive rock types which permit the identification of their source areas. The purpose of this note is to record this evidence concerning artefact source areas and to discuss the implied transportation pattern. Figure 1 shows the sites described and the geological units from which the artefacts were derived.

Site Descriptions

Site 1 (Shark Bay 1:250 000 map sheet, SG 49-8; grid reference 1239-7881) is located on top of red sand dunes at about 100 m from the sea. It is marked by two grindstones and by numerous shell fragments including baler shells. The larger grindstone measures about 40 cm x 30 cm x 5 cm, and consists of very-well-sorted, well-cemented, micaceous, silty sandstone of a characteristic greyish-purple colour. A chip from this grindstone was collected for petrographic comparison with likely source rocks, and it is petrographically indistinguishable from samples of the Yarrowolya Formation of the Proterozoic Badgeradda Group (Fig. 1; Geological Survey of Western Australia (GSWA) thin section No. 32048; reference sample Yarrowolya Formation GSWA 32070A).

The second grindstone consists of quartzitic, coarse-grained, moderately-sorted sandstone, identical in hand specimen to quartzitic sandstones that constitute the Woodrarrung Sandstone which is also part of the Badgeradda Group.

Site 2 (Edel 1:250 000 map sheet, SG 49-12; grid reference 1338-7631) is on top of low, white, calcareous coastal dunes at about 50 m from the shore. It is marked by shell fragments including baler-shell scoops, and a grindstone consisting of very-well-sorted, medium-grained, calcareous quartz arenite or quartzose calcarenite. This rock type is common along the shores of western Shark Bay in beach deposits of the Tamala Limestone.

Site 3 (Edel SG 49-12; grid reference 1392-7555) is located on top of low, white, calcareous dunes at about 100 m from the sea. Numerous shell fragments including baler-shell scoops, and stone artefact fragments are present at the site. Grindstone fragments consist of medium- and very-coarse-grained, quartzose calcarenites which are derived from various shallow marine and beach facies of the Tamala Limestone. A fragment of a quartzite pebble is similar to pebbles present in conglomeratic parts of the Permian Nangetty Formation.

Site 4 (Edel SG 49-12; grid reference 1505-6718), which was previously recorded by P. E. Playford (in Glover 1975), is on the south-eastern side of a large depression in between lithified dunes of Pleistocene Tamala Limestone. Water is present at shallow depth. The site is about 13 km south of the tidal flats at the southern end of Shark Bay, and less than 3 km from the steep Zuytdorp Cliffs. The varied artefact material is grouped according to source area.

The numerous shells including baler-shell scoops, are derived from nearby shores. Also of local origin are grindstones consisting of the well-sorted, quartzose calcarenite that forms the beach facies of the Tamala Limestone (cf. site 2), as well as calcrete flake tools and other fragments of pisolithic calcrete of a type that is common in the Tamala Limestone.

A second group of artefacts consist of grindstones of well-cemented, very-well-sorted, fine medium-, and coarse-grained quartz arenites, and pebble-sized

fragments of poorly lithified, moderately-sorted, sparsely pebbly, medium- to coarse-grained, red, feldspathic sandstone. The largest grindstone seen measured about 25 cm x 20 cm x 10 cm. Both rock types are characterized by a distinct sparkling appearance due to well-developed overgrowths on individual quartz grains. The Silurian Tumblagooda Sandstone which occurs along the Murchison River (Fig. 1) is the source of these rocks.

Chalcedony and various types of silcrete are present as flake tools and cores. Nearby outcrops of Tertiary silcrete and chalcedony along the eastern shore of Shark Bay are the most likely source. Another relatively nearby occurrence of Tertiary silcrete adjoins the outcrop area of the Tumblagooda Sandstone.

Pebbles of light grey chert, coarsely crystalline quartzite, and bright red jaspilite constitute the next group of artefacts. These pebbles are derived from con-

glomeratic parts of the Nangetty Formation, the nearest exposures of which are along the Murchison River. The basal Triassic conglomerate that crops out in the coastal cliffs south of the mouth of the Murchison River is too fine-grained to be the likely source of these pebbles.

Grindstones consisting of well-sorted, medium-grained and coarse-grained quartzite, and a pebble-sized fragment of well-cemented, very-well-sorted, greyish-purple, silty sandstone, are lithologically very similar to the grindstones at site 1. Derivation from the Woodrarrung Sandstone and the Yarrowolya Formation of the Badgeradda Group is therefore indicated.

A fragment of coarsely crystalline dolerite, similar in hand specimen to a grindstone reportedly found near Crayfish Bay, is either derived from dolerite dykes in the Proterozoic metamorphic rocks of the Ajana area,

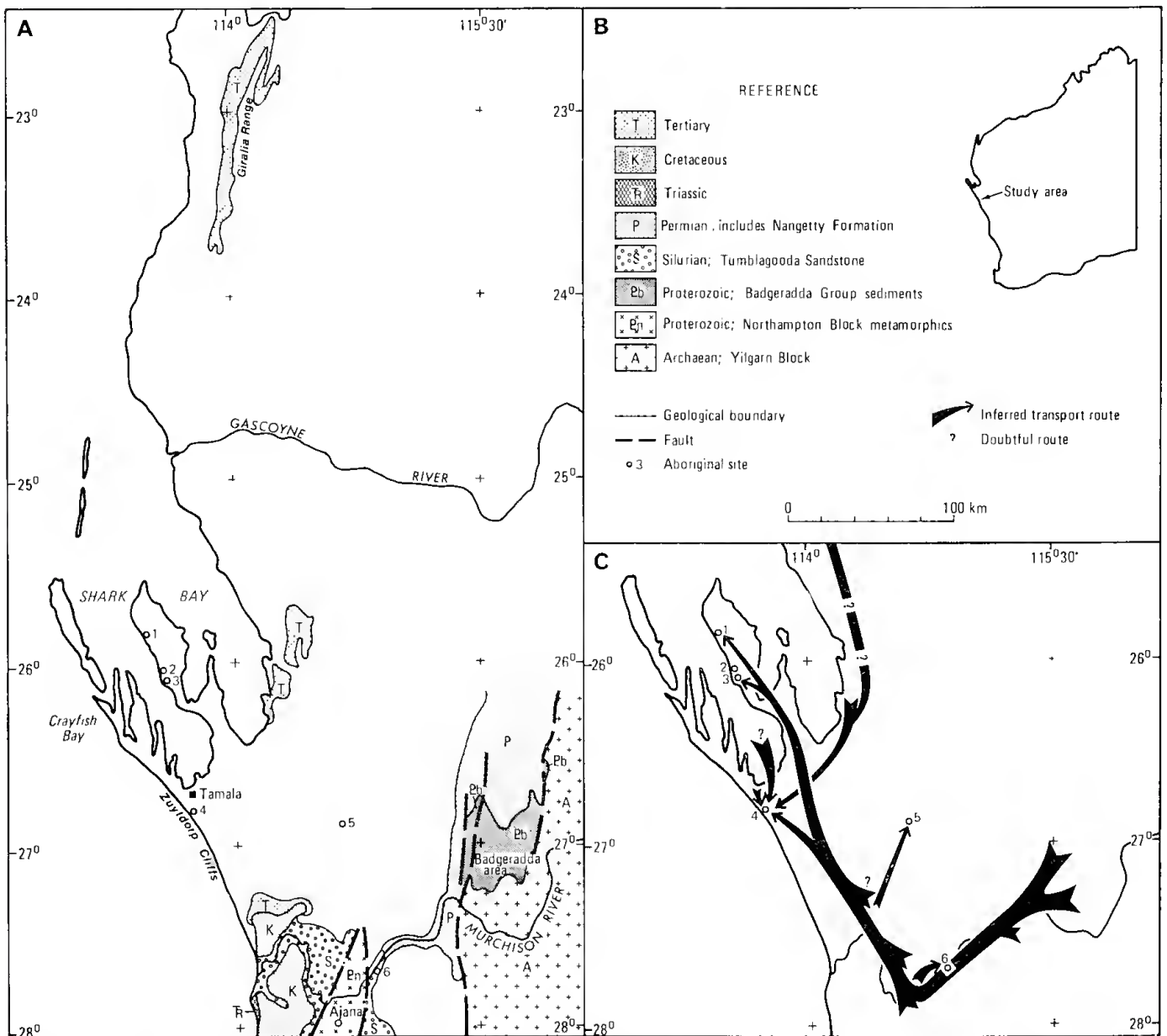


Figure 1.—A.—Location of Aboriginal sites, and potential source rocks of stone artefacts. B.—Reference. C.—Inferred transport patterns of Aboriginal artefacts.

or from similar dolerites that occur in the Archaean rocks to the east of the Badgeradda area. A pebble-sized fragment of ultramafic composition is also most probably derived from these Archaean rocks (GSWA thin section 32086 C).

The last group consists of very-fine-grained (micritic) sparsely-fossiliferous limestones. Fragments of white, micritic limestone with scattered foraminifers and bryozoans, light-grey, pelletoidal limestone with scattered bryozoans and echinoderm debris, (GSWA thin sections 32086 A, B) and greenish-grey, fossiliferous limestone were found. A. E. Cockbain (written comm.) considered the first two varieties to be of probable Early Tertiary age and lithologically similar to Palaeocene limestones known from several deep bores in the Shark Bay area. Fragments of bryozoal chert, including a large core, lithologically similar to artefacts of Eocene chert which are common in the Perth Basin area, were also collected from this site by P. E. Playford (in Glover, 1975).

The nearest known outcrops of similar Tertiary (Palaeocene) limestones are in the Giralalia Range about 440 km to the north of this site. However, as all the other artefacts from this locality have either a local or a southern source, this evidence of long-distance transport from the north is not considered to be conclusive. The alternative interpretation is that these rocks are derived from presently submerged exposures of Palaeocene rocks within the Shark Bay area. In other words, they may have been brought to this site before sea level reached its present height about 6000 years ago, as was suggested by Glover (1975) for the Eocene chert artefacts found in coastal parts of the Perth Basin. Detailed petrographic and palaeontological work on artefacts, subsurface, and surface samples is now needed to confirm this interpretation.

Site 5 (Yaringa 1:250 000 map sheet, SG 50-9; grid reference 2530-6618) is in typical red sandplain country, and consists of several tens of fragments and flakes of intensely silicified, Cretaceous Windalia Radiolarite. The nearest known outcrops of silicified Windalia Radiolarite are about 80 km to the south near the Murchison River.

Site 6 (Ajana SG 50-13; grid reference 2779-5620) is located on an alluvial flat about 100 m from the Murchison River. Artefact material at this site comprises

a grindstone as well as silcrete and quartzite flakes and chips. The silcrete and quartzite are derived from nearby outcrops, but the grindstone which consists of garnetiferous granulite has been brought upstream for at least 10 km from the high-grade metamorphic rocks of the Ajana area.

Discussion and conclusions

Aboriginal stone artefacts, for which the Murchison River Valley is the source area, are common in the Shark Bay region. Combined with the knowledge of Aboriginal occupation of the Murchison valley this is strong evidence that artefact material was carried from the Badgeradda area south-westward along the Murchison River at least as far as the Ajana area and then northward to Shark Bay. The alternative possibility that material from the Badgeradda area was transported along a straight-line route to the Shark Bay area is thought to be unlikely. Following the Murchison River would have had the advantage of reducing the distance without reliable water supplies to about 100 km, as against nearly 200 km for a straight-line route. The maximum transport distance implied by this suggested route is about 400 km for grindstones which originated in the Badgeradda area, as compared to a straight-line distance of about 250 km. As well as this extraneous artefact material, locally derived materials are also present at the sites described.

The location of Sites 1, 2 and 3 along the present-day shore suggests that occupation of these sites occurred after the Holocene transgression reached present sea level. Site 4, however, may have been occupied before 6000 years B.P.

Acknowledgements—The field data were collected during geological mapping of the Shark Bay area for the Geological Survey of Western Australia. I am grateful to the Director of the Survey, Mr J. H. Lord for the use of technical facilities and permission to publish.

Reference

- Glover, J. E., (1975).—The petrology and probable stratigraphic significance of Aboriginal artefacts from part of south-western Australia. *J. R. Soc. West. Aust.*, 58: 75–85.

Eocene bivalves from the Pallinup Siltstone near Walpole, Western Australia

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Abstract

A western occurrence of the Upper Eocene Pallinup Siltstone is reported from the Walpole district of Western Australia. The deposit occurs as a remnant valley fill at an elevation of 124 m above Australian Height Datum. It contains a diverse molluscan fauna, of which 23 species of bivalves and about 50 species of gastropods have been recognized, preserved mainly as siliceous replacements. There is a good correlation with Late Eocene faunas of south-eastern Australia. Most bivalves represent wide-ranging Eocene genera, while some (*Fasciculocardia*, *Hedecardium* and *Dosina*) are of Austral-Neozelanic affinity. One family (Glossidae) and genus (*Glossus*) are reported from the Australian Tertiary for the first time; 4 genera (*Acar*, *Plicatula*, *Epicodakia* and *Verticordia*) are recorded from the Australian Eocene for the first time. One new species, *Barbatia (Acar) gunsoni*, is described.

Introduction

The Upper Eocene Pallinup Siltstone, a transgressive marine unit of the Plantagenet Group consisting of siltstone and spongolite, occurs discontinuously along the south coastal region of Western Australia, in the Bremer Basin, between the Esperance and Northcliffe districts (Fig. 1). Near Albany and in the Fitzgerald River area, it conformably overlies the Upper Eocene Werrilup Formation and elsewhere rests directly on Proterozoic rocks of the Albany-Fraser Province (Doepel 1975). The most recent general review of the group is by Cockbain (1968); further information from later studies is provided by Quilty (1974 and references), Geological Survey of Western Australia (1975), and Ludbrook (1977).

Deposition of this and other Middle to Late Eocene marine deposits in southern Australia accompanied downwarping and transgression along the newly-formed continental margin in the aftermath of the geological separation of Australia and Antarctica and the formation of an open seaway between the two continents (Jones 1971, Veevers and Evans 1973). The Pallinup Siltstone formed in a shallow shelf environment with well-circulated water of normal marine salinity (de Laubenfels 1953, Cockbain 1974) and is richly fossiliferous. Sponges, often well preserved, are generally the dominant fossils, but the preservation of what were originally carbonate structures tends to be poor because of pronounced leaching and consequent compaction of the beds.

All specimens from Walpole discussed in this paper are in the collections of the National Museum of Victoria (NMV) and the Western Australian Museum (WAM). In molluscan taxonomy, we have been guided by the Treatise on Invertebrate Paleontology, where available.

Previous work

The first report of non-cephalopod molluscs from the Plantagenet Group appears to be that of Newton (1919), who referred to specimens identified by him as "*Rostellaria*, *Glycymeris* cf. *laticostata* (Quoy and Gaimard) and a *Pecten*". These were obtained from "the vicinity of Albany" and are presumably in the collection of the British Museum (Natural History).

Glauert's (1926) list, recording 12 bivalve and 3 gastropod species from "Albany and near", "Cape Riche" and "Bremer River", apparently combined Newton's records with the author's identifications of specimens then in the WAM collection. Attempts to locate this material have met with only partial success. The Museum collection contains 11 pieces of yellowish-brown siltstone, bearing impressions of mollusc shells, and labelled "Cape Riche, E of Albany, W.A. Govt. Geologist". Tablets accompanying the specimens are numbered 400 to 409 (405 is missing) but we have been unable to verify these numbers in the records either of the WAM or Geological Survey of Western Australia (GSWA). However, the first palaeontological catalogue of the WAM, started probably in 1897, does appear to record these specimens under the numerical sequence 271 to 281. Identifications on some of the labels and tablets accompanying the specimens and in the catalogue are the same as some of Glauert's published records from Cape Riche and we regard this material as being among that used by him. The history of the Cape Riche collection is obscure, but it may have been associated with Harry P. Woodward, who was Government Geologist in Western Australia from 1887 to 1895. Other fossil material, endorsed "H. P. Woodw. 2nd Colln." is housed in the WAM collections.

More ambitious studies on the Plantagenet Group molluscs are those of Chapman and Crespin (1926, 1934), of which the latter has greater significance. For

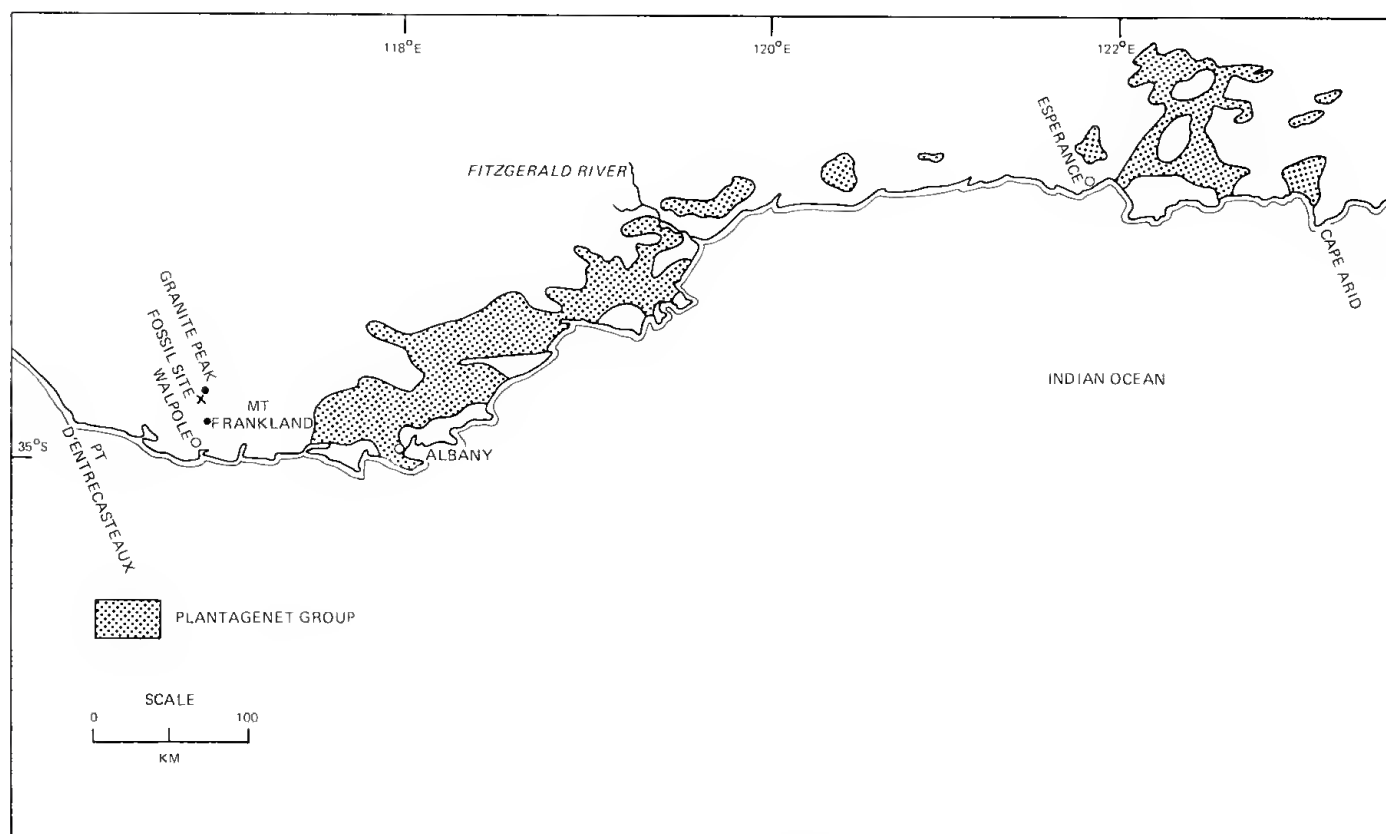


Figure 1.—Locality map. Plantagenet Group outcrops after Cockbain (1968).

their bivalve and gastropod material, Chapman and Crespin (1934) refer to two Western Australian sources. These were "the Glauert collection", actually a combination of specimens from WAM and GSWA and "the Jutson collection", housed in the National Museum of Victoria (NMV). Several South Australian and Victorian specimens from the Dennant Collection, NMV, were also cited in this paper but are of no present relevance. Chapman and Crespin excluded all of Newton's and most of Glauert's identifications from their results. A comprehensive review of the Chapman-Crespin determinations lies beyond the scope of the present paper and we do not propose to examine all in detail. We will deal however with certain aspects of their results that have come to notice in the course of our studies.

Forty four bivalve and 24 gastropod species were recorded for the Plantagenet Group by Chapman and Crespin (1934), for which, they determined a Miocene age. However, 9 of their records are from "Balladonia" and probably originated in the Nullarbor Limestone of the Eucla Group; these are discussed further below. Six other records from "Norseman" may be attributed confidently to the Eundynie Group. With the deletion of these 15 records, their corrected totals of Plantagenet Group species stand at 34 bivalves and 21 gastropods.

We have located in the WAM collection a group of 5 fossil molluscs, of which the associated labels are inscribed as follows: 6049 cast of *Diplodonta* sp., 6050 cast of *Dosinia* sp., 6052 cast of ? *Fusinus* sp., 6053 *Conus ligatus* Tate and 6054 *Seraphis* sp. Their locality, entered in the catalogue on 3 October 1927, is "Bremer Bay" and it appears that these specimens account for 5 of the 6 records from there in Chapman's and Crespin's (1934) list. The sixth record, "*Crassatellites* ? *sulcatus*

Sol.", cannot be traced further but presumably represents the missing specimen 6051. The 5 available specimens are all internal casts in a hard, pale brown limestone and are covered with sparry calcite. This lithology is unknown within the Plantagenet Group but matches closely that of WAM specimens 3247-3263, collected by W. B. Alexander at Balladonia, evidently from the Nullarbor Limestone.

The original catalogue entry for Alexander's specimens, made on 30 June 1914, comprises 17 numbers, without identifications. However, we note that Chapman and Crespin recorded only 11 species from Balladonia (1 foraminifer, 1 brachiopod, 9 molluscs) and 6 from "Bremer Bay". The lithology of the latter is foreign to the Plantagenet Group but consistent with that of the Nullarbor Limestone and we consider them to be the missing part of Alexander's original Balladonia collection. This confusion evidently arose between June 1914 and October 1927, before the material was seen by Chapman and Crespin. In view of the foregoing, we delete all 6 of the "Bremer Bay" records from their 1934 list, thus reducing their total of species validly attributed to the Plantagenet Group to 31 bivalves and 18 gastropods.

The WAM fossil collection contains 2 small pieces of friable, ferruginous sandstone bearing impressions of bivalve exteriors. An original label, numbered 6046, gives the locality "King River"; a second label in Dr Crespin's hand, is inscribed *Antigona* cf. *hormophora* (Tate). One piece (now 6046b) has attached a small, complete specimen of the living estuarine mytilid bivalve *Xenostrobus securis* (Lamarck) and both pieces show numerous small fragments of shelly material entrapped within what appear to be modern, mytilid byssal fibres. We consider that this material was collected from a modern, inter-tidal estuarine locality, such as can be

found at Lower King, Albany, near the northern end of Oyster Harbour. The shell impressions retained on the sandstone represent, in our view, the common venerid cockles *Katylisia scalarina* (Lamarck) and *K. rhytiphora* Lamy and not the Tate species from Table Cape.

The original catalogue entry for number 6046 shows it to be one of a sequence of three lots (6044-6): none is otherwise identified and we have been unable to locate specimens 6044 and 5 in the collection. Chapman and Crespin (1934, p. 126) list 3 species from "King River", *Antigona* cf. *hormophora* (Tate)", "*Lithophagus* sp." and "*Tellina* sp.", but without citing catalogue numbers. Their "*Lithophagus* sp." is described as "an ironstone cast", which suggests a relationship with the *Katylisia* specimens of 6046. There being no differentiation within the catalogue for specimens 6044-6, it is reasonable to assume that they were obtained from a common source and we consider it most unlikely that any of these specimens originated in sediments of the Plantagenet Group. The deletion of the three "King River" records from Chapman's and Crespin's list would reduce their total of species to 28 bivalves and 18 gastropods.

The collection of the GSWA contains a group of 23 pieces of Pallinup Siltstone, numbered in the sequence $\frac{1}{4131}$ to $\frac{1}{4136}$ (excluding $\frac{1}{4135}$). These were seen by Chapman and Crespin and listed by them on p. 107. The specimens include moulds and casts of bivalves, gastropods and nautiloids; the first-mentioned include what appear to be poorly preserved examples of *Barbatia limatella* Tate, *Glans latissima* (Tate) and others, unidentified.

We have located in the collection of NMV 5 bivalves and 8 gastropods from the Pallinup Siltstone, part of "the Jutson collection" of Chapman and Crespin. The bivalves are poorly preserved, though 3 are determinable to genus (*Glycymeris* sp. and *Chlamys* spp.). None of these specimens appears to have any direct relevance to our Walpole material and will not be considered further in this paper.

It has been shown above that a substantial part, about one third, of the Chapman and Crespin records were derived from sources other than the Plantagenet Group. We have been able to locate and examine part of the remainder of their material but are unable to confirm any of their bivalve identifications. As an account of bivalve species attributable to the Plantagenet Group, we consider that the Chapman and Crespin paper lacks validity. Some of their gastropods, however, appear to have been identified correctly and this will be discussed by us in a further contribution.

Locality details

The fossil material here discussed was collected by the authors and associates from a deposit first made known to GWSK in 1967 by Mr L. Gunson of the National Parks Authority of Western Australia, Walpole. It is located beside the Thompson Highway 26 km by road north from Walpole townsite (latitude 34°48'S, longitude 116°43'E; Pemberton 1:250 000 map sheet grid reference 472703). A preliminary report on the deposit and its fauna was presented by Darragh (1973).

At the fossil site, Thompson Highway crosses a low-lying poorly-drained sandy depression several hundred metres wide, which extends for a much greater distance westward, where it connects with a tributary of the Deep River. An embankment has been constructed to carry

the road across the lowest part of the depression, utilizing rock and sand obtained from shallow excavations along either side of the road. Initially, fossils were found on the disturbed surfaces of these excavations and the deposit was subsequently authenticated by sampling adjacent undisturbed ground. The undisturbed sequence comprised up to 1 m of white to brown siliceous silty sand, intensely humic near the surface, the lower third of which contained abundant sponge remains, together with occasional molluscan shells, echinoid spines, brachiopods, bryozoans, hydrozoans, scleractinian corals, annelid tubes and otoliths. The fossiliferous sand merged into an irregularly surfaced, greyish-brown, well-sorted, sandy siltstone containing similar fossils. We found no evidence of post-depositional transportation of the fossiliferous sand, which we consider to be residual and derived *in situ* by weathering from the underlying unit. To this process, acidic ground water has probably contributed.

Although the site is enclosed on three sides by lateritized hillslopes, we have found no trace of any lateritic material in sievings from the fossil bed. The depression is densely vegetated and slopes gently to the west. The fossil deposit, of unknown thickness, apparently fills the lowest part of this depression, which may represent part of an early Tertiary or older drainage system, such as has been noted with disjunct Eocene marine deposits in other parts of southern Western Australia (Lowry 1970).

Measurements made with a 2.5 inch surveying aneroid barometer indicate that the top of the fossil bed lies at 124 m above Australian Height Datum (equivalent to mean sea level) (S.A. Wilde, pers. comm.). This is well within the upper limit of 300 m established by Lowry (1970) and others for the Late Eocene shoreline in this region.

Faunal details

Preservation

The deposit and its associated fossils are strongly silicified and entirely leached of carbonate. Sponges have retained substantially their original form and texture in grey silica, whereas the molluscs and other groups are preserved as translucent brown (occasionally opaque white) replicas of the original carbonate structures. The most common mollusc species, *Tenagodus* sp. cf. *T. oclusus* Tenison Woods, has been collected *in situ* within pieces of sponge, indicating that the Eocene habitat of the genus was similar to that of modern forms.

Darragh (1973) considered that the silica of the Walpole molluscs had been precipitated as casts within natural moulds but subsequent examination of a wider range of material has led to a reconsideration of this view. The retention of the original internal structure in echinoid spines, together with the presence of residual nacreous lustre in some archaeogastropod shells, suggests rather that the specimens are molecular replacements of carbonate by silica. Cavity infillings of silica occur in a proportion of both bivalve and gastropod shells; where present, these are usually well differentiated by colour from the "shells" and appear to have been formed at a different time. Under microscopic examination, it may be seen that fidelity in reproduction varies somewhat; many specimens appear to have lost at least some finer detail, though the major features of the shells are often very well preserved. Distortion,

due apparently to compaction of the enclosing sediment, has affected a proportion of the specimens; others seem to have been abraded or damaged prior to fossilization.

In the sandy siltstone underlying the fossiliferous sand, sponges are preserved as grey to brown, often vitreous bodies, in which the internal structure may be clearly visible on broken faces. Other originally-carbonate fossils may occur either as brown, glassy replacements (silica) or as natural moulds. The latter form is more typical of fossil preservation in the Pallinup Siltstone generally and it is this, together with distortion of specimens, that has discouraged interest in the molluscs hitherto. The present material from Walpole is the first obtained from this source, in which the original shell forms or something close to them, can be examined directly. What appears to be similar preservation in Eocene molluscs from South Australia has been reported by Basedow (1904).

Palaeoecology

Oceanic temperatures to the south of Australia during the Eocene appear generally to have been somewhat higher than at present (see Kemp 1978). The presence in the Plantagenet Group of the foraminifer *Asterocyclina* (Cockbain 1967), the alga *Neomeris* (Cockbain 1969), mangroves and other tropical vegetation (Churchill 1973) and certain echinoids (Foster 1974) are in accord with this conclusion. From the Late Palaeocene, through the Eocene and Early Oligocene, surface sea temperatures in this region, though oscillating somewhat, show a general decline (Shackleton and Kennet 1975) and there is evidence of a progressive cooling within the Late Eocene Blanche Point Formation and Port Willunga Beds of the St. Vincent Basin (Daily *et al.* 1976). No such trend has as yet been demonstrated within the Plantagenet Group; however our studies on

bivalve and gastropod molluscs from Walpole suggest a fauna of temperate character, deficient in traditional tropical elements but with a high proportion of cosmopolitans. We emphasise that our evidence is drawn from a single locality only and is unlikely to be representative of the molluscan fauna of the formation and group as a whole. The presence of numerous herbivorous archaeogastropods and cerithiaceans supports the view that the site at the time of deposition was located on the inner shelf in relatively shallow water. At the time, adjacent hills such as Mt Frankland (411 m), Granite Peak (403 m) and other elevated areas would have formed temporary islands and shoals, around which a diversity of molluscan habitats and life would have become established.

The presence of predatory gastropod boreholes in molluscan specimens has been noted and will be dealt with in a later paper, describing the gastropod fauna. In the recognition of naticiform and muriciform boreholes, we have followed Carriker and Yochelson (1968). Briefly summarized, the bivalve predation data show that of 658 specimens examined, 61 (9.2%) had completed gastropod boreholes, of which 12 (1.8%) were naticiform and 49 (7.4%) were muriciform. The principal prey species were *Arcopsis dissimilis* (1 naticiform, 15 muriciform boreholes), *Limopsis chapmani* (7 naticiform, 11 muriciform), *Plicatula* sp. (10 muriciform) and *Glaus latissima* (4 muriciform).

Correlation

Chapman and Crespin (1926, 1934) correlated the Plantagenet Group fauna with that of the Tasmanian Lower Miocene Table Cape Group. However, we consider most of their molluscan identifications to be erroneous, there being little affinity with the molluscs of the Table Cape fauna, reviewed recently by Ludbrook

Table 1

Occurrences of Walpole bivalve species in other Tertiary formations in southern Australia; references in text. 1, Wilson Bluff Limestone (Eucla Basin). 2, Tortachilla Limestone and 3, Blanche Point Formation (St. Vincent Basin). 4, Brown's Creek Clay and 5, Jan Juc Formation (Otway Basin). 6, Freestone Cove Sandstone (Bass Strait).

Species	Formations and age						Remarks
	Eocene				Oligocene	Miocene	
	1	2	3	4	5	6	
<i>Nucula tatei</i> Finlay			*	*			Known only from Pallinup Siltstone.
<i>Nuculana (Saccella) chapmani</i> Finlay			*	*			
<i>Arca pseudonavicularis</i> Tate			*	*			
<i>Barbatia (B.) limatella</i> Tate			*	*			
<i>Barbatia (Acar) gunsoni</i> sp. nov.							
<i>Arcopsis dissimilis</i> (Tate)			*	*			
<i>Limopsis chapmani</i> Singleton			*	*	*		
<i>Limopsis multiradiata</i> Tate ?							
<i>Septifer</i> sp. cf. <i>S. fenestratus</i> Tate							
<i>Vulsella laevigata</i> Tate		*					
<i>Plicatula</i> sp.							Known only from Pallinup Siltstone.
<i>Spondylus</i> sp. cf. <i>S. gaderopoides</i> McCoy							
<i>Dimya sigillata</i> Tate	*		*	*			Known only from Pallinup Siltstone.
<i>Limeu (Gemellinu ?) sp.</i>							
Limid. genus and species undetermined							Known only from Pallinup Siltstone.
<i>Epicodakia</i> sp.							
<i>Glans (Fasciculicardia) lutissima</i> (Tate)			*	*			Known only from Pallinup Siltstone.
<i>Sulaputium communis</i> (Tate)			*	*			
<i>Vepricardium (Hedocardium) monilectum</i> (Tate)?							Known only from Pallinup Siltstone.
<i>Glossus (Miocardopsis) sp.</i>							
<i>Dosina multilamellata</i> (Tate)			*	*	*	*	Known only from Pallinup Siltstone.
<i>Corbula (Caryocorbula) paxidata</i> Tate			*	*			
<i>Verticordia</i> sp.							Known only from Pallinup Siltstone.
Totals	1	1	11	11	2	1	

(1973). A Late Eocene age for the Plantagenet Group was recognized first by Glaessner (1953) from the presence of the nautiloid *Aturia clarkei* Teichert and has been confirmed by all subsequent studies, for example, those by Cockbain (1967), Quilty (1969) and Backhouse (1970) on foraminifers, by Cockbain (1968) on nautiloids and by Hos (1975) on plant microfossils.

From Walpole, we recognize 23 species of bivalves, of which at least 11 are known both from the Late Eocene Blanche Point Formation of the St Vincent Basin and from the Brown's Creek Clay of the Otway Basin; 7 of the bivalve species are known only from the Pallinup Siltstone. Gastropods number about 50 species, of which 27 are known from the South Australian-Victorian formations and others are closely related to species occurring there. In general, Walpole specimens tend to be a little smaller in size than corresponding forms at Brown's Creek. New species, mainly cerithiaceans and sponge-dwellers, total about 23; this is not unexpected in view of the geographic isolation of Walpole from the South Australian-Victorian localities.

The stratigraphic position of the Eocene fossils from the Adelaide (i.e., Kent Town) Bore described by Tate (1886, 1887) has been discussed by Lindsay (1969), Ludbrook (1973) and revised by Cooper (1977). Following the last-mentioned, we refer these occurrences to the lower part of the Blanche Point Formation. A general correlation is therefore indicated with the Blanche Point Formation, Tortachilla Limestone and Brown's Creek Clay (Table 1). These lie wholly or substantially within the Aldingan Stage of Ludbrook and Lindsay (1966) and planktonic foraminiferal zones P15, P16 and P17 (Ludbrook 1973).

Most of the bivalve genera from Walpole are cosmopolitan in distribution, with related or similar species occurring in the Eocene of New Zealand, Asia, Europe and America. *Fasciocardia*, *Hedecardium* and *Dosina* are genera common to Australia and New Zealand, which have their major representation in New Zealand. *Miocardiopsis* has been recorded previously from the Eocene of Europe but the genus and family (Glossidae), have not been reported hitherto from the Australasian Tertiary. Four other genera, *Acar*, *Plicatula*, *Epicodakia* and *Verticordia*, are also recorded for the first time from the Australian Eocene; species of all 4 genera are known from later Cainozoic faunas in southern Australia.

Systematic descriptions

Bivalvia

Family Nuculidae

Genus *Nucula* Lamarck 1799 (*Pronucula* Hedley 1902)

We follow Bergmans (1978) in placing *Pronucula* Hedley in synonymy with *Nucula* Lamarck.

Nucula tatei Finlay

(Fig. 2 A-D)

1924 *Nucula tatei* Finlay: p. 107 *nom nov* for *Nucula semistriata* Tate *non* Wood.

1961 *Pronucula tatei*; Ludbrook, p. 56, pl. 1 figs. 5, 6.

Type locality: Blanche Point, Aldinga Bay, South Australia (Ludbrook 1961); Blanche Point Formation (Cooper 1977).

Material: WAM 67.94, 69.104, 74.540, 78.4083. NMV P40631, P40651.

Remarks: This species is represented by 4 articulated pairs, all deformed, 6 left and 9 right valves. Anterior/posterior hinge tooth counts of three valves are 15:8, one has 14:8 and one has 12:7; radial micro-sculpture is present on the ventral areas of the larger specimens only. Length 6.2, height 5.4, inflation (one valve) 1.2 mm. Walpole specimens agree well with topotypes. A range of variation in shell proportions is shown in the figures. Uncommon at Walpole.

Stratigraphic range: Blanche Point Formation, Brown's Creek Clay and Pallinup Siltstone; Late Eocene.

Family Nuculanidae

Genus *Nuculana* Link 1807

Subgenus *Saccella* Woodring 1925

Nuculana (*Saccella*) *chapmani* Finlay

(Fig. 2 E, F)

1924 *Nuculana chapmani* Finlay: p. 107 *nom nov* for *Leda apiculata* Tate *non* Sowerby *nec* Reuss.

1961 *Nuculana* (*Saccella*) *chapmani*; Ludbrook p. 57, pl. 2 figs. 1, 2.
Type locality: Blanche Point, Aldinga Bay, South Australia; Blanche Point Formation (Cooper 1977).

Material: WAM 67.74, 69.103, 72.260, 74.541, 74.549, 78.4084. NMV P40636, P40653.

Remarks: Altogether 126 specimens (44 articulated pairs, 44 left and 38 right valves) represent this species from Walpole. The valves have rather weak transverse ribbing similar to the majority of specimens from Brown's Creek, rather than the well developed ribbing characteristic of most from the type locality; the chondrophore is deep and proportionately wide. Length 8.6, height 5.5, inflation (one valve) 2.0 mm. Though one of the more common species at Walpole (comprising 1 in 5 of all bivalves), only 3 specimens show evidence of gastropod predation. No specimen obtained from Brown's Creek shows a gastropod borehole.

Stratigraphic range: Blanche Point Formation, Brown's Creek Clay and Pallinup Siltstone; Late Eocene.

Family Arcidae

Genus *Arca* Linnaeus 1758

Subgenus *Arca* s. s.

Arca (*Arca*) *pseudonavicularis* Tate

(Fig. 2 G)

1886 *Arca pseudonavicularis* Tate: p. 139, pl. 11 fig. 8.

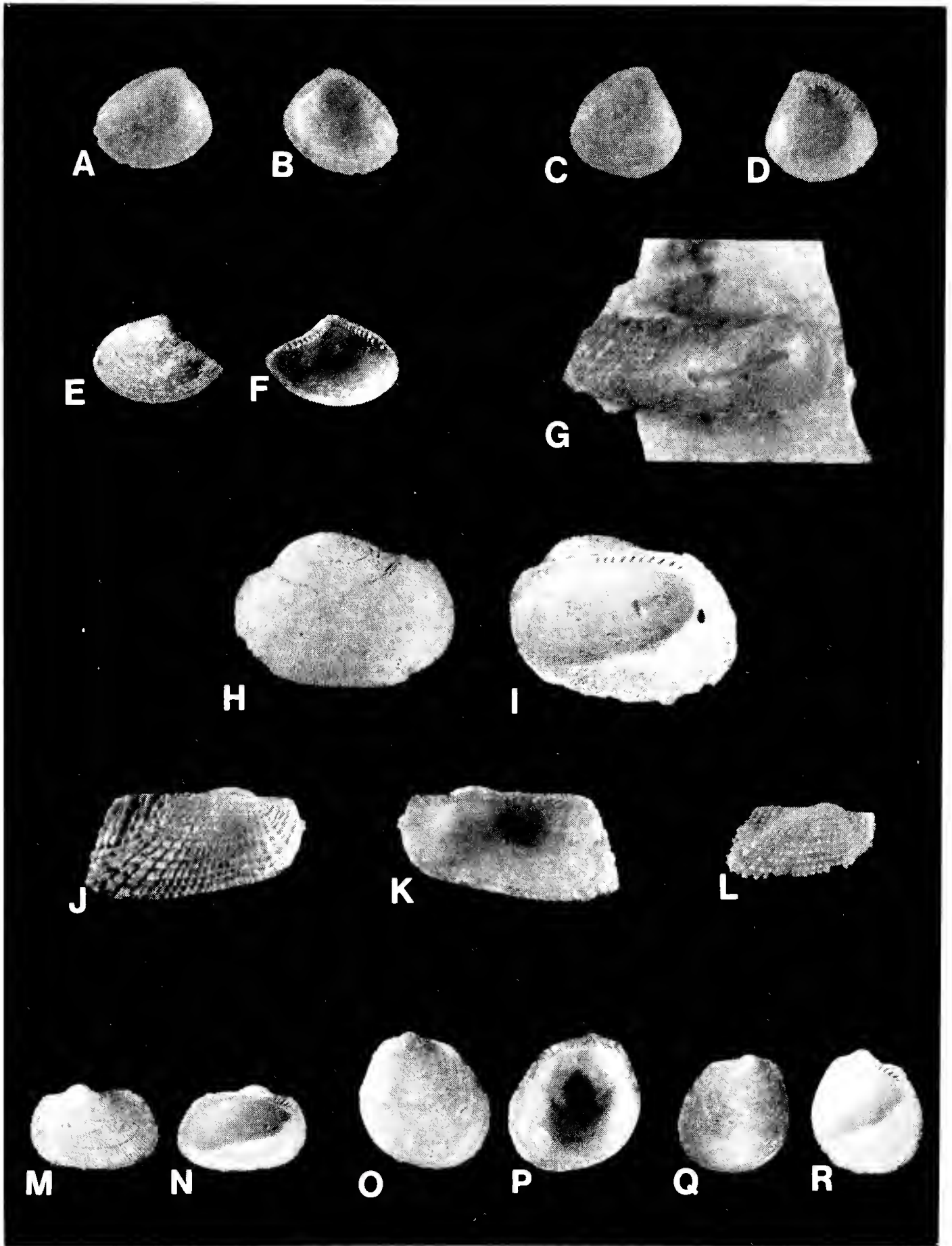
1965 *Arca pseudonavicularis*; Ludbrook p. 94-5, pl. 3 figs. 30-31.

Type locality: Adelaide (i.e. Kent Town) Bore, at 45.7-66.4 m (Ludbrook 1965). This lies within the lower part of the Blanche Point Formation as defined by Cooper (1977).

Material: WAM 67.87, 74.542, 78.4085, NMV P40648.

Remarks: The 4 available lots comprise a substantially complete right valve and some fragments. These show well-defined radial sculpture on the postero-dorsal area and a predominantly transverse sculpture elsewhere. Our figured specimen has the umbo located at about the anterior fifth. The species is uncommon at Walpole.

Stratigraphic range: Blanche Point Formation, Brown's Creek Clay and Pallinup Siltstone; Late Eocene.



Genus *Barbatia* Gray 1842

Subgenus *Barbatia* s. s.

Barbatia (Barbatia) limatella Tate

(Fig. 2 H, I)

1886 *Barbatia limatella* Tate: p. 141-142, pl. 10 fig. 2.

1965 *Barbatia (Barbatia) limatella*: Ludbrook p. 97, pl. 3 figs. 21-23.

Type locality: Adelaide (i.e. Kent Town) Bore at 45.7-66.4 m (Ludbrook 1965); Blanche Point Formation (Cooper 1977).

Material: WAM 67.46, 67.47, 72.262, 72.265, 74.538, 74.543, 78.4086. NMV P40637, P40644.

Remarks: The available specimens from Walpole comprise 1 deformed pair, 3 lefts, 2 right and 10 fragmentary valves; also 2 internal moulds in grey, silicified siltstone. Length 17.0, height 12.7, inflation (one valve) 6.0 mm. Walpole specimens generally differ from topotypes and those from Brown's Creek in that the sculpture is not as prominent. This may be an artifact of preservation or due to abrasion of the valves, rather than any true morphological variation. The figured specimen comes closest to those from South Australia and Victoria.

Stratigraphic range: Blanche Point Formation, Brown's Creek Clay and Pallinup Siltstone; Late Eocene.

Subgenus *Acar* Gray 1857

Barbatia (Acar) gunsoni sp. nov.

(Fig. 2 J-L)

Type Locality: Walpole, Western Australia. Sandy depression 26 km north from Walpole townsite along Thompson Highway; sieved from grey, silty sand overlying brown siltstone. Latitude 34°48'S Longitude 116°43'E. Pallinup Siltstone.

Material: Holotype WAM 78.4087a, a single right valve. Paratypes WAM 67.75a, 69.105a-b, 72.263, 74.544, 78.4087b-d, 78.4088a-b, NMV P40635, P40647, P56030.

Diagnosis: A small, compressed *Acar* with height equal to half the length; sculpture of fine, transverse lamellae (17 in a height of 5.3 mm); radials mostly subordinate, narrow, discontinuous and scaled in the median area, wider anteriorly; posterior area sculpture usually predominantly radial and beaded where crossed by the lamellae; marginal crenulations becoming obsolete anteriorly; anterior adductor scars subcircular.

Description: A small, rather compressed *Acar*, transversely elongate, trapezoidal and with a weak median sulcus. Anterior margin short, obliquely curved and passing into the slightly convex and sinuate ventral margin, which diverges posteriorly from the hinge margin; posterior margin straight, obliquely truncate, forming an obtuse angle with the hinge margin and an acute, rounded angle ventrally; hinge margin straight, about four fifths of the overall length. Posterior carination well defined; posterior area small, winged; umbones broad, flattened, situated at the anterior fourth; beaks incurved. Hinge slender, narrow medially, widening toward each end; teeth fine, evenly graded and oblique, very finely serrate; in the holotype, the anterior series has 8 teeth, in the posterior, 20. Ligamental area smooth, narrow, weakly recessed and tapering posteriorly. Anterior adductor scar subcircular, the posterior larger and transversely ellipsoidal; both located close to the hinge plate and raised slightly above

the inner surface of the valve. Margins, except for the hinge margin, narrowly rimmed and lightly crenulated within; crenulae tending to be obsolete antero-ventrally or below the beaks. Sculpture of the median area predominantly transverse with thin, close, imbricating lamellae (17 discernible in a height of 5.3 mm), fimbriated by narrow, discontinuous radial riblets, the number increasing with growth and bearing low, crowded transverse scales; on the posterior carination, both transverse and radial elements are accentuated. Anteriorly, the sculpture resembles that of the median area but the radials are wider and may be beaded. Sculpture of the posterior area is usually distinct from the median, being predominantly radial; costae are often beaded where crossed by the transverse lamellae; occasionally the posterior sculpture approximates to that of the median area.

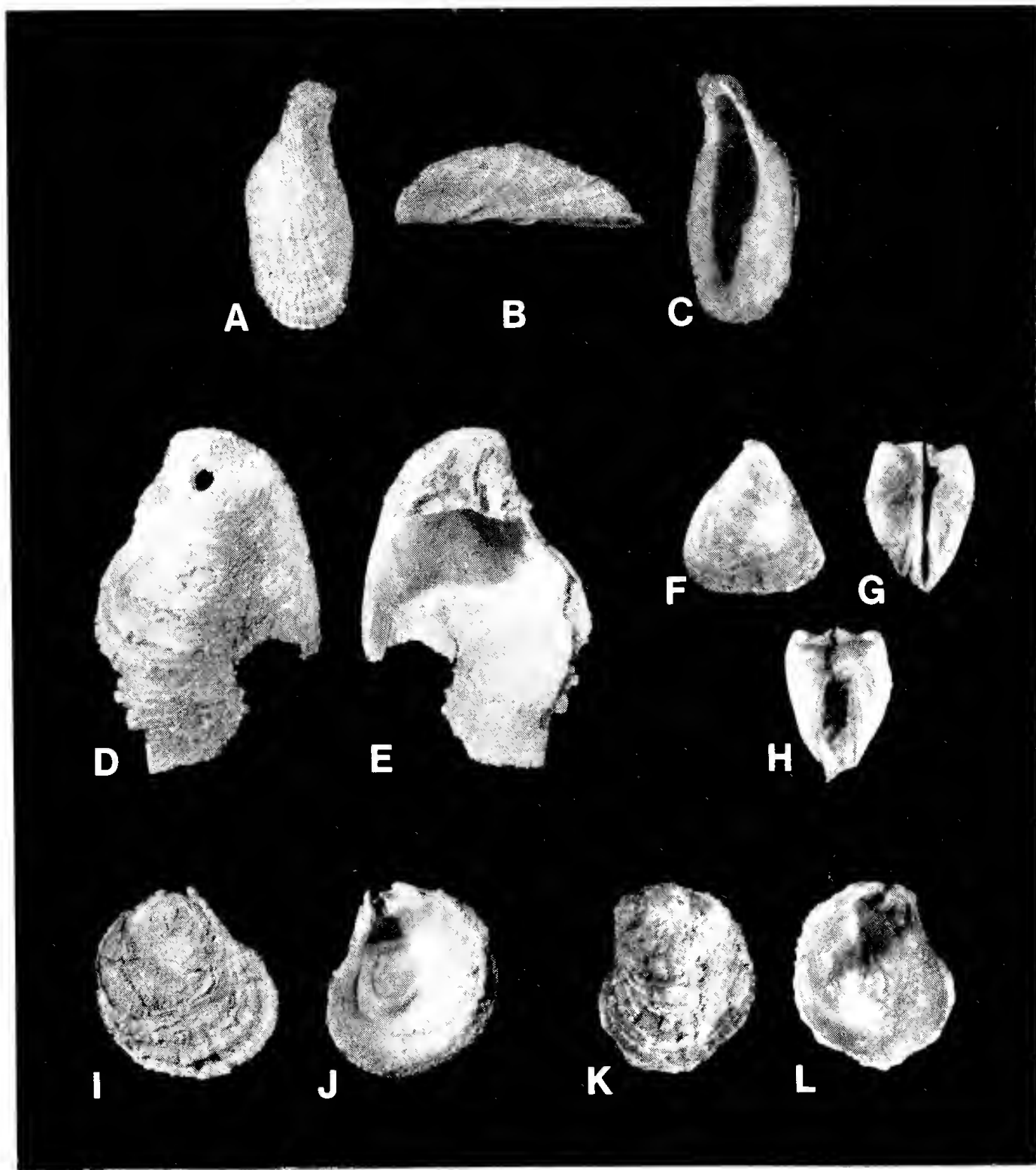
The holotype, a slightly worn right valve and the largest known specimen, has dimensions: maximum length 10.8, length of hinge margin 8.8, height 5.3, inflation (1 valve) 2.2 mm. It is complete but for a small portion of the antero-dorsal extremity; crenulation is obsolete along the entire anterior portion of the ventral margin. Paratype 78.4087b (Fig. 2 L) is an unworn right valve, on which the sculpture of the posterior area is predominantly transverse, with fine, imbricating lamellae and discontinuous radials, as on the median area.

Remarks: The available material comprises 7 right and 6 left valves plus a number of fragments. It appears to be rather uncommon at Walpole; 2 specimens show naticiform boreholes.

The new species most resembles *Barbatia (Acar) celleporacea* Tate, which occurs widely from the Early Miocene to Late Pliocene of south-eastern Australia (Ludbrook 1965). From the degree of similarity between the two, we suggest that *gunsoni* may be ancestral to Tate's species. The two may be distinguished by differences in overall proportions, size, sculpture, marginal crenulation and possibly also the shapes of the adductor scars. In *gunsoni*, the valves are shorter relative to the height, resulting in a less transversely elongate outline; Tate's species is by far the larger, with specimens as long as 27.5 mm known. The new species has a finer, more imbricate or lamellate sculpture, in which the transverse element tends to predominate; where radials are the more prominent, they carry strong beading, unlike the subnodulose sculpture of *celleporacea*. In both species, there is a tendency for crenulation of the ventral margin to become obsolete anteriorly or below the beaks; crenulation is generally weaker and given more to obsolescence in the present species, though this may be due in part to imperfect preservation and/or wear. The anterior adductor scar is near circular in *gunsoni* but more roundly sub-quadrate in *celleporacea*.

The present records from Walpole are the first reported occurrence of the subgenus *Acar* from the Australian Eocene and the oldest from the Australasian region. An internal cast of a small arcid (WAM 75.24), consistent with *B. (A.) gunsoni* has been collected from the Werrilup Formation (Nanarup Limestone Member) at the Nanarup lime quarry near Albany and may extend the stratigraphic range of the species a little lower.

Figure 2.— A, B—*Nucula tatei* Finlay. WAM 78.4083a. LV, x 3. C, D—*N. tatei*. WAM 78.4083b. LV, x 3. E, F—*Nuculana (Saccella) chapmani* (Finlay). WAM 74.549a. LV, x 3. G—*Arca psendonavicularis* Tate. WAM 78.4085. RV, x 2.8. H—*Barbatia (B.) limatella* Tate. WAM 72.262. LV, x 2. I—*B. (B.) limatella*. WAM 74.543a. RV, x 2. J, K—*Barbatia (Acar) gunsoni* sp. nov. Holotype WAM 78.4087a. RV, x 3. L—*B. (A.) gunsoni* sp. nov. Paratype WAM 78.4087b. RV, x 3. M, N—*Arcopsis (A.) dissimilis* (Tate). WAM 72.261a. LV, x 2. O, P—*Limopsis (L.) chapmani* Singleton. WAM 74.545b. LV, x 2. Q, R—*L. (L.) chapmani*. WAM 74.545a. RV, x 2.



Chapman and Crespin (1926, 1934) list from Albany an "*Arca* sp.", which they compare with *Barbatia celleporacea*. We have located this specimen (P42476) in the Jutson collection of the National Museum of Victoria and consider that it is not an arcid. It could possibly be a *Miocardiopsis*, a species of which is discussed below.

The new species is named after Mr Lionel Gunson of the Western Australian National Parks Authority, Walpole, who was responsible for bringing this deposit to our notice and who provided hospitality and assistance with field work on a number of occasions.

Stratigraphic range: Pallinup Siltstone, Werrilup Formation (Nanarup Limestone Member)?; Late Eocene.

Family Noetiidae

Genus *Arcopsis* von Koenen 1885

Subgenus *Arcopsis* s. s.

Arcopsis (*Arcopsis*) *dissimilis* (Tate)

(Fig. 2 M,N)

1886 *Barbatia dissimilis* Tate: p. 140, pl. 11 figs. 4, 5.

1965 *Arcopsis dissimilis*; Ludbrook, p. 95-6, pl. 5 figs. 26-30.

Type locality: Adelaide (i.e. Kent Town) Bore at 45.7-66.4 m (Ludbrook 1965); Blanche Point Formation (Cooper 1977).

Material: WAM 67.76, 69.106, 72.261, 74.547, 74.548. NMV P40634, P40654.

Remarks: This is a common species at Walpole, the recovery comprising 10 articulated pairs, 46 left and 53 right valves. Right valves show granose radial sculpture on the anterior and posterior dorsal areas only, elsewhere having close transverse ribs bearing low spines, which show a weak radial alignment. Some right valves are smooth medially. The left valve bears strong radial costation all over, crossed by fine transverse sculpture forming low scales upon the ribs. Length 10.2, height 6.5, inflation (one valve) 2.8 mm. The material bears 9 muriciform and 8 naticiform boreholes.

Stratigraphic range: Blanche Point Formation, Brown's Creek Clay and Pallinup Siltstone; Late Eocene.

Family Limopsidae

Genus *Limopsis* Sassi 1827

Subgenus *Limopsis* s. s.

Limopsis (*Limopsis*) *chapmani* Singleton

(Fig. 2 O-R)

1932 *Limopsis chapmani* Singleton: p. 296-9, pl. 24 figs. 12-14, pl. 25 fig. 16.

1965 *Limopsis chapmani*; Ludbrook, p. 83-4, pl. 1 figs. 1-9.

Type locality: Bird Rock Cliffs near Spring Creek, Torquay, Victoria; Jan Juc Formation.

Material: WAM 67.77, 69.107, 72.234, 72.255, 72.264, 74.535, 74.545, 74.546, 78.4090. NMV P40640, P40645.

Remarks: This is the most common bivalve at Walpole, the present recovery of 202 specimens comprising 7 articulated pairs, 101 left and 94 right valves. Shells appear to be somewhat smaller in size than the range of material figured by Ludbrook (1965) and though to a degree robust, could not be described as heavy, as noted by Singleton for the type. In Walpole specimens, sculpture is mainly and often wholly transverse; occasional specimens show weak radial threads variously distributed on the posterior, anterior and ventral areas. Length 12.0, height 13.2, inflation (one valve) 3.9 mm.

This is a highly variable species, with specimens ranging from small, highly convex valves with quadrate outline to large, shallow valves with rounded outline. Walpole specimens match the former, which is a common type in the upper part of the Brown's Creek Clay. There are 10 naticiform and 6 muriciform boreholes present in the material. A subspecies, *L. chapmani valida* Singleton, is present in the Victorian Early Miocene (Longfordian).

Stratigraphic range: Blanche Point Formation, Brown's Creek Clay, Pallinup Siltstone, Jan Juc Formation; Late Eocene to Oligocene.

Limopsis (*Limopsis*) *multiradiata* Tate?

Material: WAM 67.78.

Remarks: A single juvenile valve, similar to *multiradiata*, has been recovered from Walpole. It is distinguished from *L. (L.) chapmani* by a more symmetrical, evenly rounded outline; a fine radial sculpture covers the whole valve. Details of the ventral margin are missing. We defer positive identification of this specimen until a wider range of material is available. The type of *Limopsis multiradiata* was obtained from the Adelaide (i.e., Kent Town) Bore between 45.7 and 66.4 m and has been refigured by Ludbrook (1965). The species occurs in the Blanche Point Formation at Aldinga Bay and in the Brown's Creek Clay of the Otway Basin.

Family Mytilidae

Genus *Septifer* Récluz 1848

Subgenus *Septifer* s. s.

Septifer (*Septifer*) sp. cf. *S. (S.) fenestratus* Tate

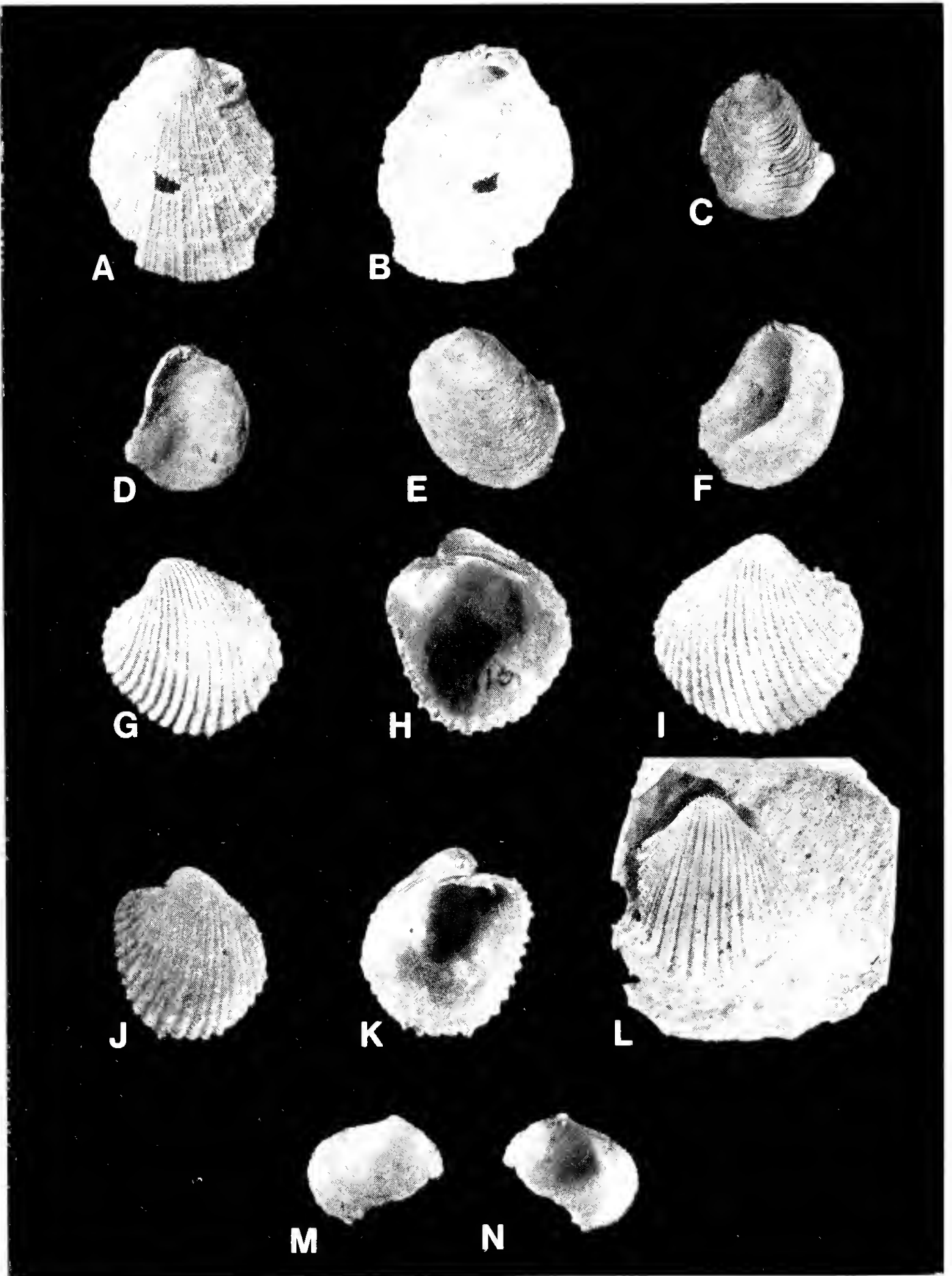
(Fig. 3 A-C)

Material: WAM 67.84, 69.109, 69.110, 74.551. NMV P40639, P40655.

Remarks: A species of *Septifer* s. s. from Walpole is represented by one substantially complete right valve and some fragments. It has a distinct, postero-dorsal marginal angulation of about 145°, a well defined antero-posterior ridge and a compressed, twisted umbo. The sculpture comprises bifurcate radial costae, relatively coarse on the median area and becoming more spaced and sharply defined dorsally near the umbo, where some fenestration develops from the additional presence of low transverse sculpture. Ventrally, the costae are numerous, fine and close; an elliptical area near the byssal gape bears transverse sculpture only. Growth pauses are indicated by the presence of low, transverse surface irregularities. Anterior adductor scar prominent, reniform and located terminally on a septum behind the umbo; posterior adductor scar poorly defined; pallial line close to the margin. The ligamental area is weakly excavate and about half the length of the dorsal margin; amphidetic teeth present behind the ligament. The margin is everted posteriorly and, where intact, shows internal crenulation. Length 16.0, height 10.5, inflation (one valve) 5.6 mm.

Of the two species of *Septifer* described from the Australian Tertiary, the Walpole material appears to be closer to the Balcombian *fenestratus* Tate, though the figure of the type of that species (Tate 1886, pl. 9 fig. 1) depicts a somewhat fine-ribbed and flattened shell. Other specimens of *fenestratus* from Muddy Creek in the collection of the National Museum of Victoria are more similar to the Walpole material. *S. (S.) subfenestratus* Basedow, described from a "pseudomorphous cast in glauconite" (Basedow 1904), possibly from the Blanche Point Formation, appears to differ from the Walpole shell in the absence of a distinct marginal angulation, the proportions of the umbo and umbo-ventral ridge and in details of the sculpture. The range of variation in *subfenestratus* being unknown, it is possible that the differences between it and the present material are due to ontogenic and/or intra-specific variation but this cannot be ascertained without further material from both South and Western Australia. One fragment in the present material has a muriciform borehole.

Figure 3. A, B, C—*Septifer* sp. cf. *S. fenestratus* Tate. WAM 69.109. RV, x 2. D, E—*Vulsella laevigata* Tate. WAM 72.266. RV, x 2. F, G, H—*V. laevigata*. WAM 78.4091a. Pair showing RV, antero-dorsal and postero-dorsal aspects, x 3. I, J—*Plicatula* sp. WAM 67.79b. LV, x 2.3. K, L—*Plicatula* sp. WAM 67.79a. RV, x 2 (77.79a, b are a pair).



Family Malleidae
Genus *Vulsella* Roeding 1798
Vulsella laevigata Tate
(Fig. 3 D-H)

1886 *Vulsella laevigata* Tate: p. 122, pl. 3 figs. 3a-b.

Type locality: Glauconitic limestone at the base of Witton Bluff, South Australia; Tortachilla Limestone.

Material: WAM 72.266, 74.536, 74.550, 78.4091. NMV P40641, P40650.

Remarks: Specimens from Walpole comprise a left and right valves, 6 small articulated pairs and some fragments. The umbos are opisthogyrate, prominent, acute and are separated by a deep ligamental area with a prominent, triangular, median pit. Length 5.5, height (estimated) 10.0, inflation (two valves) 3.5 mm. The Walpole material compares well with a topotype in the collection of the NMV. The species is uncommon at Walpole. One shell (fig. 3D) features a gastropod borehole with a bevelled margin, apparently naticiform; this is unexpected because modern *Vulsella* inhabit the interiors of sponges and other epifaunal situations, whereas the Naticidae are infaunal predators.

Stratigraphic range: Tortachilla Limestone, Pallinup Siltstone; Late Eocene.

Family Plicatulidae
Genus *Plicatula* Lamarck 1801
Subgenus *Plicatula* s. s.
Plicatula (Plicatula) sp.
(Fig. 3 I-L)

Material: WAM 67.79, 67.93, 69.108, 69.112, 69.113, 69.117, 72.267, 72.268, 74.537, 74.539, 74.552, 78.4092. NMV P40638, P52337.

Remarks: A small *Plicatula*, s. s., is not uncommon in the Walpole material, being represented by 3 articulated pairs, 36 left, 5 right valves and fragments. The shell is irregularly folded, compressed, oval and a little higher than long. The valves are thin, the right more convex and with a relatively large attachment area near the umbo; left valve more or less flat when juvenile, becoming a little concave or convex with growth. Sculpture of both valves transversely lamellose with hollow, raised, incurved scales and from fifteen to twenty irregular, often bifurcate, radial costae, weakly to moderately developed; costae are absent from the attachment area and from a corresponding part of the left valve. Adductor scars oval, centred in the postero-dorsal quadrant. Crurae thick, erect, with points directed upward somewhat as in *Spondylus*; weakly serrated. Cardinal area present on the right valve, absent on the left. Length 17.4, height 18.7, inflation (two valves) 8.5 mm.

The Walpole specimens differ from *P. ramulosa* Tate from the Lower Miocene Freestone Cove Sandstone of Table Cape (Tate 1898) by the relatively thin valves and finer, more numerous costae. The three nominal species of *Plicatula* erected by Chapman (1922) from the Miocene Muddy Creek Marl ("Lower Beds") of the Otway Basin seem more probably to represent a single variable species, close to and possibly conspecific with *ramulosa*. All of these Miocene forms have fewer more widely spaced costae than the Walpole material; their

relationships require clarification and until this is done we defer further consideration of the taxonomic status of the Walpole specimens.

The preponderance of the unattached left valves (36 to 5 rights) in the Walpole material is noteworthy. It seems that the right valves have tended to remain attached to substrates and that there has been some post-mortem transportation of the lefts.

There are 11 muriciform boreholes present on our material, a predation rate of 1:4. Ten of these boreholes occur on the upper, left valve; the other is on a right (WAM 72.267a), being positioned near the raised anterior margin and well clear of the area of attachment.

This appears to be the first record of the genus from the Eocene of Australia. A Late Cretaceous plicatulid from the Gingen Chalk of the Perth Basin, attributed to *Plicatula* by Feldtmann (1963), appears to be a species of the genus *Atreta* Etallon and not related to the Walpole material.

We draw attention to the fact that the valve orientations for *Plicatula (Plicatula) marginata* Say in the Treatise on Invertebrate Paleontology N (1), p. N377-8, fig. C98 1 a-e are recorded incorrectly; a, b and e are right valves, c and d are lefts.

Family Spondylidae
Genus *Spondylus* Linnaeus 1758
Spondylus sp. cf. *S. gaderopoides* McCoy
(Fig. 4 A,B)

Material: WAM 67.83, 72.269. NMV P40642, P52338.

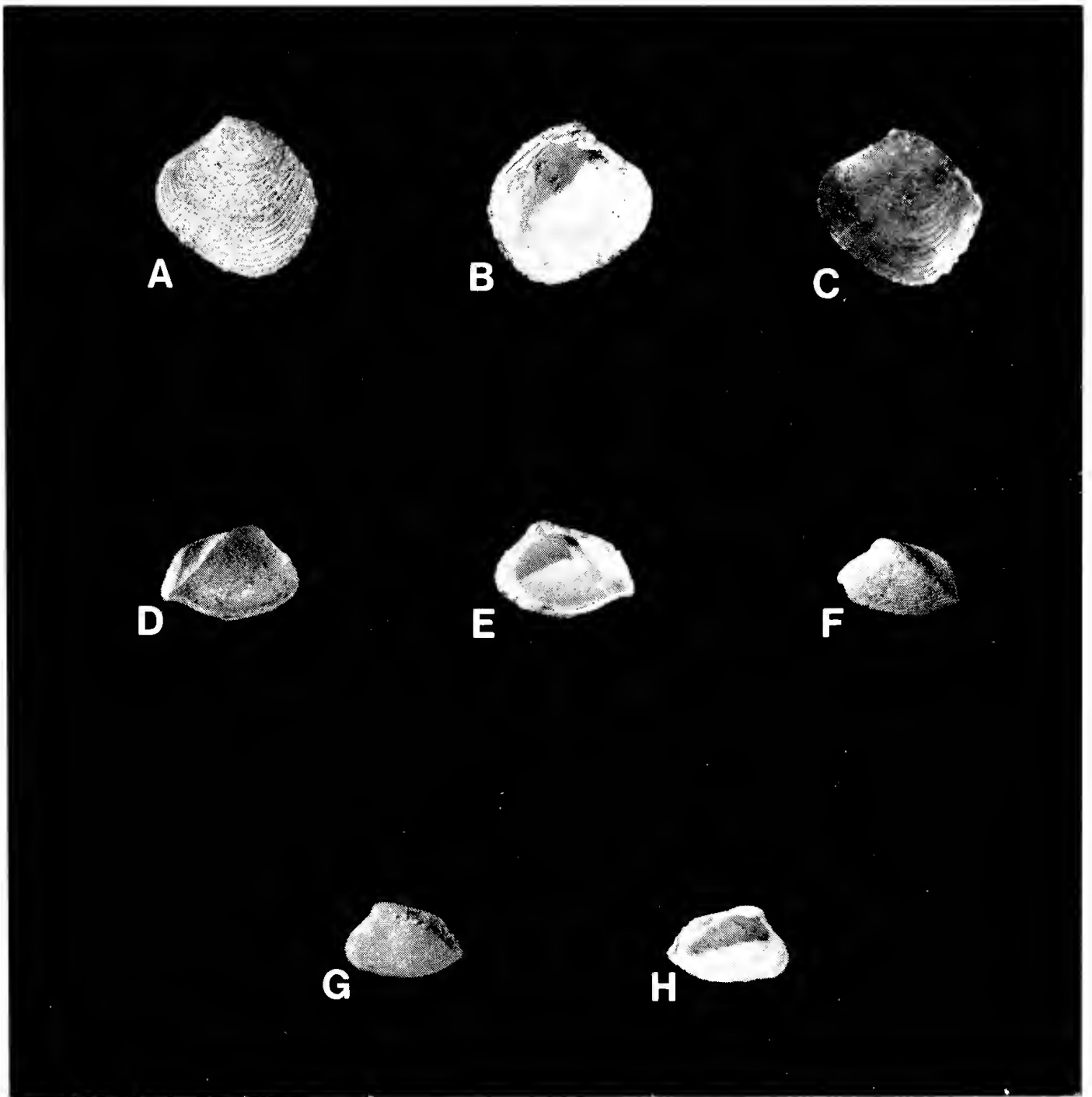
Remarks: One complete and 5 incomplete left valves, 4 of which are mere fragments, represent a species of *Spondylus* close to *S. gaderopoides* McCoy at Walpole. The figured specimen is small, thin, moderately inflated, oblique and prosogyrate; costae are numerous, fine, of 3 orders, the most prominent numbering about 12 and bearing low, spinose projections; the intercostal spaces bear weak, transverse growth lamellae. The auricles are unequal, the posterior larger. Crurae are well spaced within a rather short dorsal margin; ventral margin, where retained, weakly crenulated. Adductor scar located in a posterior-central position; poorly preserved. Length 13.1 (estimated), height 16.2, inflation (one valve) 3.5 mm.

Comparison of the limited Walpole material with a range of mature specimens of *S. gaderopoides* from the type locality shows that the Walpole shells lie within their range of variation. However as all of the present material is immature, we defer positive identification until a better range of specimens, including right valves, is available.

S. gaderopoides was described (McCoy 1876, 1877) from the Oligocene Jan Juc Formation of Bird Rock Bluff, Torquay and subsequently recorded from several Eocene sources in southern Australia by Tate (1886, 1899) and Lowry (1970). The latter, while confirming Tate's record of the species from the Eocene Wilson Bluff Limestone, reported further occurrences from the Lower Miocene Abrakurrie Limestone and Colville Sandstone of the Eucla Basin.

One specimen in the Walpole material bears a muriciform borehole.

Figure 4.—A, B—*Spondylus* sp. cf. *S. gaderopoides* McCoy. WAM 72.269. LV, x 2. C, D—*Dimya sigillata* Tate. WAM 74.553a. LV, x 3. E, F—*D. sigillata*. WAM 67.80a. LV, x 3. G—*Glans (Fasciculicardia) latissima* (Tate). WAM 67.85a. LV, x 2. H—*G. (F.) latissima*. WAM 69.116a. RV, x 2. I—*G. (F.) latissima*. WAM 74.554. RV, x 2.2. J, K—*G. (F.) latissima*. WAM 72.271a. LV, x 2. L—*Cardium arcaeformis* Chapman and Crespin. Latex cast of holotype, WAM 6048. LV, x 2. M, N—*Epicodakia* sp. WAM 78.4096b. LV, x 3.



Family Dimyidae
Genus *Dimya* Rouault 1850

Dimya sigillata Tate
(Fig. 4 C-F)

- 1886 *Dimya sigillata* Tate: p. 100 l. pl. 8 figs. 8a b.
1895 *Dimyodon sigillata*; Bittner, p. 218.
1970 *Dimyodon sigillata*; Ludbrook in Lowry, fig. 21H.
1973 *Dimya sigillata*; Ludbrook, pl. 24 figs. 14 5.

Type locality: Localities cited by Tate (1886) are "Turritella clays and glauconite limestones, Aldinga; glauconite sands, Adelaide bore; chalk rock, Bunda Cliffs of the Great Bight". The first two records are from the Blanche Point Formation; the last, corresponding to the Wilson Bluff Limestone, is confirmed by Ludbrook in Lowry (1970).

Material: WAM 67.80, 74.553. NMV P40633, P40646.

Remarks: Six complete specimens, 1 fragmentary left and 3 fragmentary right valves represent this species in the Walpole material. One of the right valves shows weak internal ribbing but there is no trace of this on the interiors of any of the lefts. External radial sculpture is present only on the right valves; lefts are finely transversely lamellose with no trace of radial costae. Length 7.0, height 8.7, inflation (one valve) 2.7 mm.

Specimens from Brown's Creek in the collection of the NMV are small and exhibit only very weak radial sculpture; they more resemble Walpole specimens than those from Aldinga. We ascribe no taxonomic significance to these differences. The specimen from Albany listed by Chapman and Crespín (1934) as *Dimya*

dissimilis (Tate) [sic] has been located in the NMV collection registered number P42467. It is a small, poorly preserved external mould, apparently of a left valve, with a suggestion of radial sculpture but is not sufficiently well-preserved for certain, specific identification. The stratigraphic range of positively identified *D. dissimilis* is Janjukian to Bairnsdalian and we consider earlier records attributed to that species to be doubtful.

With its weak cardinal dentition and bilobed posterior adductor scar, *sigillata* seems better located in *Dimya* than in *Dimyodon*, as listed by Darragh (1970) and Ludbrook in Lowry (1970). Three specimens in the present material have been pierced by muriciform boreholes. A recent study of the Dimyidae is by Yonge (1978).

Stratigraphic range: Blanche Point Formation, Brown's Creek Clay, Wilson Bluff Limestone, Pallinup Siltstone; Late Eocene.

Family Limidae

Genus *Limea* Bronn 1831

Subgenus *Gemellima* Iredale 1929

Limea (*Gemellima*)? sp.

Material: WAM 69.111.

Remarks: A small, poorly preserved and slightly deformed valve, probably a left, represents the genus and possibly the subgenus in the Walpole material. The presumed anterior side is a little more widely produced than the posterior. The umbo is prominent, tumid and prosogyrate, rising well above the dorsal margin; the beak is approximately median. Auricles are both small, the presumed anterior one the larger. Viewed hinge-down, the valve seems to have been deformed by compression across a NE—SW axis, one result of which may have been to deflect the umbo a little to the left (?anteriorly). There are about 22 prominent, raised radial costae, weakly scaled and equal in width to the interspaces, which are packed with fine, close, transverse costellae. The primary sculpture is continuous to the (presumed) anterior margin but details are not discernible on the posterior side. The ventral margin is strongly crenulated; details of the interior and dorsal margin are obscured by adherent silica. Length (antero-postero diameter) 3.4, height (umbo-ventral diameter) 5.5, inflation (one valve) 2.1 mm.

The affinities of this specimen are uncertain but appear to be tentatively with *Gemellima* Iredale, of which the type and only described species is *Limea* (*Gemellima*) *austrina* Tate, 1887. Its stratigraphic range is given as Early Pliocene to Holocene by Buona-iuto (1977). The Walpole specimen is relatively higher than Tate's species and may prove to be somewhat prosogyrate in the undeformed state. More positive identification is deferred until better specimens are available.

Stratigraphic range: Pallinup Siltstone; Late Eocene.

Limid, genus and species undetermined

Material: WAM 67.44.

Remarks: A piece of grey spongolite from Walpole shows on a weathered face a left valve of a species of Limidae. It is ovate, slightly oblique and bears about

60 evenly distributed, fine radial costae, equal in width to the interspaces and bearing traces of fine scales. The posterior auricle is the larger. Interior not visible. Length 15.0, height 20.0, inflation (one valve) 3.0 mm. Of the limid species described by Tate (1886, 1899) this appears to be closest to "*Lima*" *polynema*, but differs in the fewer costae (60 against 90). It may be a *Limea* or a *Limaria*, but this cannot be established without the internal characters. Rare at Walpole.

Family Lucinidae

Genus *Epicodakia* Iredale 1930

Epicodakia sp.

(Fig. 4 M, N)

Material: WAM 72.272, 78.4096. NMV P56029.

Remarks: A small lucinid, apparently an *Epicodakia*, is represented in the material from Walpole by 3 articulated pairs and a worn, fragmentary left valve. In most features (proportions, size, sculpture, hinge detail and pallial configuration), the fossils are broadly comparable to *Epicodakia* *consettiana* Iredale (= *Lucina minima* Tenison Woods), the type species of *Epicodakia*. Radial sculpture appears to be a little weaker on the fossil specimens and is most evident on the anterior and posterior extremities. Hinge details are available only for the left valve; 4b is thin, oblique; 2 much heavier, triangular but imperfectly preserved; AII well developed, stronger and more distant from the cardinals than PII. The anterior adductor scar is relatively long in the fossil species. Formal description is deferred until more and better preserved material, including the right valve, is obtained.

Tate (1887) described two lucinids, *Lucina araneosa* and *L. despectans* from the Middle Miocene of the Otway Basin, which Darragh (1970) refers to *Epicodakia*. Of these, the present species is closer to *E. despectans* but has finer and stronger radial and transverse sculpture and is not as strongly excavate in front of the umbo. The Walpole record is the first for the genus from the Eocene.

Stratigraphic range: Pallinup Siltstone; Late Eocene.

Family Carditidae

Genus *Glans* Mergerle 1811

Subgenus *Fasciculicardia* Maxwell 1969

Glans (*Fasciculicardia*) *latissima* (Tate)

(Fig. 4 G—L)

1886 *Cardita latissima* Tate: p. 153, pl. 2 fig. 5.

1927 *Venericardia latissima*; Chapman and Singleton, p. 118-9, pl. 11 figs. 22-3.

1934 *Cardium arcaeiformis* Chapman and Crespin: p. 121, pl. 11 figs. 25-7.

1973 *Glans latissima*; Ludbrook, p. 247, pl. 24 figs. 11-12.

Type locality: Adelaide (i.e., Kent Town) Bore, South Australia (Tate 1886, Ludbrook 1973); Blanche Point Formation.

Material: WAM 67.29, 67.30, 67.31, 67.85, 69.116, 72.235, 72.271, 74.554, 74.555, 78.4093. NMV P40643, P40656.

Remarks: This is one of the more common species at Walpole, being represented by 12 articulated pairs, 32 right and 22 left valves. Specimens generally compare well with Tate's description and figure but there is some

Figure 5.—A, B—*Salapatium communis* (Tate). WAM 69.115. LV, x 2. C—*S. communis*. WAM 78.4094. LV, x 3. D, E—*Corbula* (*Caryo-corbula*) *pixidata* Tate. WAM 74.558a. RV, x 2. F—C. (*C.*) *pixidata*. WAM 74.558c. LV, x 2. G, H—C. (*C.*) *pixidata*. WAM 74.558b. LV, x 2.

noteworthy variation. Most are obliquely subquadrate and higher than long but an occasional one has a submedian umbo on a shell about as wide as high (see Fig. 4 I). A proportion of specimens is clearly deformed, probably due to compaction, and possibly some of the "variation" noted above may be so derived. In the majority of specimens, the radial costae (as in Tate's type) are narrower than the interspaces and bear spaced, erect scales but others have wider costae with closely packed transverse scales. These differences recall those noted in other Tertiary carditid species and attributed by Heaslip (1969) to sexual dimorphism. Rib counts in the present material range from 25–30, with a mean of 22 valves at 26·1. Length 14·6, height 14·1, inflation (one valve) 6·4 mm.

We have examined the type of *Cardium arcaeorformis* Chapman and Crespin (WAM 6048, Fig. 4 L), a substantially complete external mould in grey spongolite from Albany, and consider it to be conspecific with *G. (F.) latissima*. It represents an obliquely subquadrate right valve of a form common at Walpole; the posterior side is somewhat flattened and compressed, possibly as a result of sediment compaction. Impressions of 25 radial costae are retained, a number which, in the original may have been exceeded slightly. Only vestiges of the lamellar scales remain as impressions, being more apparent at the anterior and posterior extremities. Such reduced sculpture is a feature of some Walpole specimens but whether this is due to mechanical erosion of the original carbonate shell, or to some imperfection of the silica-replacement process, is not clear.

The material contains 1 naticiform and 5 muriciform gastropod boreholes, suggesting that the species may have been epifaunal and associated with fine substrates. It is common and widespread throughout the Pallinup Siltstone.

Stratigraphic range: Blanche Point Formation, Brown's Creek Clay, Pallinup Siltstone; Late Eocene.

Family Crassatellidae

Genus *Salaputium* Iredale 1924

Salaputium communis (Tate)

(Fig. 5 A–C)

1896 *Crassatella communis* Tate in Tate and Dennant: p. 129 *nom. nov.* for *Crassatella astarifformis* Tate 1886 (*non* Nyst 1847)

1930 *Salaputium aldingensis* Finlay: p. 38 *nom. nov.* for *Crassatella corrugata* Tate 1886 (*non* Adams and Reeve 1850).

Type locality: Not precisely defined. Tate's localities were "Aldinga and Adelaide bore; R. Murray Cliffs; Muddy Creek and Schnapper Point". More than 1 species is likely to be covered by these records of Tate and we consider that the latter 3 (Miocene) localities should be disallowed for *S. communis*. The type locality for Tate's species *S. corrugata* is "Clays with *Turritella aldingae* at Blanche Point, Aldinga Bay".

Material: WAM 67.92, 69.115, 74.556, 78.4094. NMV P40632, P40649.

Remarks: Three articulated pairs, 3 lefts and a right valve represent this species from Walpole. Compared with material from South Australian and Victorian localities, they are more finely ribbed, having about 24 transverse costae in height of 6·5 mm. The minute radial striae present in Tate's material have not been observed in Walpole shells. Length 6·9, height 6·5, inflation (both valves) 3·7 mm.

In our view, this is a somewhat variable species, particularly in the sculptural features. We have examined Tate's types of *communis*, which show little

variation in this respect, and have compared them with a wider and more representative range of material from the Late Eocene of South Australia and Victoria in the NMV collection. *S. aldingensis* is based on a specimen having relatively few coarse ribs and all grades can be seen between this and the typically finer more numerous ribbing of *communis*. Transverse sculpture on South Australian specimens in the NMV collection varies from 9 coarse (*aldingensis* form) to about 13 fine ribs (*communis* form). Victorian specimens, though more variable than those from South Australia, tend also to be coarser in sculpture than the Walpole shells but at present, we ascribe no taxonomic significance to these differences. Study of a wider range of material, both from south-western and south-eastern Australia should serve to clarify this question.

Other species of *Salaputium* (*lamellata* and *abbreviata* both of Tate and *corioensis* Chapple) occur in the Eocene, Oligocene and Miocene of South Australia and Victoria (Darragh 1970). A generic revision of the entire group may now be warranted.

Stratigraphic range: Blanche Point Formation, Brown's Creek Clay, Pallinup Siltstone; Late Eocene.

Family Cardiidae

Genus *Vepricardium* Iredale 1929

Subgenus *Hedecardium* Marwick 1944

Vepricardium (*Hedecardium*) *monilectum* (Tate)?

1887 *Cardium monilectum* Tate: p. 151, pl. 14 figs. 3a–b.

Type locality: Adelaide (i.e., Kent Town) Bore, South Australia; Blanche Point Formation.

Material: WAM 67.27.

Remarks: A natural mould of a fragment of a valve agrees well with Tate's original description and figure. Positive identification is deferred until further material becomes available. *V. monilectum* occurs in the Blanche Point Formation of the St. Vincent Basin.

Family Glossidae

Genus *Glossus* Poli 1795

Subgenus *Miocardiopsis* Glibert 1936

Glossus (*Miocardiopsis*) sp.

Material: WAM 67.89, 74.559, 78.4095. NMV P52339.

Remarks: A *Glossus*, probably of the subgenus *Miocardiopsis*, is represented in the Walpole material by 2 deformed pairs and 2 fragmentary left valves. It appears to be an undescribed species and the first record for the family from the Australian Eocene; previous records of the subgenus are confined to the Eocene of Europe, according to Keen and Casey (1969). Formal description is deferred until a range of better material is available.

From the specimens to hand, the shell is small, compressed, inequilateral and sub-quadrate in outline. The umbo is prominent, prosogyrate but not twisted and located at about the anterior third. Dorsal margin arched, lower on the anterior side; anterior margin short, rounded, merging into a gently rounded rather long ventral margin; posterior margin obliquely truncate, meeting the ventral edge at an angle of about 90°. Postero-ventral ridge well-defined (apparently accentuated by deformation in the only entire specimen) and with a corresponding internal groove. Lunule apparently absent; escutcheon well defined, bordered by a distinct angulation and lightly transversely striate.

The posterior slope bears fine, close transverse sculpture; median sculpture similar but much finer and crossed by very faint, discontinuous radial striae. Ligamental groove marginal, nymph strong, located well behind the umbo. Left valve with 2 widely divergent cardinals behind the umbo and a distant posterior lateral. Aductor and pallial attachment scars not visible; anterior features generally obscure. Length 13.6, height 10.9, inflation (one valve) 3.5 mm.

The specimen listed by Chapman and Crespin (1926, 1934) as "*Arca* sp", from Albany has been located in the NMV collection (P42476). It is not an arcid but could possibly represent a glossid such as the present species.

Stratigraphic range: Pallinup Siltstone; Late Eocene.

Family Veneridae

Genus *Dosina* Gray 1835

Subgenus *Dosina* s. s.

Dosina (Dosina) multilamellata (Tate)

1887 *Chione multilamellata* Tate: p. 154-5, pl. 15 figs. 6a-b.

1934 *Callanaitis Cainozoicus* (Tate) (sic); Chapman and Crespin, p. 126.

1973 *Dosina (Dosina) multitaeniata* (Tate); Ludbrook, pl. 24 figs. 18, 19.

Type locality: Adelaide (i.e., Kent Town) Bore, South Australia; Blanche Point Formation.

Material: WAM 67.90, 78.4097.

Remarks: Four small articulated pairs and some fragments represent this species from Walpole. They have been compared with specimens from Blanche Point and Brown's Creek in the collection of the National Museum of Victoria and found to be very close.

We have located in the WAM collection specimen 5435 from "Hassell's Road, 10 miles from Cheyne Beach", which appears to be one of those listed by Chapman and Crespin as "*Callanaitis Cainozoicus* (Tate)", evidently an error for "*Callanaitis Cainozoicus* (Tenison Woods), a Table Cape species. The specimen, a piece of pale brown siltstone, bears an external impression consistent with the present species.

The name *Chione multitaeniata* was erected by Tate in Tate and Dennant (1896 p. 129, footnote) as a replacement for "*C. multilamellata* non Br.". An intensive search through the literature has failed to find any name, which could be interpreted as a homonym. In view of the fact that the author and date of the name were not cited, *C. multitaeniata* is regarded as an invalid name.

The material shows 1 naticiform and 1 muriciform borehole. Uncommon at Walpole.

Stratigraphic range: Blanche Point Formation, Brown's Creek Clay, Pallinup Siltstone, Jan Juc Formation, Freestone Cove Sandstone; Late Eocene to Early Miocene.

Family Corbulidae

Genus *Corbula* Bruguière 1797

Subgenus *Caryocorbula* Gardner 1926

Corbula (Caryocorbula) pixidata Tate

(Fig. 5 D-H)

1887 *Corbula pixidata* Tate: p. 177, pl. 17 figs. 12a-b.

1973 *Corbula (Caryocorbula) pixidata*; Ludbrook, p. 247

Type locality: Blanche Point, Aldinga, South Australia;

Material: WAM 67.91, 72.273, 74.558, 78.4098. NMV P40630, P40652.

Remarks: A series of 9 articulated pairs, 1 right and 7 left valves from Walpole agrees closely with the original description and topotypes of *pixidata*. Both valves are posteriorly carinate and there is little or no pallial sinus. Length 9.5, height 6.3, inflation (one valve) 2.4 mm. One valve in the collection has a muriciform borehole. The species is uncommon at Walpole.

Stratigraphic range: Blanche Point Formation, Brown's Creek Clay, Pallinup Siltstone; Late Eocene.

Family Verticordiidae

Genus *Verticordia* Sowerby 1844

Subgenus *Verticordia* s. s.

Verticordia (Verticordia) sp.

Material: WAM 67.86.

Remarks: A minute single right valve represents the genus in the present material. It has 16 costae, a little narrower than the interspaces, and bearing low spines on the crests only. Lunule small; hinge poorly preserved. Of the species of *Verticordia* described from the Australian Tertiary by Tate (1887) and Pritchard (1901), the Walpole specimen differs in shape and number of costae. It appears to be undescribed but must so remain until further specimens are collected. Length 2.6, height 2.6 mm. This appears to be the first record for the genus from the Eocene of Australia.

Stratigraphic range: Pallinup Siltstone; Late Eocene.

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A phenological investigation of various invertebrates in forest and woodland areas in the south-west of Western Australia

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Abstract

Invertebrates were collected in pitfall traps at 3 localities in the south-west of Western Australia: namely Perth (Reabold Hill), Dwellingup and Manjimup. The pitfall traps (diameter 1.8 cm) were spaced 3 m apart in a 6 x 6 grid at each locality. Between March 1976 and February 1977 collections were made once a month from traps exposed for a week. The groups reported on are: Araneida, Acarina, Scorpionida, Pseudoscorpionida, Phalangida, Diplopoda, Chilopoda, Isopoda, Annelida and Gastropoda.

The differences in species richness and abundance between sites are discussed in terms of soil type, fire history and climatic pattern. Species richness of decomposers and predators is lowest at the most recently burnt site (Manjimup) suggesting that there is a period of decreased species richness of at least 3 years following fire. Decomposer abundance, and presumably rate of decomposition, is higher in the wetter months at Perth and Dwellingup although abundance is more closely associated with the warmer months at Manjimup. Predators are active throughout the year although, at Dwellingup and Manjimup, there is a decrease in activity associated with cool moist conditions.

Introduction

Compared to the numerous phenological (seasonal-succession) studies on plant communities (see Lieth 1974), those on invertebrate communities are few. Although such studies have been performed on individual invertebrate species, e.g. cocoa capsids (Gibbs et al. 1968) and on taxonomic groups (e.g. tropical butterflies; Owen and Chanter 1972), the works of Gillon and Gillon (1967) and Gibbs and Leston (1970) on West African savanna and rainforests respectively, are two of the few phenological studies on invertebrate communities.

The results of studies on the continuing biological interactions of ground-dwelling invertebrates of forests and woodlands may ultimately be of value for several reasons; they may (1) lead to a more satisfactory understanding of seasonal influences than solely by using meteorological variables (as pointed out by Gibbs and Leston 1970), (2) reveal the relative importance of various faunal groups in biological systems such as litter decomposition (Springett 1976a, b), and (3) provide a framework of ecological information on which to base forest-management decisions such as suitable seeding or burning times.

During the current studies in the south-west of Western Australia, a great diversity of forms has been encountered. The present paper is confined to the phenology of the arachnids and other non-hexapod invertebrates that were collected from March 1976 to February 1977 inclusive. An attempt is made to define

the seasonal succession of the various species at 3 sites having differing climatic regimes. The data on insects will be presented in subsequent papers.

The specimens were collected as a result of a pitfall trapping programme that had been devised to investigate the ants in jarrah forests. The pitfall traps primarily sample the epigaic fauna, the soil fauna not being efficiently sampled by this method. Southwood (1966) has reviewed the literature and assessed the value of sampling by pitfall trapping and concluded that although unsuitable for obtaining estimates of abundance, this technique may be used to study daily and seasonal activity and also the dispersion of a species in a particular type of vegetation. Greenslade and Greenslade (1971) investigated the performance of pitfall traps containing an alcohol/glycerol preservative and found that whereas the traps did not attract or repel ants, they selectively trapped certain other invertebrates. In the present paper, owing to the likelihood of selective trapping and because of the low numbers of some species collected, the data are considered to be of more value for discussing the seasonal trends than the relative abundance at each site. The overall diversity of invertebrates at each site is also considered.

The study sites

Features of the study sites are summarized in Table 1. The sites are located in a woodland at Perth (Reabold Hill), and in forests at Dwellingup and Manjimup. The trees in these areas are mainly jarrah (*Eucalyptus*

Table 1

Comparison of sites.

Site	Perth (Reabold Hill)	Dwellingup (Curara block)	Manjimup (Dingup block)
Latitude and longitude	31°57'S, 115°47'E	32°52'S, 116°13'E	34°19'S, 116°11'E
Trees present	Jarraah, Tuart, Marri	Jarraah, Marri	Jarri, Marri, Karri
Tree canopy cover at site of grid	59%	70%	87%
Ground cover	70%	24%	32%
Leaf litter	Moderate	Moderate	Moderate
Dead wood	Sparse	Dense	Dense
Time since last burn before survey	ca 5 years	ca 8 years	ca 3 years
Soil and bedrock	Calcareous sands overlying aeolianite (Spearwood dune system)	Residual laterite with gravelly sands overlying ironstone	Grey podsol on Precambrian metamorphic rocks
Comments	Site totally colonised by veldt grass resulting in low density of native plants	Non-commercial trees thinned out since 1970	

marginata); but the Perth site includes tuart (*E. gomphocephala*), whereas karri (*E. diversicolor*) is sparsely distributed throughout the Manjimup site, and all the areas contain marri (*E. calophylla*).

The Perth site is degraded woodland, having been logged; it is colonized by the exotic veldt grass (*Ehrharta calycina*). The other two sites are Forests Department land of high-quality timber. Unmerchantable jarraah and other species of tree have been felled at Dwellingup as part of an experiment to investigate the effects of reduced competition with prospective timber trees. The fire at the Perth site, unlike that at the other sites, was accidental.

Site data on tree canopy and percentage ground cover were obtained by densiometer and metre quadrats respectively. A visual assessment was also made of the amounts of litter and deadwood on the ground, and of the soil type. The figure for the number of years between the last burn and the start of the survey was obtained from City of Perth records for Reabold Hill, and the Forests Department for the two southern sites.

Climatic data

The monthly rainfall totals, monthly maximum and minimum temperatures, and mean monthly relative humidities recorded at the three sites during the study are shown (Figs. 1 and 2).

Relative humidity records are for 0900 hours at Perth and Dwellingup, and 0800 hours at Manjimup. Although the consistently higher humidities observed at Manjimup were undoubtedly influenced by the lower temperatures at the time of recording, there are some Manjimup readings available for 0900 hours and they suggest that the humidity is generally higher here than at the other 2 localities.

Collecting procedure

The pitfall traps consisted of Pyrex test tubes sunk vertically at ground level within PVC sleeves (Majer 1978). They were positioned 3 m apart in a 6 x 6 grid in a typical part of the general environment at each of the three sites. Each of the test tubes (length 15 cm,

internal diameter 1.8 cm) contained a 3 mL mixture of alcohol/glycerol (70/30 v/v). The grid of PVC sleeves was retained in the ground to minimise the disturbance to soil and litter during the replacement of tubes. In order to avoid the effects of "digging-in" (Greenslade 1973), trapping was not started until a week after the initial placement of traps.

Every 4 weeks, the tubes were collected after having been left uncorked in their sleeves in the field for 7 days. They were replaced by a set of tubes which were left corked until the start of the next 7-day collecting period.

The collections were hand sorted and identified in the laboratory using a stereo microscope. Specimens have been lodged in the Western Australian Museum, and representatives sent to specialists.

Results

The number of specimens of each species collected during each trapping week over the study period is shown in Table 2. Because sampling was performed at 4-week intervals, the sampling dates did not necessarily coincide with the calendar months. Therefore for clarity, the data have been centralised under each calendar month in Table 2. In the few instances where 2 samples were obtained in a month the mean number is given.

The specimens collected belong to 2 broad feeding categories, predators and decomposers. The feeding type to which each species belongs is indicated in Table 2. The total number of species in the 2 feeding groups trapped per month at each site, and the total number of species and individuals for the year are shown in Table 3.

It should be noted that both in numbers of species and individuals, the predators exceed decomposers at all sites. This is due to lower vagility rather than to lower densities of the decomposers. Also, overall species richness at the Manjimup site is less than that at the other 2 sites. No inter-site comparisons will be made on the total numbers of individuals at each site because the results were probably influenced by variations in trapping efficiency.

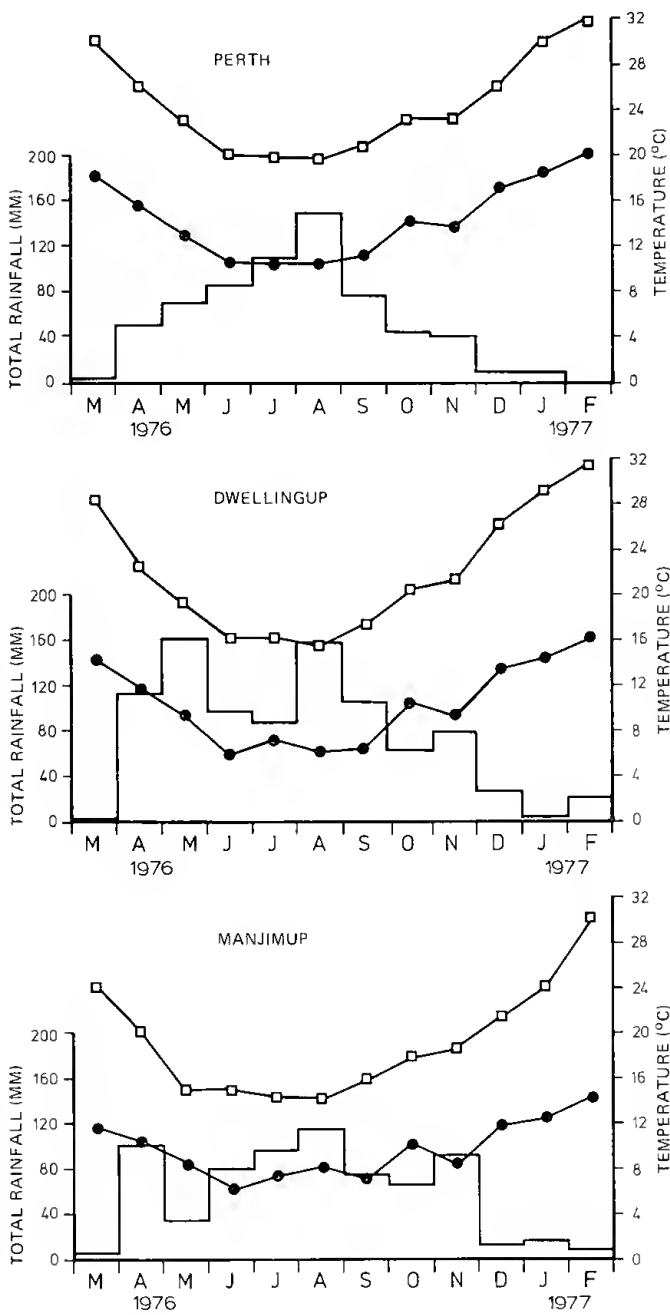


Figure 1.—The monthly rainfall and mean monthly temperatures (maximum \square — \square ; and minimum \bullet — \bullet) at Perth, Dwellingup and Manjimup from March 1976 to February 1977.

At Perth, the activity period of decomposers, as measured by species richness, occurred in late winter and spring. At Dwellingup the period of decomposer occurrence in the traps started earlier (May) and extended into early summer (December). At Manjimup, the seasonal trend was reversed and the activity period was from November to April (Table 3).

Predators were present in all months at each site although reductions in predator occurrence in traps were noted at Dwellingup in May and June, and at Manjimup in June and July. No obvious trends were noticeable at Perth (Table 3).

The number of decomposer and predator species trapped per month may be regarded as an index of decomposer and predator activity. The numbers trapped per month were compared (using Spearman's Rank Correlation) with the climatic data for the corresponding month and the previous month. The correlation coefficients and significance values are shown in Table 4. The correlations that are significant (at the 0.05 and 0.01 probability levels) are discussed below.

The species richness of decomposers is positively correlated with the relative humidity and rainfall of the previous month at Perth, and with the rainfall of the previous month at Dwellingup. Unlike those at the two northern sites, the decomposers at Manjimup are positively correlated with the temperature of the corresponding and also of the previous month; they are negatively correlated with the relative humidity of the corresponding month.

Compared to decomposers, the activity of predators is less tied to climatic conditions. At Dwellingup, rainfall of the previous month is negatively correlated with species richness of predators. At Manjimup, relative humidity of the corresponding month is negatively correlated with species richness of predators, whereas temperature of the previous month is positively correlated with it. There are no significant correlations at Perth between the climatic data and the species richness of predators.

Discussion

There are few studies of Western Australian forest-floor invertebrates. Most synecological investigations have regarded the effects of prescribed burning on the soil and litter fauna. In his pioneer work, McNamara (1955) studied the invertebrates of the soil and humus in jarrah forests and compared burnt and unburnt compartments and also areas suffering from crown deterioration. He concluded that the microfauna contained more individuals and taxa in places with accumulated organic matter. Springett (1976a) working on soil and litter fauna in burnt and unburnt forests of jarrah at Dwellingup and karri at Pemberton found that species

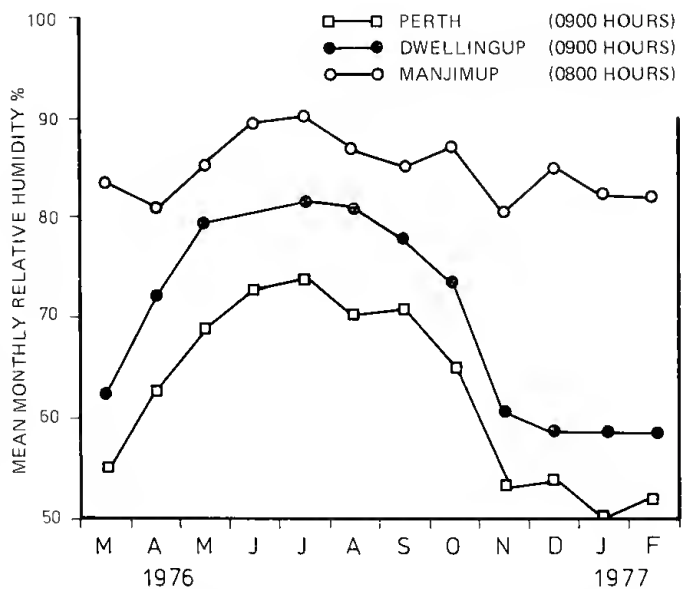


Figure 2.—The mean monthly percentage relative humidities at Perth, Dwellingup and Manjimup from March 1976 to February 1977.

Table 2

The number of individuals of each species of non-hexapod invertebrate collected per month in pitfall traps at three sites in the south-west of Western Australia from March 1976 to February 1977.

		1976						1977					
		M	A	M	J	J	A	S	O	N	D	J	F
ARACHNIDA: ARANEIDA													
(Mygalomorphae)													
Ctenizidae													
<i>Missulena</i> (pred.)†	M*	0	0	1	0	0	0	0	0	0	0	0	0
Dipluridae													
<i>Chenistonia tepperi</i> (pred.)	P	0	0	0	0	0	0	0	0	0	1	0	0
	D	0	0	0	0	0	0	0	0	0	1	0	0
(Araneomorphae)													
Oonopidae (pred.)													
	P	0	0	0	0	0	0	0	0	3	0	1	0
	D	0	1	0	0	0	1	0	0	0	0	0	0
Salticidae (pred.)													
	P	1	1	0	0	0	2	0	1	1	0	0	6
	D	0	2	0	0	0	0	0	1	3	2	1	1
	M	0	0	0	0	0	1	0	0	2	0	0	0
Clubionidae (a) (pred.)													
	D	1	6	0	0	0	2	1	0	0	2	0	0
Clubionidae (b) (pred.)													
	M	0	0	0	0	0	0	2	0	0	0	0	0
Clubionidae (c) (pred.)													
	D	0	1	0	0	0	1	1	0	2	0	0	0
Gnaphosidae (pred.)													
	P	5	1	1	15	0	0	1	0	5	7	3	6
	D	4	5	0	0	5	1	1	13	7	3	8	0
	M	1	1	1	2	0	0	0	1	5	5	0	0
Ctenidae													
<i>Elassoctenus harpax</i> (pred.)	P	5	1	7	2	0	0	2	1	1	0	0	0
	D	0	4	0	0	1	0	2	0	0	0	0	0
Ctenidae (b) (pred.)													
	P	0	0	0	1	0	0	0	6	0	0	0	0
Linyphiidae (a) (pred.)													
	D	0	0	0	4	2	0	1	0	0	0	0	0
	M	0	0	0	0	0	0	1	0	0	0	0	0
Linyphiidae (b) (pred.)													
	D	0	0	0	8	11	0	2	0	0	0	0	0
	M	0	0	0	1	0	0	0	0	0	0	0	0
Zodariidae													
<i>Storena</i> (pred.)	P	0	0	0	0	0	0	0	2	3	1	0	0
	D	5	1	0	0	0	0	1	6	1	2	6	2
	M	2	0	0	0	0	4	0	2	5	0	0	0
Zodariidae (b) (pred.)													
	P	0	0	0	0	0	0	1	1	0	0	0	0
	D	0	0	0	0	0	0	0	0	0	0	1	0
Lycosidae													
<i>Artoria</i> (a) (pred.)	P	0	0	0	21	27	83	123	0	8	3	2	0
	D	0	0	0	0	0	0	2	1	1	2	1	0
	M	0	0	0	0	0	0	5	0	0	0	0	0
<i>Artoria</i> (b) (pred.)	D	0	0	0	0	3	1	0	0	0	0	0	0
	M	0	0	1	0	8	1	0	0	0	0	0	0
<i>Artoria</i> (c) (pred.)	P	0	0	0	0	0	1	0	0	0	0	0	0
ARACHNIDA: ACARINA													
Rhodacaridae (pred.)													
	P	2	0	113	0	0	0	22	0	0	0	0	0
	D	17	1	0	0	3	0	0	0	1	0	0	0
Trombidiidae (pred.)													
	P	190	12	5	2	2	0	0	2	13	17	79	156
	D	28	1	0	0	3	1	2	25	87	46	31	18
	M	30	1	0	0	0	0	0	0	0	24	67	139
Anystidae (pred.)													
	P	1	0	0	0	0	0	0	0	0	3	32	4
	D	24	7	1	0	0	0	0	1	12	24	46	15
ARACHNIDA: SCORPIONIDA													
Bothriuridae													
<i>Cercophonius squama</i> (pred.)	P	0	0	1	1	0	2	0	0	0	0	0	0
	M	1	1	1	0	0	0	0	0	0	0	2	2
Buthidae													
<i>Lychas marmoreus</i> (pred.)	P	0	0	0	0	0	0	0	0	0	0	0	1
	D	0	0	0	0	0	0	0	1	0	0	1	0

		1976								1977			
		M	A	M	J	J	A	S	O	N	D	J	F
ARACHNIDA: PSEUDOSCORPIONIDA													
Chthoniidae													
<i>Austrochthonius australis</i> (pred.)													
P		0	0	0	1	0	0	0	0	1	0	0	0
D		0	0	0	0	1	0	0	1	0	0	0	0
ARACHNIDA: PHALANGIDA													
Trianenonychidae													
<i>Nunciella</i> (pred.)													
P		0	0	0	4	7	0	0	0	0	0	0	0
D		4	3	6	3	0	0	3	6	2	1	0	0
M		0	5	1	0	0	3	0	2	5	4	2	0
DIPLOPODA													
Polyzoniidae													
<i>Rhinotus</i> (dec.)													
D		0	0	0	0	0	0	1	0	0	0	0	0
<i>Siphonotus flavomarginatus</i> (dec.)													
P		0	0	0	0	3	0	0	0	0	0	0	0
Paradoxosomatidae													
<i>Antichiropus fossulifrons</i> (dec.)													
P		0	2	0	0	0	0	3	5	1	0	0	0
D		0	0	0	0	1	0	0	0	1	2	0	0
<i>Antichiropus</i> (b) (dec.)													
M		0	0	0	0	0	0	0	0	1	0	0	0
<i>Antichiropus</i> (c) (dec.)													
P		0	0	0	0	0	0	0	3	0	0	0	0
CHILOPODA													
Henicopidae													
<i>Henicops</i> (pred.)													
P		0	0	0	2	9	2	2	8	0	0	0	0
D		0	0	0	0	0	0	0	1	1	1	0	0
Scolopendridae													
<i>Cormocephalus</i> (pred.)													
P		0	0	0	0	1	0	0	0	0	0	2	3
D		0	0	0	0	0	1	0	0	0	0	0	3
Geophilidae (pred.)													
M		0	0	0	0	0	0	0	0	0	0	0	1
CRUSTACEA: ISOPODA													
Armadillididae (a) (dec.)													
P		0	0	0	0	0	0	1	1	0	0	0	0
D		0	0	0	0	0	0	2	0	1	1	0	0
M		3	2	0	0	0	0	0	0	2	14	5	0
Armadillididae (b) (dec.)													
P		0	0	0	0	0	2	0	1	0	0	0	0
Oniscidae													
<i>Laevophiloscia</i> (a) (dec.)													
P		0	0	0	0	0	0	0	1	0	0	0	0
D		0	0	1	1	0	0	0	0	1	0	0	0
M		3	2	0	1	0	2	0	0	2	0	0	0
<i>Laevophiloscia</i> (b) (dec.)													
D		0	0	0	0	0	0	0	1	1	0	0	0
<i>Laevophiloscia</i> (c) (dec.)													
P		0	0	0	0	0	0	0	1	0	0	0	0
M		2	0	0	0	0	0	0	0	4	0	2	21
Oniscidae (b) (dec.)													
D		0	0	0	0	1	0	0	0	0	0	0	0
Oniscidae (c) (dec.)													
D		0	0	0	1	0	0	0	0	0	0	0	0
ANNELIDA													
Megascolecidae (dec.)													
D		0	0	0	0	1	0	0	0	0	0	0	0
MOLLUSCA: GASTROPODA													
Bulimulidae													
<i>Bothriembryon</i> (dec.)													
P		0	0	0	0	2	0	0	0	0	0	0	0

* P — Perth; D — Dwellingup; M — Manjimup; † (pred.) — predator; (dec.) — decomposer.

Table 3

The numbers of species trapped per month (March 1976 to February 1977) and the total species and individuals of decomposers and predators trapped at each of the three sites.

Site	M	A	M	J	J	A	S	O	N	D	J	F	Total species trapped at site	Total individuals trapped at site
Decomposers														
Perth	0	1	0	0	2	1	2	6	1	0	0	0	8	26
Dwellingup	0	0	1	2	3	0	3	2	3	2	0	0	8	19
Manjimup	3	1	0	0	0	0	0	0	3	1	3	2	3	65
Predators														
Perth	6	4	5	8	5	5	6	6	8	6	7	6	19	1065
Dwellingup	7	11	2	4	8	6	10	9	10	10	8	5	21	582
Manjimup	4	4	4	2	1	4	3	3	4	3	3	3	13	341

diversity and density are reduced following burning of the native forests. Bornemissza (1969) studied the soil and litter invertebrates in a burnt area of native bushland at Kings Park, Perth, and concluded that most soil- and litter-dwelling invertebrates had regained normal population levels after 2 or 3 years.

Springett (1971, 1976b) compared the soil and litter fauna of *Pinus pinaster* plantations and native woodlands at Gngangara, north of Perth. This study suggested a lower species diversity of soil microarthropods in pine plantations than in native vegetation, but abundance levels were similar. Associated decomposition experiments suggested that the microfauna in pine plantations was impoverished and unable to decompose litter as fast as in native vegetation.

The only other reported synecological studies on forest-floor invertebrates in Western Australia are the analysis of arthropod succession in decomposing carrion and the effects of this on soil fauna (Bornemissza 1957), the investigation of epigeic invertebrate succession in replanted bauxite mines at Jarrahdale (Scott 1974), and the attempt to relate karri forest invertebrate abundance to that of the insectivorous marsupial, the mardo, *Antechinus flavipes* (Hindmarsh and Majer 1977). With the exception of certain taxa in Springett's work,

these studies have sorted most of the invertebrates only to ordinal level. The present study provides data on individual species and for the first time provides information on the phenology of certain invertebrates.

In accordance with differences in geological, vegetational, drainage and other characteristics, the soil is different in the various areas. Unlike the other two sites, the Perth site (Reabold Hill) has tuart (Table 1) which is characteristically found on the soils of the Spearwood dune system of Pleistocene age. The residual laterite of the Dwellingup site overlies ironstone, whereas the Manjimup soils are grey podsol on Precambrian metamorphic rocks. The calcium content is high at the Perth site, unlike at the other two sites and at Gngangara, near Perth. The Gngangara soil is quartz sand, not limestone; its calcium content is very low, and its pine-litter layer is highly acidic. The calcium content affects creatures such as snails (e.g. *Bothriembryon*) which are dependent upon this element for their shells. It is interesting to note that snails of this genus were collected in pitfall traps only at Perth. Similarly, the varying preferences of other creatures for calcium and other features of the soil and litter layers no doubt contribute towards determining which species occur in each area.

Table 4

Spearman's rank correlation coefficients and significance values for trapped species (decomposers and predators) and climate of corresponding month and previous month at three sites (n = 12).

Site	Average Temperature†		Relative Humidity		Rainfall	
	Corresponding month	Previous month	Corresponding month	Previous month	Corresponding month	Previous month
Decomposers						
Perth	-0.29	-0.34	0.46	0.75**	0.48	0.75**
Dwellingup	-0.51	0.11	0.33	0.48	0.17	0.56
Manjimup	0.77**	0.74**	-0.74**	0.48	-0.38	0.43
Predators						
Perth	0.17	0.06	-0.34	-0.25	-0.37	-0.16
Dwellingup	0.17	-0.36	-0.28	-0.27	-0.09	-0.70*
Manjimup	0.20	0.57*	-0.62*	-0.12	0.001	0.31

* P < 0.05 ** P < 0.01

† The average of the monthly maximum and minimum temperatures was used.

Our observations have indicated that the numbers of species in our traps are a true reflection of the total numbers of species present at each of these sites, so the lower diversity of decomposers and predators at the Manjimup site requires an explanation. The number of taxa collected at a particular site does not necessarily reflect that of the general locality. Springett (1976a) found that the mesofauna in jarrah and the more southern karri forests is represented by similar numbers of species, and the studies by one of us (Majer; unpublished) on forest ants indicate that there are similar species richness values for these three localities. A striking difference between the Manjimup site and the other two sites is that it had been burnt only 3 years before the study commenced (Table 1). This falls well within Springett's (1976a) period of post-fire species diversity reduction—suggesting that fire could be the reason for the observed differences in species richness.

It is expected that the amount of decomposition or predation is proportional to the number of species of decomposers or predators respectively that are active (and hence trapped) at any given time. The data on decomposers are therefore interesting in that they point to variations in the rate of decomposition throughout the year and between sites. Before discussing this, the differences in climates at the 3 sites should briefly be considered (Figs. 1 and 2). There is no consistent trend in rainfall as one passes south through the study sites, although Dwellingup has the highest rainfall in most months. There is, however, a reduction in mean maximum and minimum temperatures from north to south and, with this, an increase in relative humidity. There are probably moister conditions on the forest floor at the 2 more southerly sites.

Decomposers at Perth and Dwellingup have a winter-spring activity. They are correlated with the previous month's rainfall and relative humidity at Perth, and with the previous month's rainfall at Dwellingup (Table 4). There is a longer period of decomposer activity at Dwellingup than at Perth (Table 3), indicating that Dwellingup's higher rainfall and humidity (Figs. 1 and 2) result in the moist conditions that favour the processes of decomposition lasting longer. This conclusion is in agreement with the findings by Hatch (1955) that there was a very slow rate of decomposition of jarrah leaf litter at Dwellingup during the summer and a rapid initial loss of weight of litter during March to August inclusive. The Perth data tie in with Springett's (1976b) observation that there was a lower loss of weight of litter under pines at Gnangara during mid-summer. Although no data are available, we postulate that decomposition continues for a longer period at Dwellingup than at Perth.

At Manjimup, the absence of non-hexapod decomposers in traps run between May and October suggests that the winter period is here in some way less suitable for decomposition. Four possible reasons for this different surface activity of decomposers are: (1) that the low winter temperatures are unfavourable; (2) that the extremely wet soil and litter in winter may be unsuitable; (3) that the rains in the warmer season at Manjimup make these periods the most suitable for decomposition; (4) that it is an artifact of the sampling programme. It would be interesting to place out litter bags or calico strips, as Springett did, in order to evaluate the decomposition period at Manjimup.

With regard to the predators, no clear seasonal trends can be defined for the winter decreases in activity at Dwellingup and Manjimup. These are associated with

high rainfall of the previous month at Dwellingup, and high humidity of the corresponding month at Manjimup. It may simply be that conditions are too cool for predator activity during this winter period; this view is supported by correlation of predator numbers with the high temperatures of the previous month at Manjimup (Table 4). Certainly when one looks at the numbers of the more abundant predators, such as spiders (and also ants), marked periods of increased activity are noticeable in the spring-summer-autumn period. It may well be that the bulked data used here obscure the fact that a succession of predators is active throughout the year.

To summarise, this study has suggested: (1) that there is a period of decrease in species richness for at least 3 years after fire; (2) that decomposer abundance, and presumably decomposition, is higher in the wetter months (except at Manjimup where decomposers are associated with warmer conditions); and (3) that predators are active throughout the year although there is a decrease of activity (at least at Dwellingup and Manjimup) associated with cool, moist conditions.

It would be interesting to know what the relative impact of autumn and spring controlled burns at Perth and Dwellingup will be on predators and decomposers. Probably, an autumn burn would remove the litter layer on which decomposers feed in the months immediately following the burn, and a spring burn would allow a period of litter recovery which would give decomposer organisms a food-base for the following wet period (winter). Our data suggest that different sequences of biological events are operating at the southern locality, Manjimup, and therefore the effects of fire might be different there.

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Royal Society Medallists, 1979

In order to mark the centenary of the birth of Lord Kelvin (26 June 1924) the Royal Society of Western Australia decided to institute an award for outstanding work in science associated with Western Australia, to be known as the Royal Society Medal (it should be noted that the term Kelvin Medal sometimes associated with this award is incorrect and owes its origin to the Kelvin celebrations with which the award was associated at its inauguration.) The last medal (the 11th) to be awarded was in 1970 and the Royal Society Council has selected three medallists for the year 1979. This was decided because of the very high calibre of the scientists available for selection and in acknowledgement of the State's 150th Anniversary (CFHJ).

R. M. Berndt

Ronald Murray Berndt, born in Adelaide in July 1916, received his early education at Pulteney Grammar. Prior to going to Sydney to study under the late Professor A. P. Elkin, he was attached to the South Australian Museum in an honorary capacity. At the University of Sydney he obtained a Diploma of Anthropology in 1943, B.A. in 1950 and M.A. with First Class Honours in Anthropology and the University Medal in 1951. Jointly with his wife, Dr. Catherine Berndt, he was awarded by the Royal Society of N.S.W. the Edgeworth David Medal for Anthropology in 1950.

Professor Berndt and his wife have carried out extensive field research in Aboriginal Australia, and during 1951-53 they worked in the eastern highlands of New Guinea. Then they studied at the London School of Economics under Professor (later Sir) Raymond Firth, obtaining their doctorates in 1955. Ronald Berndt held a Nuffield Foundation Travelling Fellowship and a Leverhulme Award at that time, and then a Carnegie Corporation Travelling Fellowship which enabled them both to visit a wide range of university departments of Anthropology and Sociology in Canada and the U.S.A.

Returning to Australia in 1956, Ronald Berndt took up a senior lecturership in Anthropology at the University of Western Australia to develop teaching and research in that discipline. He became a Reader in 1959, and Foundation Professor of Anthropology in 1963. Over the years the Department of Anthropology has expanded considerably, and in 1976 it took up its new quarters in the Social Sciences Building, where the Anthropology Museum is located.

Professor Berndt and his wife have continued to specialize in Aboriginal studies, carrying out research in the Western Desert, the Kimberleys and Arnhem Land. He has concentrated primarily on problems of social control, structure and organisation, mythology and ritual, as well as socio-cultural change. His publications, some of which are written in conjunction with his wife, reflect these emphases. Among them are *Kunapiipi* (1951), *Djanggalwil* (1952) and *Australian Aboriginal Religion* (1974). With his wife, there are



Man, Land and Myth in North Australia (1970), *The First Australians* (1952/1974) and *The World of the First Australians* (1964, revised 1977). He has also edited, for instance, *Australian Aboriginal Anthropology* (1970), *The Australian Aboriginal Heritage* (1973) and *Aborigines and Change* (1977); and edited with his wife *Aboriginal Man in Australia* (1965), and one of the sesquicentennial series of volumes, *Aborigines of the West* (1979).

Professor Berndt is a member of a number of societies. For example, he is a foundation and Council member of the Australian Institute of Aboriginal Studies; first chairman of the (breakaway) Australian Association of Social Anthropologists (which later became the Anthropology Association of Australia); Fellow of the Academy of Social Sciences in Australia; the first President of the Anthropological Society of Western Australia; Past-President of Section F. of ANZAAS; and was President of the Royal Society of Western Australia in 1972-73.

B. J. Grieve

Brian John Grieve was born in Allan's Flat Victoria in August 1907 and was educated at Williamstown High School and the University of Melbourne. He graduated B.Sc. with 1st class honours in botany in 1929 and received an M.Sc. in 1930. As an 1851 Exhibition Scholar he continued his studies at the Botany Department of the Imperial College of Science obtaining a Ph.D and a Diploma of Imperial College in 1932.



In 1933 he joined the staff of the Botany Department University of Melbourne and later carried out research at the University of Cambridge. At the outbreak of World War II he served as Lieut. Cdr. (S), R.A.N.R. but was manpowered back to university work. In 1947 Grieve was appointed Head of the Botany Department at the University of Western Australia and became Foundation Professor of Botany in 1957, a position which he held until his retirement in 1972 with the title of Emeritus Professor. He has continued research as an Honorary Research Fellow in the University.

Throughout his career Professor Grieve has held many important positions and has served on numerous influential committees and organisations. He was Dean of the Faculty of Science University of Western Australia for 1954-55 and was for many years a member of the CSIRO State Committee and the Nuffield Foundation Advisory Committee. He also served as a member of the King's Park Board from 1959-78 and was instrumental in the establishment of the State's Botanical Gardens. Prof. Grieve was elected President of Section M (Botany) for the Brisbane meeting of ANZAAS in 1951 and was President of the Royal Society of Western Australia on two occasions, in 1952-53 and 1970-71.

The value of his research has been recognised on several occasions: by the award of the Syme Prize and Gold Medal in 1943, election as a Fellow of the Linnean Society of London in 1939, Fulbright and Rockefeller Grants and a Scandinavian Fellowship award in 1956, election as a Fellow of the Institute of Biology, London in 1966 and admission to Honorary Membership of the Royal Society of Western Australia in 1975.

Apart from his official duties as Professor of Botany, Prof. Grieve has made a great contribution to botanical knowledge in Western Australia. His experimental research has centred on the absorption and transpiration

of water, the photosynthesis and the adaptation to summer drought of native plants. This work on the eco-physiology of Western Australian plants has brought him international recognition. Of outstanding significance is the 4 volume work entitled *How to know Western Australian wildflowers*. Appearing under the authorship of Grieve and Blackall the work is now almost entirely that of Prof. Grieve although it maintains the original format of the late Dr. Blackall's text. Revision of earlier published parts of this work—the only modern manual on the flora of this floristically diverse region—is actively continuing with parts IIIA and IIIB shortly to be published.

D. L. Serventy

Dominic Louis Serventy was born at Brown Hill Western Australia in March 1904. As a school boy he showed a keen interest in natural history and attracted the attention of an eminent long-serving member of this Society and former medallist, Ludwig Glaucrt. Glaucrt had a powerful influence on Serventy's early career and watched with satisfaction as the enthusiastic young naturalist grew into a biologist with a world-wide reputation.

Educated at Perth Boys' and Perth Modern School, Serventy graduated B.Sc. with 1st class honours in zoology at the University of Western Australia in 1931, and, as an 1851 Exhibition Scholar, he continued his studies at Gonville and Caius College Cambridge and was awarded a Ph.D in 1933. He returned to Western



Photo: Mercury, Hobart

Australia in 1934 to take up the position of lecturer in zoology at the University of Western Australia and after several years he joined the Fisheries Division of CSIRO. Dr Serventy later transferred to the newly formed CSIRO Division of Wildlife Research where he served for eight years and rose to the position of Senior Principal Research Scientist and officer-in-charge of the Western Australian Field Station. He still maintains an association with this station in an honorary capacity.

Throughout his career Dr Serventy has taken a keen interest in nature conservation and was a foundation member and the first secretary of the Western Australian Naturalists' Club. He has had a longer association with the Royal Society of Western Australia than any other living member, having joined in 1924. He was elected to Honorary Membership in 1973 and served as Vice-President in 1968–69.

Dr Serventy's reputation as an ornithologist is indicated by the honours which have been conferred upon him from around the world. He was elected President of the Royal Australasian Ornithologists Union in 1948 and made a Fellow in 1951. On 3 May, 1973 he was made a Ridder of the Order of the Golden Ark at an investiture at the Soestdijk Palace by His Royal Highness Prince Bernhard, Grand Master of the Order. He was elected an Honorary Member of the British Ornithologists Union in 1977, the German Ornithological Society in 1974, a Corresponding Member of the French

Ornithological Society in 1970, Asociacion Ornitologica del Plata (Argentina) in 1964 and he has been a member of the Permanent Executive Council of the International Ornithological Council since 1966 and was Vice-President of the 1978 Congress.

He is an Honorary Life Member of the Western Australian Naturalists' Club and has been editor of the Club's journal since 1947. He has served as a councillor in the Tree Society, the National Trust, the Society for the Preservation of King's Park and the Swan River, the Western Australian Gould League and the Australian Conservation Foundation. He is a Corresponding Member of the Advisory Committee of the Percy Fitzpatrick Institute of African Ornithology and between 1949 and 1966 was Australia's representative on the Standing Committee on Conservation of the Pacific Science Association, being Chairman from 1953–57.

Dr Serventy was awarded the Australian Natural History Medallion in 1956 and the Medal of the Royal Society of Tasmania in 1970. His publications are numerous and cover a wide range of zoological topics with valuable papers on marine science and outstanding contributions in the field of ornithology. Amongst the latter are the *Handbook of Australian Sea-birds* written in 1971 in collaboration with V. N. Serventy and John Warham and *Birds of Western Australia* first produced in collaboration with the late Major H. M. Whittell in 1948 and now in its 5th edition.

Addendum

An ecological reconnaissance of four islands in the Archipelago of the Recherche, Western Australia. By Ian Abbott and Robert Black, Volume 60, Part 4, 1978, p. 115–128.

Three species of seabirds were inadvertently omitted from the list on p. 123; after *Eudyptula minor*, insert the following:

Puffinus assimilis, Little Shearwater.—Wilson I., 1 carcass found and many scattered black and white feathers were found among burrows in the *Atriplex* area on the northern side of the east part of the island (new record).

P. carneipes, Flesh-footed Shearwater.—Woody I., 50–100 burrows under *Melaleuca lanceolata* at south-west part of the east peninsula. Mondrain I., burrows patchily present over most of the island, especially in *Carpobrotus* breaks in forest as well as in tussockland and amongst succulents near the edge of the island. Wilson I., 1 carcass found on east part of island; the many hundreds of burrows here presumably belong to this species (new record).

Pterodroma macroptera, Great-winged Petrel.—Mondrain I., 1 bird was heard calling on the night of 26 April near the campsite; the status of this species on Mondrain I. is unknown, as it has not previously been reported from the island. Wilson I., 1 carcass and about 60 burrows were found in deep soil on the east slope of the 68 m peak (new record).

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Observations on the nest-building habits of the brush-tailed rat-kangaroo or woylie (*Bettongia penicillata*)

by P. Christensen and T. Leftwich

Forests Department Research Branch, Manjimup, W.A. 6258
Manuscript received 19 July, 1978; accepted 19 February, 1980

Abstract

The brush-tailed rat-kangaroo, or woylie (*Bettongia penicillata* Gray 1837), spends the daylight hours in an elaborate well-concealed nest. These nests may be located by radio tracking the animal or by careful systematic searching along transect lines. Nests are located in low dense clumped vegetation types. They are constructed, over shallow depressions dug in the soil, using long strands of material carried as a bundle in the curled-up tail. With the exception of mothers with 'at heel' joeys, the nests are occupied by single animals. Each animal usually has 3 to 4 nests in use at any given time and occupies them in a random fashion. It is speculated that the function of the nest may be avoidance of temperature extremes by the animal.

Introduction

When European man first arrived in Australia, the brush-tailed rat-kangaroo, or woylie, was widespread across the southern portion of the continent. This rabbit-sized kangaroo-like marsupial now inhabits only a few isolated areas of dry sclerophyll woodland in Western Australia (Wakefield 1967, Sampson 1971). Like many Australian mammals it is nocturnal and it spends the daylight hours in an elaborate well-concealed nest (Serventy 1970, Sampson 1971).

With the exception of 2 studies on its biology (Sampson 1971, Christensen 1977), little has been published on the ecology of the woylie and little detailed information is available on its nesting habits. During a study on the fire ecology of this species (Christensen 1977), interesting data, not directly relevant to the study, were accumulated on woylie nests. Although not complete these data provide a useful addition to our knowledge of the biology of this species.

Location of nests

Finding a nest is normally a rare event. Being well-concealed, they are usually found only when an observer comes upon one by chance, flushing the woylie almost underfoot. Radio telemetry has been used successfully to locate nests (Sampson 1971, Christensen 1977). During a study of the biology of the woylie in the Perup forest area, located east of Manjimup (Christensen 1977), a successful technique consisting of careful searching of all possible hiding places along transect lines was employed to locate nests. This technique was used to obtain data on the relative density of populations of the woylie in different areas. Altogether, along a total of 41 km of transect lines, 221 nests were located

in this way. A further 74 nests were found using radio tracking, and several hundred burnt-out nests were located after fires. Burnt-out nests are quite distinctive and clearly visible directly after a fire (Fig. 1).

The nests which were found varied in age from 1 or 2 day-old uncompleted nests to very old collapsed and dilapidated nests several years old and long since vacated by their builders.

Concealment and construction of nests

Woylies in the Perup area live in dry sclerophyll jarrah (*Eucalyptus marginata*) and wandoo (*E. wandoo*) forest. Low flat ridges with an understorey of woody scrub are separated by wide shallow valleys



Figure 1.—A burnt-out woylie nest showing the typical hollow surrounded by raised edges on 3 sides. The entrance is facing the camera.



Figure 2.—An overhanging *Bossiaea ornata* bush held back to reveal a woylie nest. The entrance and part of the roof of the nest can be clearly seen.

and flats generally with a taller more open understorey, and often treeless. Nests are usually found in well-drained areas, on ridges, well concealed under low dense scrub (Fig. 2).

The woylie exhibits distinct preferences in terms of the vegetation communities used for nesting (Table 1). Low, dense, clumped vegetation containing such species as *Bossiaea ornata*, *Leucopogon capitellatus*, *Xanthorrhoea gracilis* or *Dryandra armata* is often preferred. Two of the 3 most-preferred scrub communities for nesting, *Hakea lissocarpa/Leucopogon capitellatus* and *Bossiaea ornata*, are also the most common in the area. The third, dense 'grassy' monocotyledons, has a very restricted distribution.

Occasionally nests may be found in other places, such as in or underneath fallen logs, or under newly-fallen leafy branches. However, such sites are normally only used when little else is available, for example on recently burnt ground following a bush-fire.

The material from which nests are constructed may vary from one locality to the next, once again depending on availability. In the Perup area jarrah bark stripped from fallen trees or large limbs is preferred. The long narrow leaves of *Persoonia lougifolia* may be used on occasions, and nests are often built using grass where this is available. Whatever the material used it must consist of long strands, as the woylie carries it as a bundle in the curled-up tip of its tail (Serventy 1970, Troughton 1967). This remarkable behaviour seems only to have been observed in captive animals. However 7 separate discarded bundles of nesting material made up for transporting in this manner (Fig. 3) have been found in the Perup area. Two bundles were found in traps, the woylie having been captured on its way to its nest with the nesting material in its tail.

Nests are built in shallow depressions from which the earth has been scraped to form a ridge around the rim on 3 sides (Fig. 2). Each nest consists of 2 distinct layers, an exterior layer covering the top and sides, and an inner lining covering the top, sides and floor of the nest.

Observations made on several different nests during radio telemetry studies reveal the sequence of events. First a depression is dug underneath a suitable bush, then a rough outer framework, often of coarse broad strips of jarrah bark, is constructed over the top of the depression. This is then gradually added to, apparently from the inside, until a sufficient thickness is obtained. A soft inner lining of finely shredded jarrah phloem, the inner-most layer of the bark, is added last of all. It appears that it may take up to 2 weeks to finish a nest, although a rough shelter composed of strips of outer bark may be completed in 2 to 3 nights if needs dictate, for example following the destruction of all of an animal's nests during a fire.

Mean measurements and weights of ordinary 'single' nests, and a 'family nest' are shown in Table 2. Nests occupied by a mother and out of pouch juvenile are here referred to as 'family nests'. Family nests are distinguished from single nests largely by their width and the size of the entrance.

Table 1

Distribution of woylie nests by understorey vegetation communities, Perup area

	Vegetation communities sampled in the survey									
	<i>Hakea lissocarpa/Leucopogon capitellatus</i>	<i>Bossiaea ornata</i>	Open wandoos	<i>Acacia pulchella</i>	<i>Hypocalymna angustifolia</i>	Dry laterite	<i>Melaleuca viminea</i>	<i>Gastrolobium bilobum</i>	Dense 'grassy' monocotyledons	Granite outcrops
Area searched m ²	131 250	66 132	28 908	52 356	55 080	37 440	10 170	51 534	24 600	17 610
Nests	82	66	1	7	16	.....	.....	6	17	6
Nests/ha	6.25	5.44	0.35	1.34	2.90	0.00	0.00	1.16	6.91	3.14
% of total nests	22.5	19.6	1.30	4.80	10.4	0.00	0.00	4.20	24.9	12.3

The dominant scrub species are used to indicate the scrub communities sampled in the survey. The communities are arranged in descending order of frequency in terms of the total area covered by each in the Perup area. Three miscellaneous categories are also included:

Open wandoos—low open cover of various scrub species.

Dry laterite—open scrub on infertile soils.

Granite outcrops—dense low cover on shallow sandy soils overlaying granite, typically *Dryandra armata*.

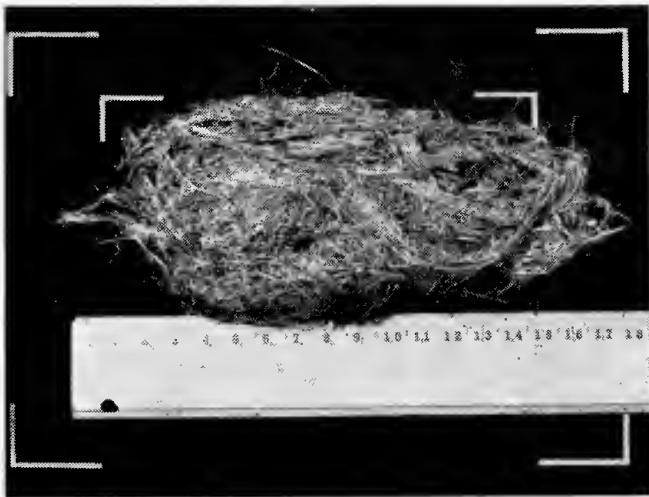


Figure 3.—Bundle of nesting material, consisting of shredded jarrah bark used for inner lining, found discarded in the Perup area.

Oven-dry weights of bundles of nesting material found were as follows: One bundle of outer covering material = 17.5 g; inner lining, mean weight of five bundles = 11.5 g, (range 3.6 — 28.7 g). Woylies must therefore transport from 20 to 25 bundles of outer covering, and 5 to 25 of inner lining in order to make a completed nest. In 4 instances where the source of nesting material was definitely located, it was found to have been obtained from logs located between 20 to 60 m from the nest site. The construction of a nest therefore involves a considerable amount of cartage.

Table 2

Dimensions and weights of woylie nests

	'Single' nest (mean of four nests)	Nest of adult female with juvenile (family nest)
Height	13.5 cm	14 cm
Width	18.9 cm	21 cm
Depth (front to rear)	21.5 cm	21 cm
Height of entrance	7.8 cm	10 cm
Width of entrance	9.0 cm	15 cm
Thickness of nesting materials:		
roof	4.3 cm	2-3 cm
wall	6.0 cm	4 cm
Weight of outer layer	394.7 g	
Weight of inner lining	96.2 g	

All measurements refer to inside dimensions. Weights are oven-dry weights.

Use of the nest

Radio-tracking results obtained by tracking a total of 18 animals (Christensen 1977), reveal that woylies have 3 to 4 separate nests in use, at any one time. Nests are used in a random fashion, one nest rarely being used for more than 2 to 3 consecutive days at a time. Typical data illustrating the use of nests by one individual male followed intermittently over a period of 4 months are given in Figures 4 and 5.

New nests appear to be made at the rate of approximately one per month, at which time one of the old nests is generally abandoned.

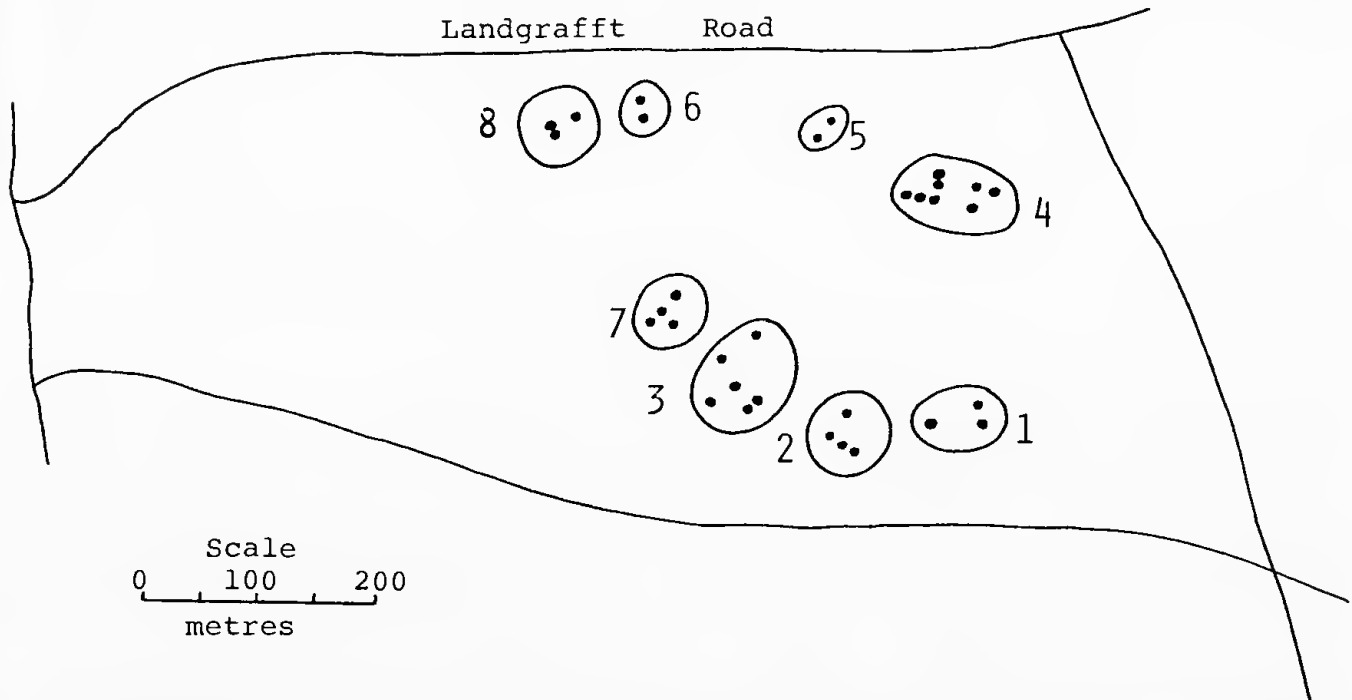


Figure 4.—Location of 8 nests used by a male woylie (transmitter animal 4.35) over the period 20 February 1976 to 16 June 1976. A point on the map represents one radio location of the animal on a particular day. Triangulation errors make it impossible to locate the exact position of the nests (Christensen 1977) which are therefore indicated by clusters of points.

The young out-of-pouch joey remains in the company of its mother, sharing her nest, from the time when it leaves the pouch, at approximately 90 days old, till the next joey vacates the pouch, approximately 100 days later (Christensen 1977). Adult woylies seldom if ever share their nests with other adults. On only 14 occasions out of 88 recorded woylie flushings were 2 animals flushed from the same nest. Nine of these paired flushings were radio-tracked individuals and the pair were known to be a mother with its out-of-pouch joey. In 3 of the remaining double flushings one of the pair was identified as a juvenile by its smaller size.

When flushed, the woylie 'explodes' from its nest almost underfoot. When a mother and joey occupy the same nest, the mother invariably leaves the nest first, to be followed moments later by the joey. The survival value of this was made apparent when in one such instance a dog was present. The dog immediately took off in pursuit of the mother, leaving the slower-moving joey to make good its escape in the opposite direction some moments later.

The woylie spends the daylight hours in its nest. It leaves its nest in search of food at dusk, returning again in the early hours, usually between 0400 and 0500 hours. Animals were located out of the nest during the day only during unusual circumstances, for example, after disturbance by fire, and on 3 separate occasions when juveniles were observed sitting next to cages in which their mothers had been captured. Occasionally woylies may be found still in their nests after dark, but this is rare.

Location of nest sites

Woylies have distinct home ranges within which feeding and nesting areas may be distinguished. Nesting areas are territorial, that of one individual seldom

overlapping that of any other individual. Such nesting areas have very specific requirements in relation to scrub density, and are generally situated on ridges. The intervening low-lying areas usually include their feeding range (Christensen 1977). The pattern of nest distribution is well illustrated in the transects described earlier (Fig. 6).

Immediately following fire, nest sites are easy to locate, later rain and weathering soon obscure the small hollows left unprotected by the removal of the nest and scrub cover. Plotting nest sites following fire reveals that they may occur in extraordinary densities on favourable sites (Fig. 7).

The distribution of nest sites appears to be a function of time and scrub density, there being more nests in the 9 year-old scrub because there has been more time for them to accumulate and it is also denser than the 4 year-old scrub. The preference for dense ground cover is further demonstrated by the high density of nests in the area of dense jarrah regrowth by comparison with the other 4 year-old scrub. This requirement of a relatively dense ground cover for nesting has already been demonstrated in a more detailed study (Christensen 1977).

In addition to the cover-density requirement, nest placement appears also to be influenced by the distribution of ground cover. Thus the distribution of nests conforms to a non-random pattern. Groupings of nests observed within randomly located quadrats differ significantly from the expected. The Chi-square test shows that this non-random distribution is more pronounced in the 4 year-old scrub area (signif. 0.001 level) than in the 9 year-old scrub area (signif. 0.05 level).

Prior to the burn, the scrub on the 4 year-old area was patchy, dense areas of *B. ornata* and *H. lissocarpa* being interspersed with areas of sparse vegetation. The 9 year-old scrub comprised a more homogeneous stand of dense *B. ornata*.

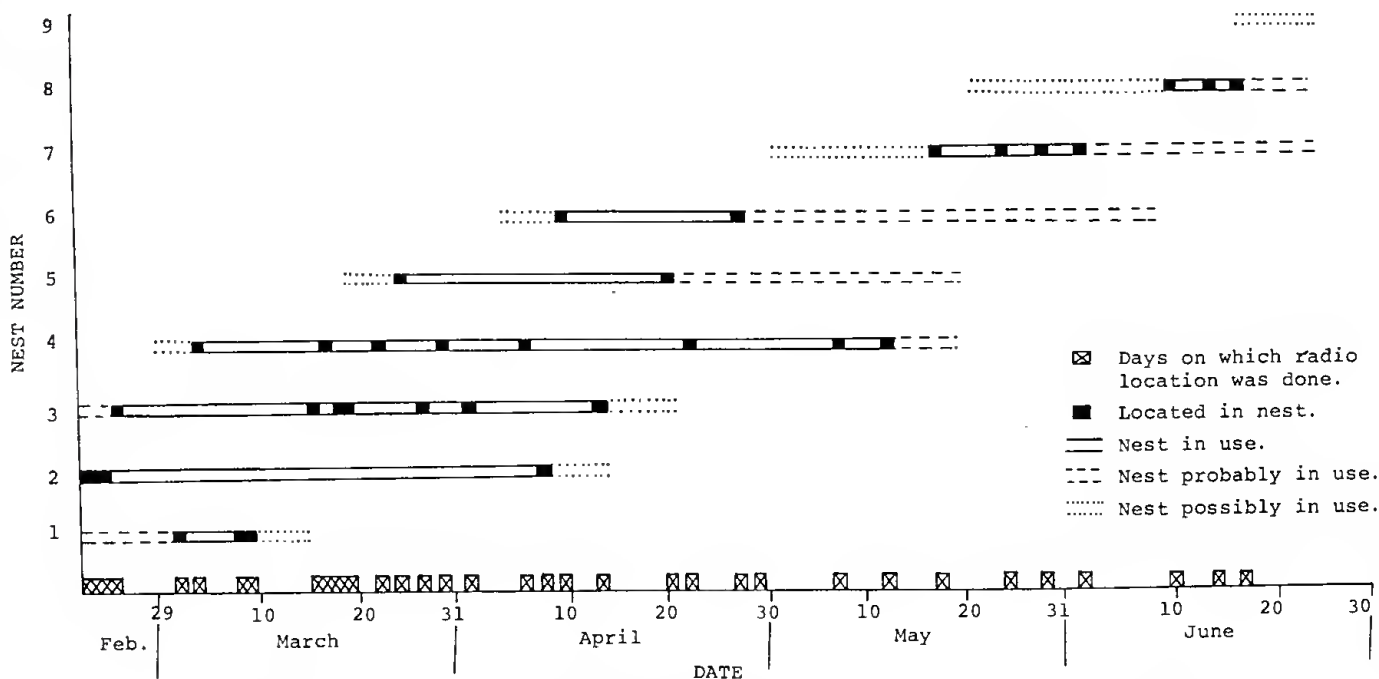
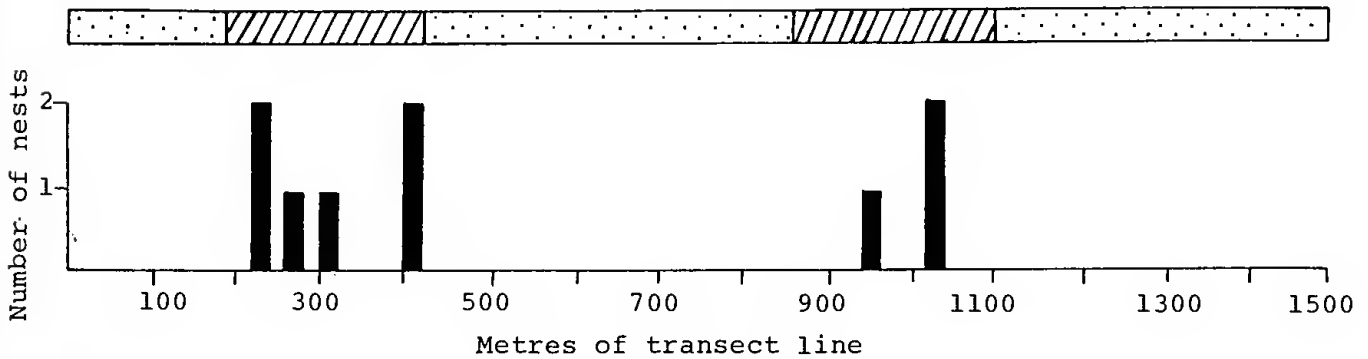
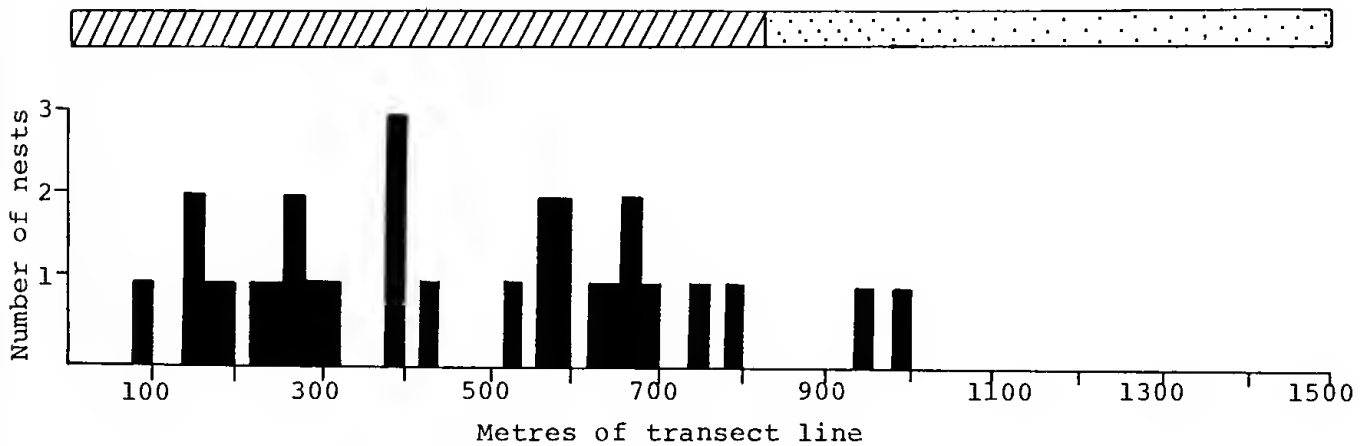




Figure 5.—Nest use by a male woylie (transmitter animal 4.35). For location of nests, see Figure 4.

Transect 1



Transect 2



 Elevated areas - ridges. * Scrub density @ 0-60cm = 50 - 80%
 Bare ground = 20 - 40%.
 Low lying areas - valleys Scrub density @ 0 - 60 = 0 - 25%
 Bare ground = 75%+

* See Christensen 1977.

Figure 6.—Distribution of woylie nests in relation to vegetation type and topographical position. Nests located along two 12 m-wide transects.

Significance of the nest

It is not known what role the nest may play in the biology of the woylie.

Most small mammals shelter in nests or burrows during the daytime in order to avoid exposure to extremes of temperatures. The woylie obtains all its water requirements from its food (Sampson 1971). During the summer-autumn months, daytime temperatures are often high, and relative humidity low and body moisture conservation is essential. The very low moisture content of summer scats as compared with winter scats found in traps (personal observation) bear testimony to the efficient water-retention capacity of the animals. Nests may help the animals to further reduce evapo-transpiration

levels during periods of excessive heat. Burbidge (pers. comm), has shown measurable differences between nest temperatures, and the ambient air temperature on hot days

The nest may also be important in conserving body temperatures during the colder months when night temperatures often drop below freezing point. Radio-tracking data indicate that woylies usually spend the cold early morning hours within their nests, returning to them long before daylight. During the winter months the woylie is in poor condition (Sampson 1971, Christensen 1977), and this behaviour may assist in the conservation of energy resources which might otherwise be wasted keeping the animal warm.

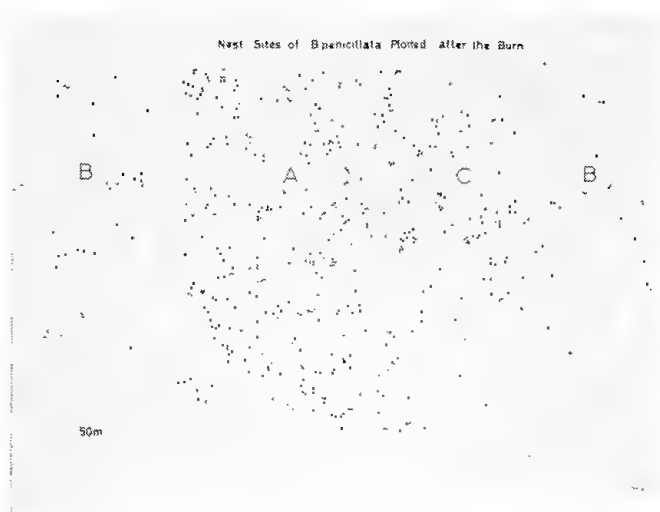


Figure 7.—Map showing distribution of burnt-out woylie nests following a fire in the Perup area. Nests were plotted using a compass and chain. A.—area previously unburnt for 9 years. B.—area previously unburnt for 4 years. C.—area previously unburnt for 4 years with a dense thicket of jarrah regrowth. ///—unburnt area with very sparse vegetation.

Acknowledgements.—The data presented here were collected during a 3 year study on the fire ecology of the woylie and the tammar financed by a Commonwealth post-graduate Research Award administered by the Director General, Forestry and Timber Bureau, Canberra. The authors also wish to acknowledge the assistance of the Conservator of Forests, Western Australia who supplied transport, equipment and facilities during the entire period of the study.

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The distribution and cover of plant species on Carnac Island, Western Australia.

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Abstract

The projective foliage cover in 1975 of all 97 plant species present on Carnac Island, a small island near Fremantle, was assigned to one of 6 categories. Although 53 species are naturalized aliens, most have a small distribution and/or low cover on the island. Closed-heath is the major structural vegetation formation. Distribution maps of 9 species characterizing 9 plant communities on Carnac Island are given. Possible ecological bases of these groupings are discussed in terms of exposure to sea spray, soil depth and nesting populations of seabirds. Parts of the vegetation map for the island are different from one drawn up in 1952.

Introduction

Carnac Island is a small low island 8 km west of Fremantle, Western Australia. It has an area of 16 ha and a maximum elevation of 17 m. During 1975-7 70 days were spent on the island chiefly studying the ecology of a bird species. Much time, however, was spent mapping the distribution of the most common and the rarest plant species, as well as compiling a list of the island's flora. This list, together with lists of plant species from adjacent islands, formed the basis of a paper dealing with the biogeography of the floras of the islands near Perth (Abbott 1977).

In this paper distribution maps are presented of 9 of the most conspicuous species and of 16 of the rarest and least conspicuous species, and a complete list of angiosperm species found is provided. The projective foliage cover of all species has been assigned to one of 6 categories. The paper concludes with a brief discussion of the plant ecology of Carnac Island relative to soil types, seaspray, seabirds and other factors.

Previous botanical studies on the island are relatively extensive. Preiss visited the island on 8 November 1839 but collected only 5 species (Lehmann 1838-1841), of which 4 have never been re-collected on the island (see later). The ornithologist Gilbert was there during 1839 and recorded 'a species of *Malva*', probably *Lavatera plebeia* (see Whittell 1942). There is then a long interval until McArthur collected 34 species on 21 January 1952 (McArthur 1957). In the late 1950s G. M. Storr and M. E. Gillham collected on the island. Storr's list was used in the study referred to above (Abbott 1977) and Gillham made use of some of her observations in developing her theory concerning the role of seabirds in vegetational cycles on islands (Gill-

ham 1961). Lindgren visited the island for one day each month during 1966-7 and has provided a useful list of the phenology of all plant species (Lindgren 1973, p. 163).

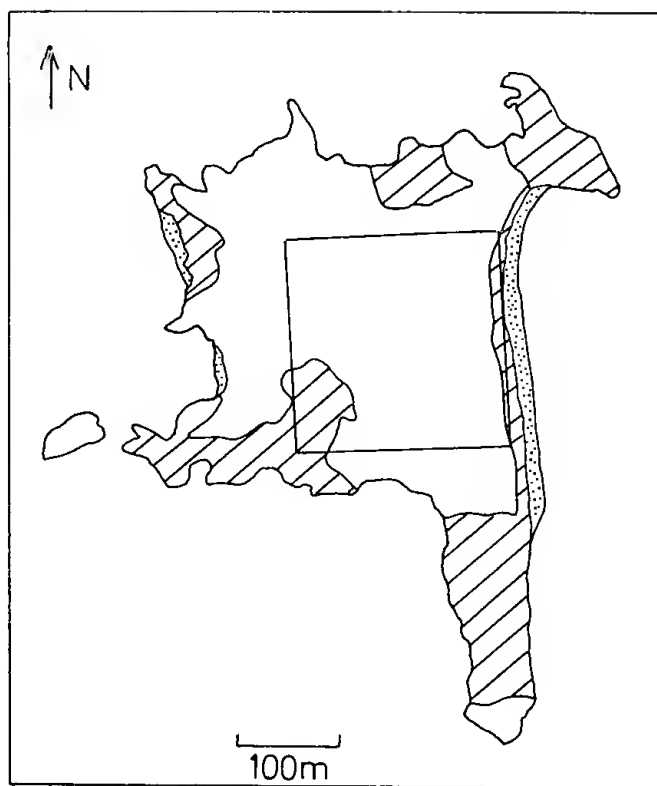


Figure 1.—Carnac Island, showing sand beaches (dots), Silver gull rookeries (diagonal lines) and 4 ha area in which quadrats were distributed at random (square).

Table 1

List of plant species found on Carnac Island in 1975.

* indicates naturalized alien species. Cover classes represent the following areas: 1, < 10 m²; 2, 10–100 m²; 3, 10²–10³ m²; 4, 10³–10⁴ m²; 5, 10⁴–10⁵ m²; 6, > 10⁵ m².

Species	Family	Cover class
<i>Acacia cyclops</i> A. Cunn. ex G. Don	Mimosaceae	3
<i>A. rostellifera</i> Benth.	Mimosaceae	5
<i>Acanthocarpus preissii</i> Lehm.	Liliaceae	5
* <i>Anagallis arvensis</i> L.	Primulaceae	4
<i>Apium prostratum</i> Vent.	Apiaceae	4
* <i>Arctotheca calendula</i> (L.) M. Levyns	Asteraceae	2
* <i>Atriplex patula</i> L.	Chenopodiaceae	1
* <i>Avena barbata</i> Brot.	Poaceae	3
* <i>Bellardia trixago</i> (L.) All.	Scrophulariaceae	2
* <i>Brassica tournefortii</i> Gouan	Brassicaceae	2
<i>Bromus arenarius</i> Labill.	Poaceae	1
* <i>B. diandrus</i> Roth	Poaceae	3
<i>Calandrinia calyptata</i> Hook.f.	Portulacaceae	2
<i>Calocephalus brownii</i> (Cass.) F. Muell.	Asteraceae	1
* <i>Carduus pycnocephalus</i> L.	Asteraceae	2
<i>Carex preissii</i> Nees	Cyperaceae	1
<i>Carpobrotus virescens</i> (Haw.) Schwantes	Aizoaceae	4
* <i>Catapodium rigidum</i> (L.) C.E. Hubb.	Poaceae	1
* <i>Centaurea melitensis</i> L.	Asteraceae	1
* <i>Cerastium glomeratum</i> Thuill.	Caryophyllaceae	1
* <i>Ctenopodium murale</i> L.	Chenopodiaceae	2
<i>Clematis microphylla</i> DC.	Ranunculaceae	4
<i>Comesperma integerrimum</i> Endl.	Polygalaceae	1
<i>Cotula coronopifolia</i> L.	Asteraceae	1
<i>Crassula colorata</i> (Nees) Ostenf.	Crassulaceae	2
<i>C. glomerata</i> L.	Crassulaceae	1
<i>C. pedicellosa</i> (F. Muell.) Ostenf.	Crassulaceae	1
* <i>Crepis foetida</i> L.	Asteraceae	1
<i>Daucus glochidiatus</i> (Labill.) Fisch. et al.	Apiaceae	1
* <i>Dischisma arenarium</i> E. Mey.	Scrophulariaceae	1
* <i>Ehrharta brevifolia</i> Schrad.	Poaceae	1
<i>E. longiflora</i> Sm.	Poaceae	3
<i>Enchylaena tomentosa</i> R.Br.	Chenopodiaceae	4
* <i>Erodium cicutarium</i> (L.) L'Herit. ex Ait.	Geraniaceae	2
* <i>Euphorbia pepus</i> L.	Euphorbiaceae	3
<i>Frankenia pauciflora</i> DC.	Frankeniaceae	5
* <i>Galium murale</i> (L.) All.	Rubiaceae	3
* <i>Gasoul crystallinum</i> (L.) Rothmaler	Aizoaceae	1
* <i>Geranium molle</i> L.	Geraniaceae	3
* <i>Hordeum leporinum</i> Link	Poaceae	2
<i>Hydrocotyle diantha</i> DC.	Apiaceae	1
<i>Hymenolobus procumbens</i> (L.) Nutt.	Brassicaceae	1
* <i>Hypochoeris glabra</i> L.	Asteraceae	2
* <i>Lactuca serriola</i> L.	Asteraceae	1
* <i>Lagurus ovatus</i> L.	Poaceae	2
* <i>Lavatera arborea</i> L.	Malvaceae	3
<i>L. plebeia</i> Sims	Malvaceae	2
<i>Lepidium foliosum</i> Desv.	Brassicaceae	4
<i>Lepidosperma gladiatum</i> Labill.	Cyperaceae	3
* <i>Lolium rigidum</i> var. <i>rottbollioides</i> Boiss.	Poaceae	3
* <i>Malva parviflora</i> L.	Malvaceae	2
* <i>Medicago polymorpha</i> L.	Fabaceae	2
* <i>Melilotus indica</i> (L.) All.	Fabaceae	3
<i>Nitraria schoberi</i> L.	Zygophyllaceae	4
<i>Olearia axillaris</i> (DC.) F. Muell.	Asteraceae	5
* <i>Parapholis incurva</i> (L.) C.E. Hubb.	Poaceae	1
<i>Parietaria debilis</i> Forst. f.	Urticaceae	2
<i>Pelargonium capitatum</i> (L.) Ait.	Geraniaceae	3
* <i>Phoenix canariensis</i> Hort. ex Chabaud	Arecaceae	1
* <i>Poa annua</i> L.	Poaceae	2
<i>P. poliformis</i> (Labill.) Druce (formerly called <i>P. australis</i> R.Br. at W.A. Herbarium)	Poaceae	2
<i>Podosperma angustifolium</i> Labill.	Asteraceae	2
* <i>Polycarpon tetraphyllum</i> Loef.	Caryophyllaceae	1
* <i>Raphanus raphanistrum</i> L.	Brassicaceae	1
* <i>Rapistrum rugosum</i> (L.) All.	Brassicaceae	1
<i>Rhagodia baccata</i> (Labill.) Moq.	Chenopodiaceae	5
* <i>Rumex pulcher</i> L.	Polygonaceae	1
* <i>Sagina apetala</i> Ard.	Caryophyllaceae	1
<i>Sarcocornia quinqueflora</i> (Bunge) ex Ung.-Stern. A.J. Scott	Chenopodiaceae	1
<i>Salsola kali</i> L.	Chenopodiaceae	1
<i>Scaevola crassifolia</i> Labill.	Goodeniaceae	5
<i>Scirpus antarcticus</i> Labill.	Cyperaceae	1
<i>S. nodosus</i> L.	Cyperaceae	2
<i>Senecio lautus</i> Forst.f. ex Willd.	Asteraceae	2
* <i>Silene nocturna</i> L.	Caryophyllaceae	3
* <i>Sisymbrium irio</i> L.	Brassicaceae	1
* <i>S. orientale</i> L.	Brassicaceae	2

Table 1—continued

Species	Family	Cover class
* <i>Solanum nigrum</i> L.	Solanaceae	1
<i>S. synonymii</i> Eichler	Solanaceae	1
* <i>Sonchus oleraceus</i> (Hook.f.) J.M. Black	Asteraceae	1
* <i>S. oleraceus</i> L.	Asteraceae	2
* <i>Spinifex longifolius</i> R.Br.	Poaceae	3
<i>Spyridium globulosum</i> (Labill.) Benth.	Rhamnaceae	2
* <i>Stellaria media</i> (L.) Vill.	Caryophyllaceae	3
<i>Stipa flavescens</i> Labill. (formerly called <i>S. variabilis</i> D.K. Hughes at W.A. Herbarium)	Poaceae	2
<i>Tetragonia anplexicoma</i> (Miq.) Hook.f.	Aizoaceae	2
<i>T. decumbens</i> Mill.	Aizoaceae	3
<i>Threlkeldia diffusa</i> R.Br.	Chenopodiaceae	4
* <i>Trachyandra divaricata</i> (Jacq.) Kunth.	Liliaceae	3
* <i>Trifolium campestre</i> Schreb. in Sturm	Fabaceae	2
* <i>T. scabrum</i> L.	Fabaceae	1
* <i>T. tomentosum</i> L.	Fabaceae	1
<i>Triglochin trichophora</i> Nees	Juncaginaceae	1
* <i>Urospermum picroides</i> (L.) F.W. Schmidt	Asteraceae	2
* <i>Urtica urens</i> L.	Urticaceae	2
* <i>Vulpia myuros</i> (L.) Gmel.	Poaceae	1
* <i>Zantedeschia aethiopica</i> (L.) Spreng.	Araceae	1

Methods

Carnac Island was visited 10 times over 3 years, spanning all seasons. Each visit was of one week's duration. Dates of these visits are given by Abbott (1978). Specimens were collected of all species seen and were determined by the staff of the Western Australian Herbarium and the Botany Department, University of Western Australia. Only fragments of very rare species were collected, so as not to cause their depletion or extinction. The distribution of various species was marked on maps made from a large scale aerial photograph of the island. The projective foliage cover of each plant species was then estimated and assigned to one of six categories (see Table 1). The maximum cover possible is 1.6×10^5 m², the area of the island. High cover values need not necessarily indicate great abundance; a projective foliage cover value of 150 m², for example, could represent either species with many individual plants (e.g. weeds) or those medium-sized shrubs such as *Acacia rostellifera* with fewer individual plants.

In January 1975 a 4 ha site (Fig. 1) was sampled with 50 1 m² randomly placed quadrats. This permitted a more detailed analysis of the most widespread plant community on the island.

Results

Ninety seven plant species were recorded (Table 1), of which 53 are aliens (indicated by an asterisk in Table 1). Table 2 shows the number of plant species in each cover class. The cover classes have been defined on a log₁₀ scale, but this is approximate only because class 1 is defined as < 10 m² and not 1 - 10 m². Despite this, the frequency (in the statistical sense) of the projective foliage cover of plant species on Carnac Island shows a reasonable approximation to the commonly found lognormal distribution (Preston 1962) in which there are more species with small cover than ones with large cover. Only one alien species has a cover value greater than 3, whereas 13 native species are category 3 or higher. In the first 3 classes of cover there are more alien

Table 2

Number of plant species in each class of projective foliage cover.

	Cover class					
	1	2	3	4	5	6
All species	38	28	17	8	6	0
Aliens	23	18	11	1	0	0
Natives	15	10	6	7	6	0

Table 3

Frequency and median and mean projective foliage cover of the seven most frequent plant species on a 4 ha site on Carnac Island in January 1975.

Species	% Frequency	% Cover		
		Mean	Median	Range
<i>Acacia rostellifera</i>	66	35	25	2-100
<i>Rhagodia baccata</i>	64	37	20	2-100
<i>Olearia axillaris</i>	40	20	15	5-60
<i>Threlkeldia diffusa</i>	38	22	11	2-60
<i>Acanthocarpus preissii</i>	38	28	15	3-100
<i>Clematis microphylla</i>	26	15	15	5-25
<i>Carpobrotus virescens</i>	20	18	9	1-100

Based on fifty 1 m² quadrats randomly distributed in a 4 ha site (Fig. 1). Only species with a frequency of 20% or more are included.

species represented (52) than native ones (31). There is therefore a significant association between plant origin (i.e. native vs alien) and cover ($\chi^2_1 = 12$, $P < 0.001$).

These quantitative data may allow future workers to monitor whether alien species on Carnac Island increase in projective foliage cover at the expense of native species.

Quadrat analysis

Because sampling was in summer only the frequency (i.e. per cent occurrence in 50 1 m² quadrats) and projective foliage cover (in the same number of quadrats) of perennial species are given (Table 3). Seven species had a frequency of 20% or higher. In almost every case the median percentage cover is less than the mean percentage cover, indicating that cover values are not normally distributed but instead are positively skewed. Most quadrats have a low percentage projective foliage cover for each plant species. The most frequent perennial species tend to have the highest median projective foliage covers (Table 3).

Maps of species distribution

Six of the 7 most abundant species are mapped: *Acacia rostellifera* and *A. cyclops* (Fig. 2), *Rhagodia baccata* and *Frankenia pauciflora* (Fig. 3), *Scaevola crassifolia* (Fig. 4), *Olearia axillaris* (Fig. 5) and *Nitraria schoberi*, *Tetragonia decumbens* and *T. amplexicoma* (Fig. 4). Several locally rare species or easily overlooked species are mapped in Figure 6; this is to aid future workers in relocating these species.

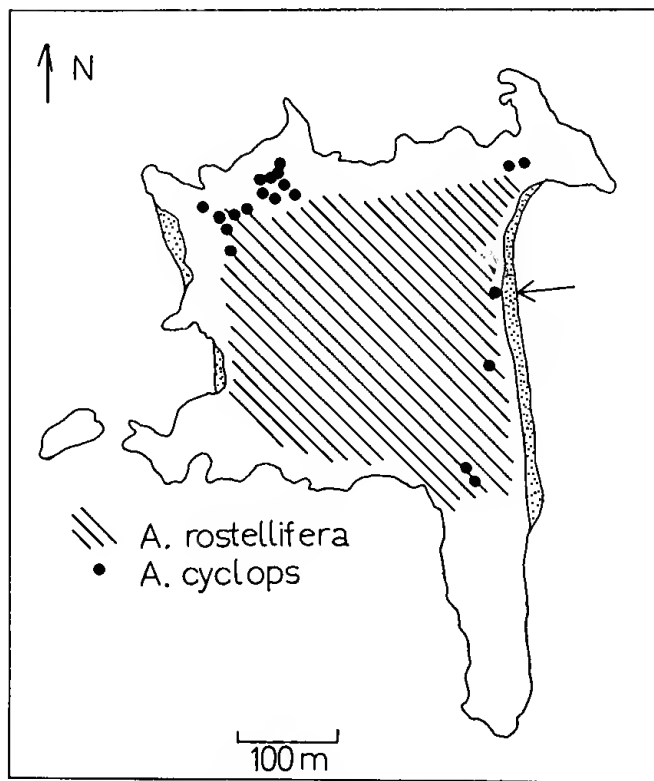


Figure 2.—Distribution of *Acacia rostellifera* and *A. cyclops* on Carnac Island. The use of black circles for *A. cyclops* is meant to convey the patchiness of its distribution; they do not necessarily represent single individuals. The arrow indicates a tree that was killed by exceptionally high tides during winter 1975.

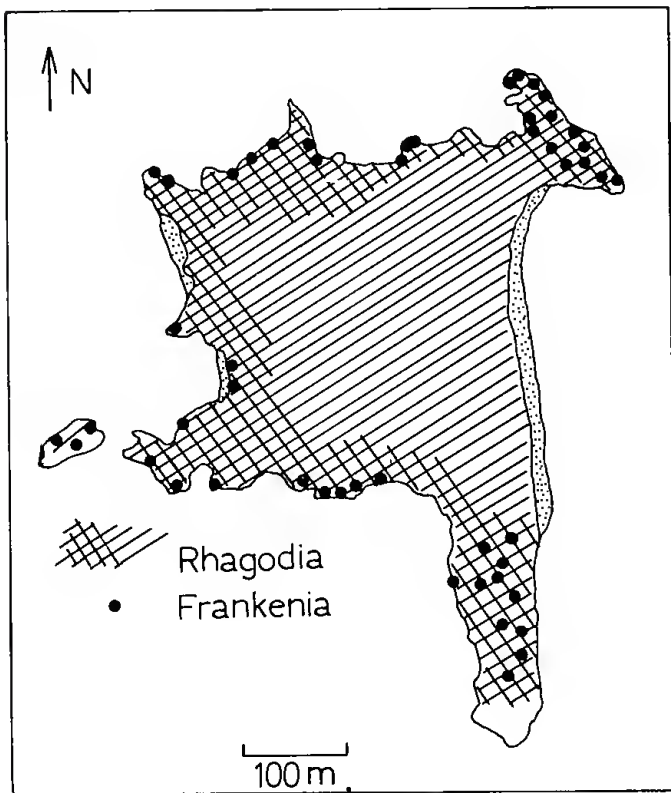


Figure 3.—Distribution of *Rhagodia baccata* and *Fraukenia pauciflora* on Carnac Island. Cross-hatching indicates places where *Rhagodia* is particularly common. Use of solid circles as in Figure 2.

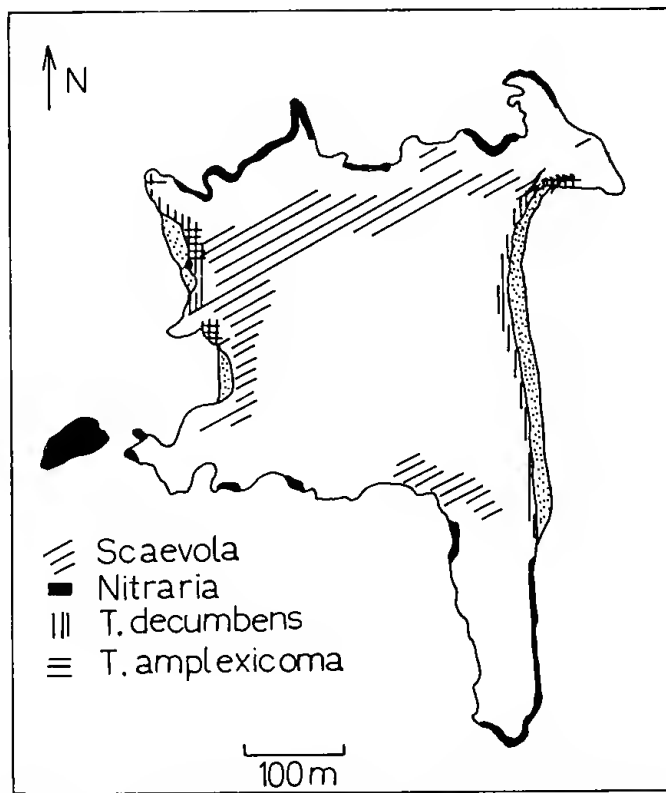


Figure 4.—Distribution of *Scaevola crassifolia*, *Nitraria schoberi*, *Tetragonia decumbens* and *T. amplexicoma* on Carnac Island.

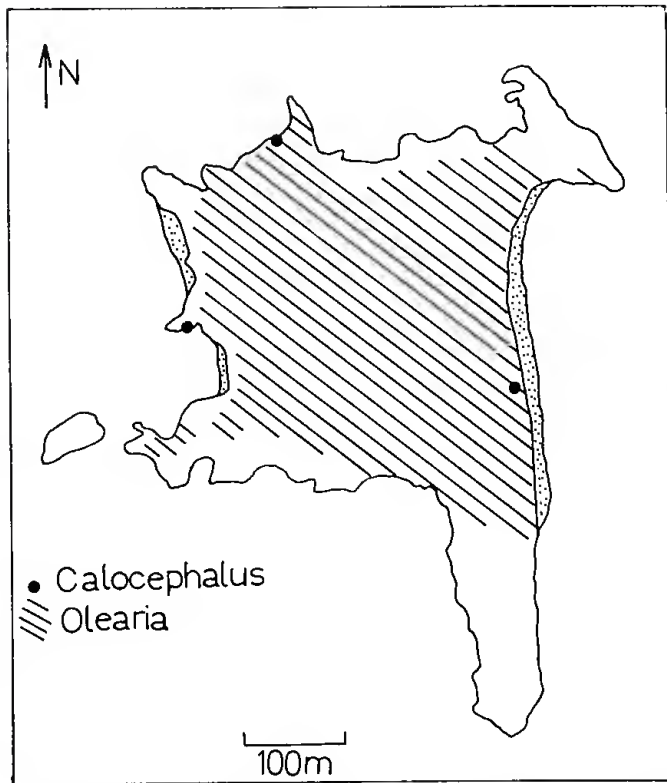


Figure 5.—Distribution of *Olearia axillaris* and *Calocephalus brownii* on Carnac Island. Use of solid circles as in Figure 2.

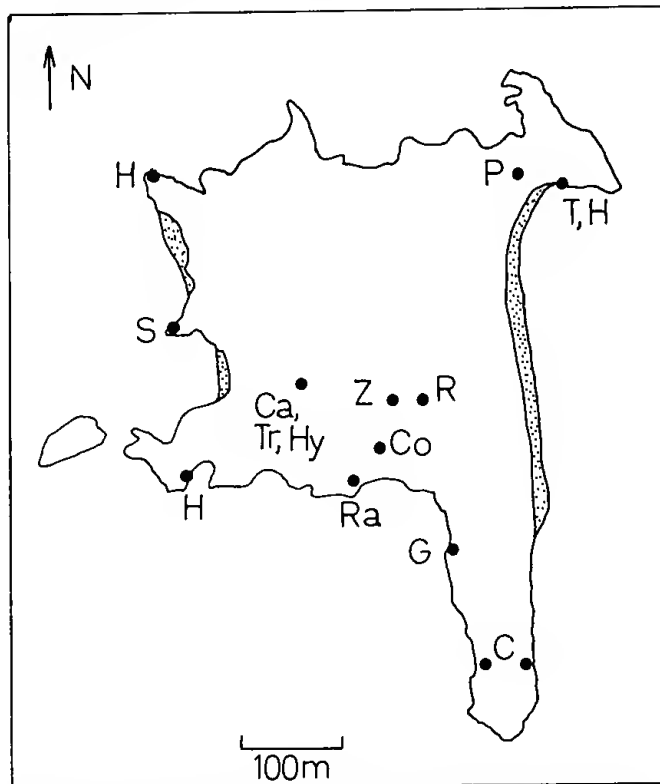


Figure 6.—Distribution of 16 of the rarest plant species on Carnac Island. Ca—*Carex preissii*; C—*Cotula coronopifolia*; Co—*Comesperma integerrimum*; G—**Gasoul crystallinum*; H—*Hymenolobus procumbens*; Hy—*Hydrocotyle diantha*; P—**Phoenix canariensis*; R—**Rumex pulcher*; Ra—**Raphanus raphanistrum* and **Rapistrum rugosum*; S—*Sarcocornia quinqueflora*; T—*Triglochin trichophora*; Tr—**Trifolium cauprestr*, **T. scabrum* and **T. tomentosum*; Z—**Zantedeschia aethiopica*.

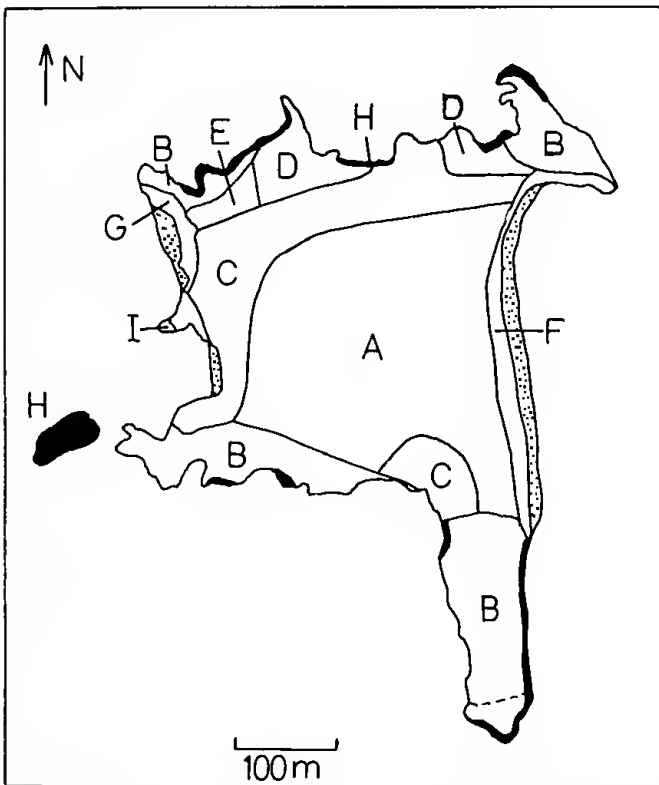


Figure 7.—Vegetation map (1975) of Carnac Island. Plant communities are designated as follows: A—*Acacia rostelifera*-*Rhagodia baccata*-*Olearia axillaris* closed-heath; B—*Rhagodia*-*Frankenia pauciflora* closed-heath; C—*Scaevola crassifolia*-*Rhagodia*-*Olearia* closed-heath; D—*Rhagodia*-*Olearia* closed-heath; E—*Acacia cyclops*-*Rhagodia* closed-heath; F—*Tetragonia decumbens* closed-herbland; G—*Tetragonia*-*Rhagodia* closed-heath; H—*Nitraria schoberi* closed-heath; I—*Sarcocornia quinqueflora* open-herbland.

Vegetation map of Carnac Island

When Figures 2-5 are integrated, 9 plant communities can be recognized (Fig. 7). The most extensive is closed-heath (Specht 1970) comprising mainly *Acacia rostelifera*, *Rhagodia baccata* and *Olearia axillaris* (designated A in Fig. 7). This occupies most of the centre and most sheltered part of the island. Comparison of Figures 1 and 7 shows that the 4 ha site sampled with quadrats covered most of this community (see also Table 3). As prevailing winds come from the west or south-west, the height of *Acacia rostelifera*, the tallest member of this community, increases from 1 m to 3-4 m from west to east. Open spaces in this community are occupied most commonly by *Bromus diandrus*, *Avena barbata*, *Brassica tournefortii*, *Ehrharta longiflora* and *Sonchus oleraceus*. (The asterisks indicate species that are naturalized aliens). Prior to disturbance by man on the island, it is suspected that *Acanthocarpus preissii* was probably the dominant ground cover in this community.

The next most extensive community is a closed-heath (B in Fig. 7) dominated by *Rhagodia baccata* and *Frankenia pauciflora*. The *Rhagodia* is between 0.5 and 1 m in height, and the *Frankenia* rarely exceeds 0.5 m. This community is restricted to areas on the edge of the island where the aeolianite has only a shallow depth of soil over it.

The third most extensive community consists predominantly of *Scaevola crassifolia*, *Rhagodia baccata* and *Olearia axillaris* closed-heath (C, Fig. 7). Height of the tallest member, *Olearia*, rarely exceeds 1 m. Community D is a depauperate version of C, lacking *Scaevola crassifolia*. Community E consists of a closed-heath of *Acacia cyclops* and *Rhagodia baccata*; the height of the *Acacia* just exceeds 2 m. Communities F and G occur on deep sands on the periphery of the island. F is a closed-herbland of *Tetragonia decumbens*, and G a closed-heath of *T. decumbens* with *Rhagodia baccata*. Community H is a monospecific closed-heath found on cliffs and talus slopes around much of the island and consists of *Nitraria schoberi*. The smallest recognizable community on the island, I, consists of *Sarcocornia quinqueflora* open-herbland on the mid-western point.

This vegetation map may be compared with one produced earlier (McArthur 1957). Seven communities were then recognized (Fig. 8): A, *Acacia rostelifera*-*Olearia axillaris* scrub; B, *Olearia*-*Scaevola crassifolia* low scrub; C, *Rhagodia baccata*-*Frankenia pauciflora* low scrub; D, *Scaevola*-*Calocephalus brownii* low scrub; E, *Rhagodia* low scrub; F, *Carpobrotus virescens*-*Tetragonia* spp.-*Suaeda maritima* (sic, apparently an error for *Threlkeldia diffusa*), and G, *Nitraria schoberi*. Some of the more obvious differences between the two maps include the following. *Rhagodia baccata* was not seen to be a codominant in McArthur's communities A and B (Fig. 8) whereas Table 3 and Figure

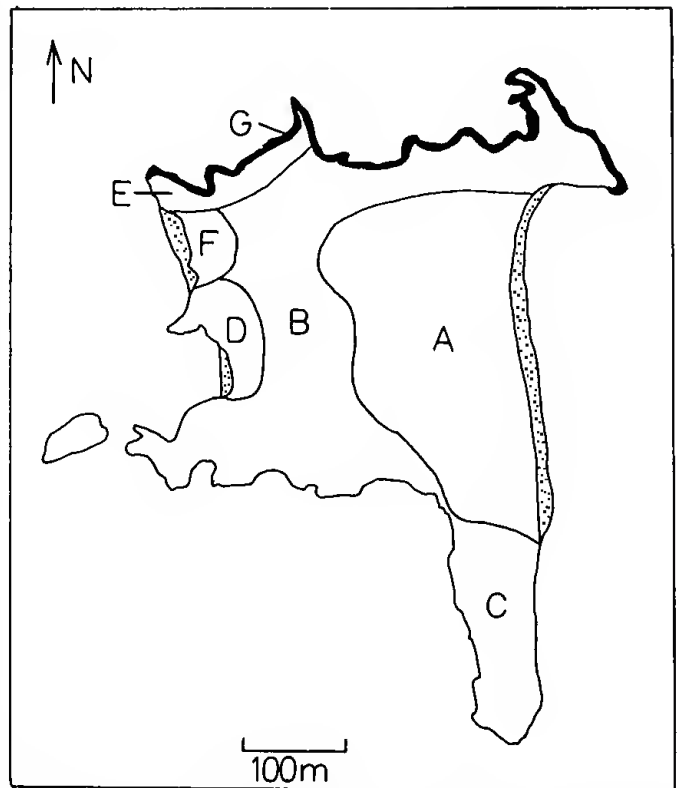


Figure 8.—Vegetation map (1952), after McArthur (1957). A—*Acacia rostelifera*-*Olearia axillaris* scrub; B—*Olearia*-*Scaevola crassifolia* low scrub; C—*Frankenia pauciflora*-*Rhagodia* low scrub; D—*Scaevola*-*Calocephalus brownii* low scrub; E—*Rhagodia* low scrub; F—*Carpobrotus virescens*-*Tetragonia* spp.-*Suaeda maritima* (sic) mat; G—*Nitraria schoberi* low scrub.

3 show it to be widespread and with a high projective foliage cover. Second, McArthur indicated that the community on the north-east peninsula was the same as his community B, but this is not so now. McArthur's community D (Fig. 8) gives *Calocephalus brownii* the status of a codominant species, whereas today it is quite rare on Carnac Island (Fig. 5) and makes no contribution to the physiognomy of the vegetation. McArthur (1952) stated that this species extended about 50 m back from the coast. *Nitraria schieberi* was stated by McArthur to be present only on the northern side of the island, but its distribution now is wider. Other differences are evident from carefully comparing Figures 7 and 8.

There are two possibilities to be considered in explaining these changes in vegetation over 25 years. First, changes in weather patterns, the density of grazing rabbits, occurrence of fires or of human use of the island may be responsible. Alternatively, differences between Figures 7 and 8 may be more apparent than real because McArthur was only able to spend one day (in mid-summer) on the island. I prefer to adopt the conservative conclusion that Figure 8 was based on insufficient reconnaissance to form a reliable baseline. This of course does not rule out that a real change in vegetation did not occur.

Plant ecology of Carnac Island

Without appropriate experimentation it is difficult to sort out the effect of differences in exposure to seaspray, the type and depth of soil, and the concentration of seabird guano in determining the distribution and cover of the plant species on Carnac Island.

Because McArthur visited the island in summer, when none of the surface-nesting species of seabirds breed, he not surprisingly makes no mention of the importance that seabirds have on the plant ecology. Instead, soil and substrate type, as well as wind and hence seaspray, were emphasized as factors controlling the vegetational and plant diversity. As is clear from Figure 1, nesting areas of Silver gulls (*Larus novaehollandiae*) covered, in 1975, at least half of the island. Gull rookeries alter the vegetation structure to a certain extent. Thus parts of communities A, B, and C (Fig. 7) have been converted from closed-heath to open-heath, mainly through the deposition of guano (Gillham 1961). Seventeen plant species are either found only in the gull rookeries or are most common in them: *Arctotheca calendula*, *Bromus arenarius*, *Calandrinia calyptrata*, *Chenopodium murale*, *Erodium cicutarium*, *Lavatera aborea*, *L. plebeia*, *Lepidium foliosum*, *Lolium rigidum*, *Malva parviflora*, *Medicago polymorpha*, *Parietaria debilis*, *Poa annua*, *Senecio laevis*, *Sisymbrium orientale*, *Stellaria media* and *Urtica urens*.

Certain species are restricted to, or are most common near, the edge of the island. This is the part of the island most prone to receive heavy deposition of salt spray, but it is also where aeolianite mainly outcrops, so that soils (pH 7.1) there are the shallowest on the island. These sites are favoured by nesting Silver gulls. Such plant species are: *Apium prostratum*, *Bromus arenarius*, *Calandrinia calyptrata*, *Calocephalus brownii*, *Cotula coronopifolia*, *Frankenia pauciflora*, *Lavatera plebeia*, *Lepidium*

foliosum, *Lolium rigidum*, *Malva parviflora*, *Nitraria schieberi* (more common on talus slopes), *Poa annua*, *Sagina apetala*, *Sarcocornia quinqueflora*, *Senecio laevis*, *Sisymbrium orientale*, *Stellaria media* and *Urtica urens*.

Species apparently restricted to, or best developed in, deep sandy soil (pH 7.4) occur in the central-eastern sector of the island. Such species include both *Acacia* species, *Acanthocarpus preissii*, *Anagallis arvensis*, *Avena barbata*, *Bellardia trixago*, *Brassica tournefortii*, *Bromus diandrus*, *Carduus pycnocephalus*, *Centaurea melitensis*, *Cerastium glomeratum*, *Clematis microphylla*, *Crepis foetida*, *Daucus glochidiatus*, *Dischisma arenarium*, *Ehrlharta longiflora*, *Euphorbia pepus*, *Galium murale*, *Geranium molle*, *Lepidosperma gladiatum*, *Melilotus indica*, *Olearia axillaris*, *Parietaria debilis*, *Pelargonium capitatum*, *Podosperma angustifolium*, *Salsola kali*, *Scaevola crassifolia*, *Scirpus antarcticus*, *S. nodosus*, *Silene nocturna*, both *Sonchus* species, *Spinifex longifolius*, *Tetragonia decumbens*, *Trachyandra divaricata* and *Urospermum picroides*. Deepest sands tend to be best developed in the eastern half of the island, which is the most sheltered from seaspray, so these species may be responding to absence of guano and salt spray as well as soil depth. Some species could be excluded from aeolianite pavement through competition.

The remainder of the plant species are widespread over the island or require no special comment.

As is usual with most island floras, there are species which should be expected on, but are missing from, Carnac Island. Judging from my experience on all the islands near Perth (Abbott 1977), and in particular the northern end of Garden Island, only 3 km south of Carnac Island, I include the following plant species in this category: *Acrotriche cordata* (Labill.) R.Br., *Alyxia buxifolia* R.Br., *Cassytha* species, *Conostylis caudicans* Endl., *Dichondra repens* Forst. & Forst. f., *Eremophila glabra* (R.Br.) Ostenf., *Exocarpos sparteus* R.Br., *Hardenbergia comptoniana* (Andr.) Benth., *Leucopogon parviflorus* (Andr.) Lindl., *Myoporum adscendens* R.Br., *Pittosporum phylliraeoides* DC. and *Sporobolus virginicus* (L.) Kunth. Doubtless many of these species were present when the bridge between Carnac and Garden Islands became submerged about 5000 yr BP (deduced from RAN chart 117 and graph in Thom and Chappell 1975), but have since become extinct on Carnac Island. *Alyxia buxifolia* (in the above list), as well as *Stipa elegantissima* Labill., *Phyllanthus calyciinus* Labill. and *Zygophyllum australasicum* Miq. were collected on Carnac Island in November 1839 by Dr L. Preiss (Lehmann 1838-1841), but they are not now present on the island.

Factors that may have played a part in causing extinctions include the extinction of the Tamar wallaby *Macropus eugenii* probably soon after Carnac became isolated (A. R. Main, 1976 pers. comm.); increased degree of exposure to salt spray; presumed increase in abundance of nesting Silver gulls, especially since the founding of Perth in 1829; the introduction of rabbits in the 1820s (Seddon 1972, Abbott 1978), and attempts to farm sheep on the island (there is a well in the central-eastern sector which was probably cleared at some stage, but no details are available). These herbivores would have altered the vegetation and flora of the island by preferentially

cating palatable plant species, thereby allowing the unpalatable ones to become more common. Some of the early effects of man on the ecology of Carnac Island are briefly discussed by Seddon (1972, p. 215).

The impact of rabbits on the ecology of Carnac Island was evidenced when carrots, poisoned with the fluoroacetate 1080, were distributed by hand over the island on 13 May 1969. The next day 60 carcasses were found and all subsequent inspections have shown that rabbits are now absent (A. J. Oliver, 1978 pers. comm.; pers. obs.). Comparison of colour aerial photographs (scale 1 : 4800) taken on 21 April 1969 and 14 February 1972 clearly show the marked recovery of the island's vegetation. At the second date there was more straw (dead grass) in community A, replacing much bare sand evident in the earlier photograph. The communities dominated by low-growing plant species (B, F and G in Fig. 7) show an increase in ground cover. Studies elsewhere have shown that grazing by rabbits tends to cause the less palatable plant species to increase in cover and to lead to a decline in dry matter production (Myers and Poole 1963), as well as increasing plant species diversity if the tall-growing species are preferentially browsed (Gillham 1955).

The role of grazing by Tammars especially requires further study if their influence on the vegetation of the island is to be evaluated properly. The vegetation on the western coast of Garden Island is similar to that on Carnac Island, and Tammars have the lowest density there of all habitats on Garden Island (Kelsall 1965). Tammars find *Rhagodia baccata* palatable on Garden Island, so their absence from Carnac Island may help explain the abundance of this plant species on Carnac. On West Wallabi Island in the Houtman Abrolhos, *Alyxia buxifolia* and *Nitraria schoberi* amongst other plant species are over-browsed by Tammars (Kelsall 1965). Several species, including *Acacia rostellifera*, *Eremophila glabra*, *Myoporum adscendens*, *Nitraria schoberi*, *Olearia axillaris*, *Scaevola crassifolia*, *Sporobolus virginicus* and *Spyridium globulosum*, on Rottnest Island are preferentially grazed by the Quokka *Setonix brachyurus* (Storr 1957). Plant species resistant to this grazing dominate the vegetation, although on Rottnest other factors such as fire history are important. The sedge *Carex preissii*, although rare on Carnac Island (Fig. 6), was of vigorous stature and was found fruiting. On Rottnest and Garden Islands the wallabies find them very palatable and consequently the sedge is continually browsed. I have not found *Carex preissii* in fruit on these two islands.

In summary, little that is definitive can be written about the causes of the distribution and cover of individual plant species on Carnac Island until appropriate experimental studies are made. These will involve the role of seabirds, grazing wallabies and rabbits, seaspray, and competition between plant species, considered together.

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Further searches for the Dibbler, *Antechinus apicalis* (Marsupialia: Dasyuridae)

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Abstract

The Dibbler, *Antechinus apicalis*, is a rare dasyurid marsupial. At the present time Dibblers are known to occur in only two localities (Cheyne Beach and Jerdacuttup) in the south of Western Australia. A total of 9 Dibblers have been trapped at Cheyne Beach since 1967, when the first specimens collected for 83 years were captured. Dibblers have been found there in only one small area of about 10 ha of *Banksia*-dominated heathland. At Jerdacuttup 2 Dibblers were reported from farms in 1976 but all attempts to trap them in the region have been unsuccessful, despite intensive trapping in a variety of vegetation associations, including heathland similar to that in the Cheyne Beach locality. The search for the Dibbler has been extended to the Fitzgerald River National Park, between Cheyne Beach and Jerdacuttup, but trapping in heathland there was also unsuccessful.

Introduction

The Dibbler, *Antechinus apicalis*, was considered to be extremely rare, if not extinct, prior to 1967 when Morcombe (1967) collected 2 specimens at Cheyne Beach, Western Australia. Following Morcombe's discovery many attempts were made to collect more specimens. In a previous paper Woolley (1977) recorded the results of all known attempts to trap the Dibbler in the one known habitat at Cheyne Beach and in other localities from the time of re-discovery until February 1976. The other localities included one near Jerdacuttup, some 225 km to the north-east of Cheyne Beach, where a Dibbler was brought in by a cat on a farm in January 1976. The habitat of the Dibbler in this region was not discovered.

Further trapping was carried out late in 1976 at Cheyne Beach and Jerdacuttup. Following the report of a second Dibbler on another farm near Jerdacuttup in December 1976 more trapping was carried out in this region in 1977 and 1978. In addition a search has been made in the Fitzgerald River National Park, which lies within the present known range of the Dibbler. This paper records the results of attempts to trap the Dibbler at Cheyne Beach, Jerdacuttup and the Fitzgerald River National Park between November 1976 and February 1978.

Trapping at Cheyne Beach

November-December 1976

The reason for trapping in the known Dibbler habitat at Cheyne Beach (Area A, Locality 1; Woolley 1977) was to compare the efficiency of a new type of trap with that of the large Sherman traps (23 × 8 × 9 cm) used previously, and to test the

relative effectiveness of unbaited traps and traps baited with two different baits. The new trap was a special non-folding Elliott (26 × 10 × 10 cm) with perforated metal sides, top and rear end designed for a study of the ecology of *Sminthopsis leucopus* (Ahern 1974). Fifty special Elliott and 50 Sherman traps were set in pairs in Area A on the nights of 29 and 30 November and 1 December. The traps were washed before use and on the first night were set unbaited. On the second night 3 live male crickets (*Teleogryllus commodus*) per trap, confined in wire mesh containers, were used as bait. On the third night the traps were baited with bacon and peanut butter, the bait used in previous trapping. The results of trapping on the 3 nights are shown in Table 1.

The *Rattus fuscipes* trapped on the first and second nights were marked with semi-permanent ink and released at the site of capture. The male *Tarsipes spencerae* was in poor condition when removed from the trap and it died later in the day. The specimen was lodged in the Western Australian Museum (number M14948). The *R. fuscipes* and the *A. apicalis* trapped on the third night were released. Both *A. apicalis* females captured were judged on pouch condition (nipples minute, pouch fur pale) to be less than 1 year old. The body weight of one was 42.5 g and the other, 50 g. In a total of 300 trap-nights 12 *R. fuscipes* (minimum of 8 individuals), 1 *T. spencerae* and 2 *A. apicalis* were trapped. Trapping success for *A. apicalis*, was approximately 0.6% or, if each pair of traps at one site is regarded as one, 1.2%.

It can be seen from Table 1 that a greater number and variety of animals were caught in the special Elliott traps than in the Sherman traps, and that more animals were captured in baited traps than in unbaited

Table 1

Animals captured on 3 nights using 2 types of trap, unbaited on the first night and with different baits on the second and third nights

	Night 1 (no bait)	Night 2 (live crickets)	Night 3 (bacon & peanut butter)	Total
Special Elliott traps	1 <i>R.f.</i> ♀	3 <i>R.f.</i> 2♀, 1♂ (R) 1 <i>T.s.</i> ♂	5 <i>R.f.</i> 3♀ (1R), 2♂ (1R) 2 <i>A.a.</i> 2♀	9 <i>R.f.</i> (3R) 1 <i>T.s.</i> 2 <i>A.a.</i>
Sherman traps	1 <i>R.f.</i> ♂	1 <i>R.f.</i> ♀	1 <i>R.f.</i> ♀ (R)	3 <i>R.f.</i> (1R)
Total	2 <i>R.f.</i>	4 <i>R.f.</i> (1R) 1 <i>T.s.</i>	6 <i>R.f.</i> (3R) 2 <i>A.a.</i>	12 <i>R.f.</i> (4R) 1 <i>T.s.</i> 2 <i>A.a.</i>

R.f. = *Rattus fuscipes*, *T.s.* = *Tarsipes spencerae*, *A.a.* = *Antechinus apicalis*, R = recapture.

traps. The two Dibblers were both trapped in special Elliott traps on the third night when bacon and peanut butter was used as bait.

In November 1975 (Woolley 1977) 3 Dibblers were trapped in 90 trap-nights over 4 nights (2 on the first night and one on the third) using Sherman traps baited with bacon and peanut butter, giving a trapping success of approximately 3%. Comparison of the results obtained in 1975 and 1976 suggests that the bait is more important than the type of trap when trapping for *A. apicalis*, although when a choice of traps containing the same bait is available the special Elliott traps are preferred. Since bacon and peanut butter seemed to be the most effective bait it was used in all subsequent trapping. Because the special Elliott traps were non-folding, and therefore less convenient, their use was discontinued after trapping at Jerdacuttup in December 1976.

Trapping at Jerdacuttup

December 1976

The trapping, carried out following the report of the first Dibbler found on a farm near Jerdacuttup, was done in February 1976. No Dibblers were trapped in over 1000 trap-nights. One possible explanation for the lack of success was that the trapping was carried out too close to the breeding season, when, in a related species, trapping success was known to be lower than at other times (Woolley 1977). For this reason further trapping was carried out in December, approximately 3 months before the expected commencement of the breeding season (Woolley 1971). Sherman and special Elliott traps baited with bacon and peanut butter were set in 2 of the 4 localities in which trapping had previously been carried out.

Tamarine Road and Oldfield Location 829; Locality 7, Figure 1.—The south-east corner of Oldfield Location 829 is a block of uncleared land adjacent to the Tamarine Road reserve. Fifty Sherman traps were set along 0.8 km of the northern edge of this block on the nights of 2 and 3 December. No animals were trapped. Another 50 Sherman traps were set along the route of an old telegraph line running roughly east to west through the centre of the block on the nights of 4 and 5 December. Two *R. fuscipes* were trapped. Fifty Sherman traps were set on the road reserve on the night of 6 December, when another 2 *R. fuscipes* were trapped. In a total of 250 trap-nights over 5 days only 4 *R. fuscipes* were trapped.

“Slieve Donard” (Oldfield Location 826) and adjacent land; Locality 10, Figure 1.—Trapping in this locality was carried out in Areas A and C (see Figure 4, Woolley 1977) and in a narrow border of native vegetation along 0.5 km of the drive in from the main road to the house. Fifty special Elliott traps were set along the drive on the nights of 2 and 3 December and 50 Sherman traps were set in Area A on the nights of 3, 4 and 5 December. The 50 Elliott traps were moved to Area C for the nights of 4 and 5 December. In a total of 350 trap-nights in Locality 10 only 1 skink was captured.

January 1977

On 17 December 1976 a second Dibbler was found dead near the house on a farm approximately 10 km to the north-east of “Slieve Donard”. The specimen, which was a dry and badly decomposed male, was lodged in the Western Australian Museum (number M14931). Following the finding of this specimen further attempts to trap the Dibbler were made. Apart from very small areas of native vegetation near the house and around 2 creek beds near the northern boundary there was no uncleared land remaining on the property (Oldfield Location 813) where the Dibbler was found so most of the trapping was done in nearby areas of bushland. Large Sherman and standard Elliott traps (32 × 8 × 10 cm) baited with bacon and peanut butter were used.

Oldfield Location 813 and adjacent land; Locality 11, Figure 1.—Fifty Sherman traps were set around the creek beds near the northern boundary of the property on the nights of 14, 15 and 16 January. Another 50 were set in the adjacent road reserve on the south side of North Jerdacuttup Road and 25 on the north side on the nights of 16, 17 and 18 January. Fifty Sherman traps were set around the house area on the night of 22 January. In a total of 425 trap-nights 1 *M. musculus* and 2 lizards were trapped.

Oldfield Location 812; Locality 12, Figure 1.—Fifty Sherman traps were set between the creek and the northern boundary in a line approximately 1 km long starting from the eastern boundary for 3 consecutive nights from 19 January. No animals were caught in a total of 150 trap-nights.

Vacant Crown Land (Oldfield Location 1221); Locality 13, Figure 1.—Fifty Sherman and 50 Elliott traps were set on the eastern edge of the northern

half of this block on the nights of 14 and 15 January. In a total of 200 trap-nights no animals were captured.

Oldfield Location 814; Locality 14, Figure 1.—Fifty Elliott traps were set in bushland to the north of a cleared, fenced block in the south-eastern corner of this property on the nights of 22 and 23 January. No animals were trapped in 100 trap-nights.

Government Requirements Reserve No. 28110; Locality 9, Figure 1.—One hundred Sherman traps were set on the northern boundary of this block in a line extending approximately 1.5 km from the eastern boundary on the nights of 21 and 22 January. Another 50 Sherman traps were set on the eastern side at the southern end of this block on the nights of 22 and 23 January. In a total of 300 trap-nights 2 skinks, 1 *M. musculus* and 2 *T. spencerae* (both females without young in the pouch) were captured.

February 1978

Traps were set in 3 of the localities in which trapping had previously been carried out. Large Sherman and standard Elliott traps baited with bacon and peanut butter were used.

Tamarine Road and Oldfield Location 829; Locality 7, Figure 1.—One hundred and twenty-five Sherman traps were set for 3 consecutive nights from 6 February on a line 1 km long across the southern end of the block of uncleared land in Oldfield Location 829 (see above). The trap line passed through an area not burnt in the last 20 years (G. Boothey, pers. comm.). In 375 trap-nights 31 *R. fuscipes* (22 individuals, 9 males, 13 females), 1 female *T. spencerae* with 2 pouch young (crown-rump length of young approximately 17 mm) and 1 Tiger-snake were trapped.

"Slieve Donard" (Oldfield Location 826) and adjacent land; Locality 10, Figure 1.—Sherman traps were set in Area A and Elliott traps in Area D (see Figure 4, Woolley 1977) for 3 consecutive nights from 8 February. In a total of 140 trap-nights in Area A 2 *M. musculus* were trapped, and in 225 trap-nights in Area D, 1 *M. musculus* was trapped.

Government Requirements Reserve No. 28110; Locality 9, Figure 1.—One hundred Sherman traps were set on the nights of 9 and 10 February along 1 km at the eastern end of the northern boundary. Only 1 frog was caught in 200 trap-nights.

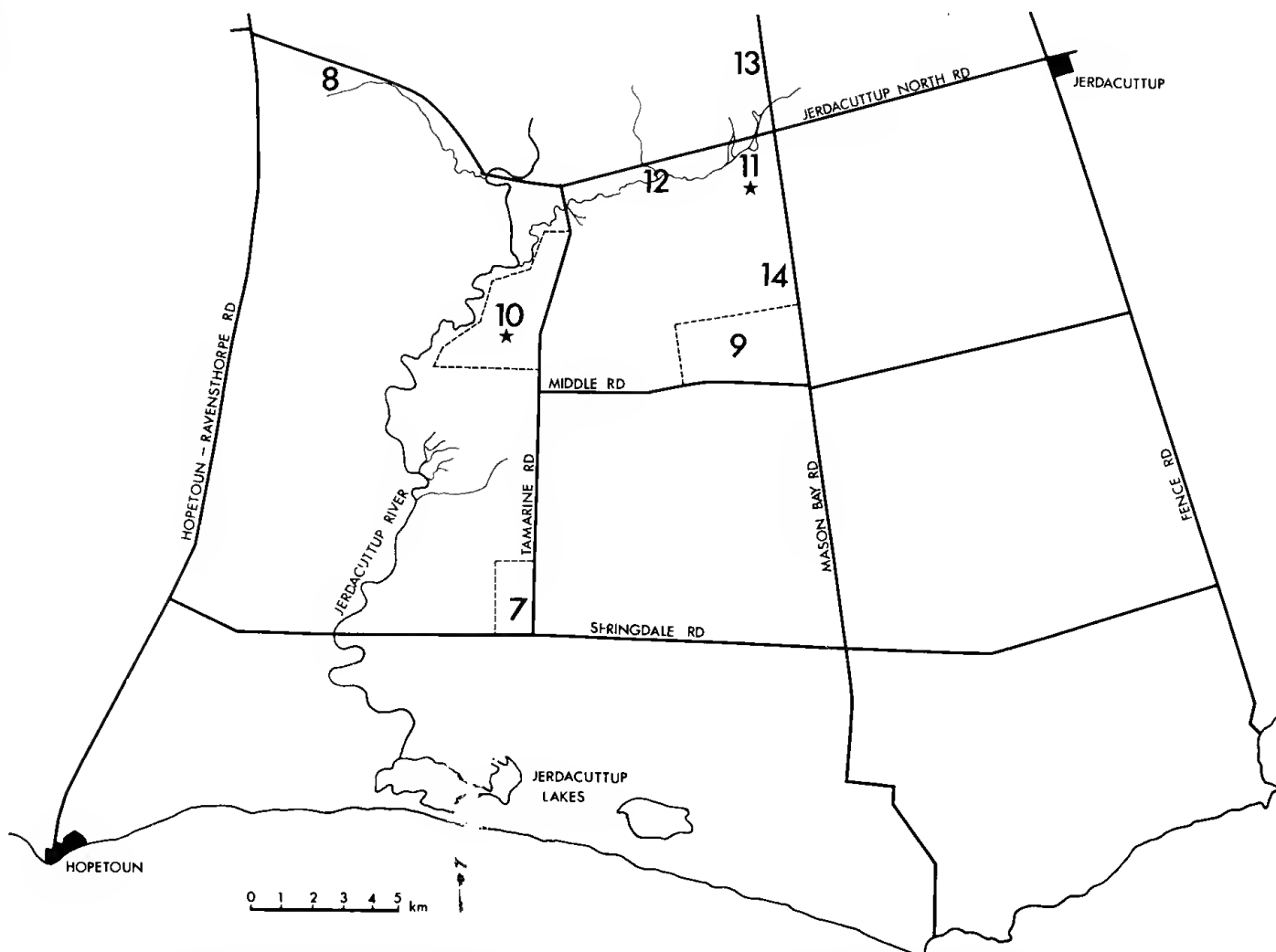


Figure 1.—Map showing the trapping localities in the Jerdacuttup region (modified from Woolley 1977). Drawn from Western Australia Department of Lands and Surveys 1 inch to 1 mile maps. The boundaries of the block of uncleared land on Oldfield Location 829 (Locality 7) and Government Requirements Reserve No. 28110 (Locality 9) are shown. The two localities (10 and 11) from which Dibblers have been reported are starred.

Trapping in the Fitzgerald River National Park

January-February 1978

The Fitzgerald River National Park (Fig. 2) lies between the 2 localities in which Dibblers have been found in recent years and it contains areas of heathland very similar to that in the known Dibbler habitat at Cheyne Beach. Morcombe (1969) suggested that Dibblers might be found in the park, the fauna of which is little known. Trapping has been carried out in 4 localities in the south-western corner of the park, and at "Quaalup", a freehold property within the boundaries of the park in the same region. The traps used were both Sherman and standard Elliotts, baited with bacon and peanut butter.

Quaalup Road North; Locality 15, Figure 3.—Five trap lines (A, B, C, D and E) were set in a variety of vegetation associations alongside Quaalup Road North commencing from Gairdner Road and finishing at the Rabbit Proof Fence Road. Trap lines A to D were set for 4 consecutive nights and trap line E

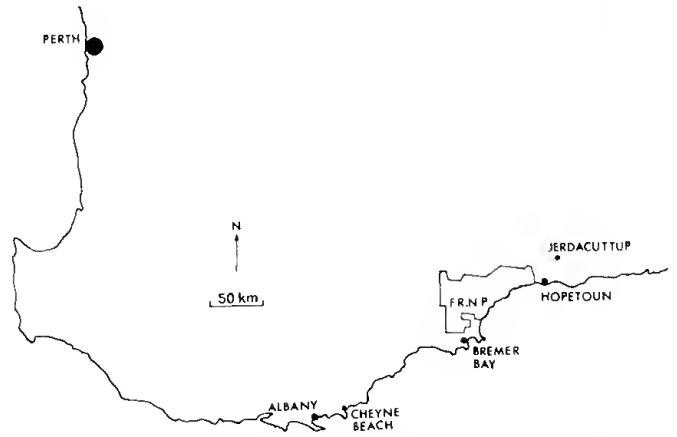


Figure 2.—Map showing the 3 regions (Cheyne Beach, Fitzgerald River National Park and Jerdacuttup) in which trapping has been carried out. Drawn from Map R201, Sheet 111, Australia S.W. Sheet 2nd ed. Division of National Mapping, Canberra, A.C.T.

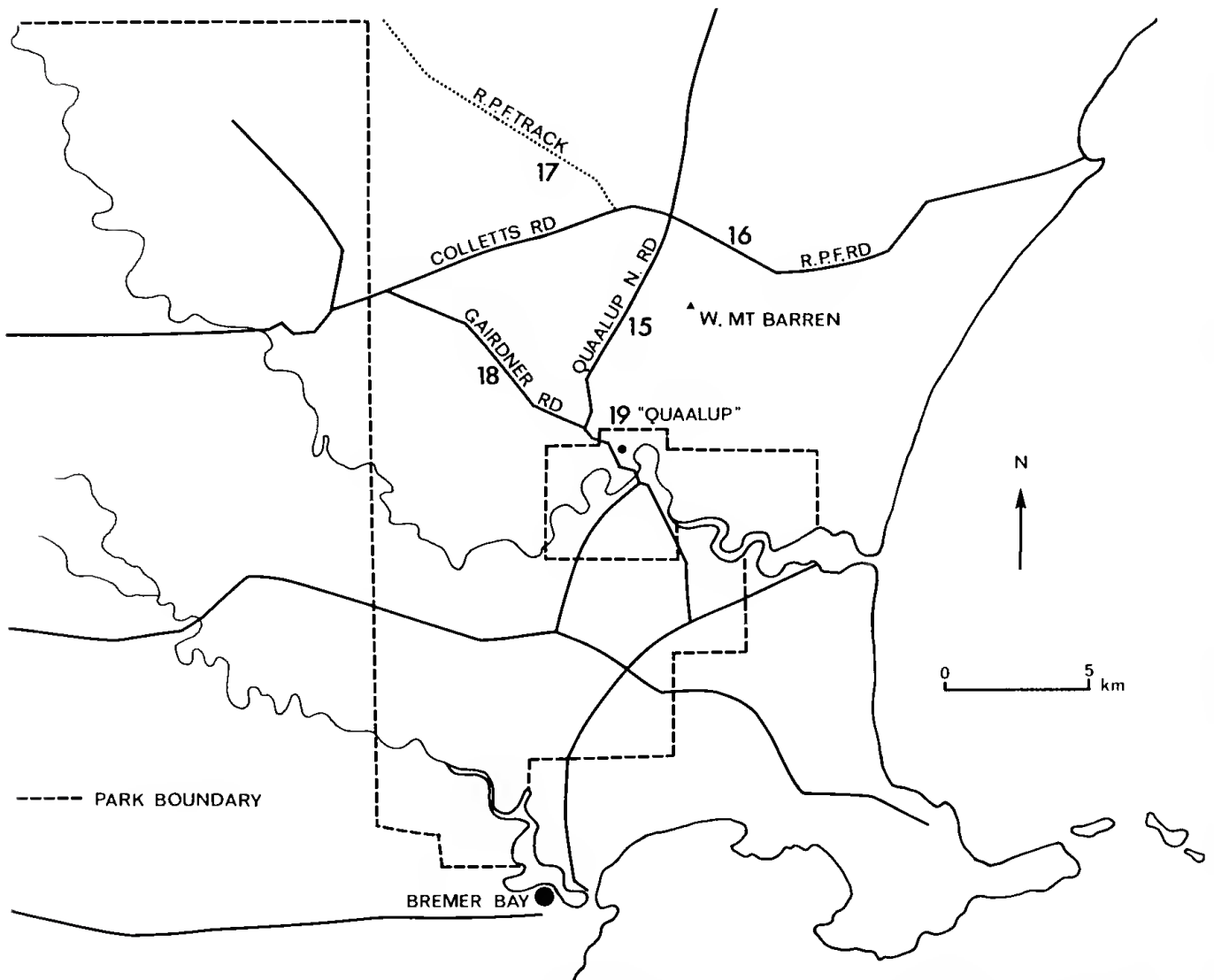


Figure 3.—Map showing the trapping localities in the Fitzgerald River National Park and "Quaalup". Drawn from a map of the Park prepared under the direction of the Director, National Parks Authority, Western Australia, 1977, based on the 1:250 000 National Mapping Series.

Table 2

Length of the trap lines, and the number and type of trap in each line in Locality 15

Trap line	A	B	C	D	E
Length (km)	0.8 (1.6)	0.2 (0.5)	1.3 (0.9)	0.3 (2.5)	0.9
No. of traps	50	20	105	25	75
Type of traps	S	S	30S, 75E	E	E

S = Sherman, E = Elliott. Distance between the trap lines shown in parentheses.

for 5 consecutive nights between 24 and 30 January. The length of the trap lines, the number and types of traps used in each line, and the distance between the lines are given in Table 2.

The results of trapping in Locality 15 are summarised in Table 3, together with the results from Localities 16, 17, 18 and 19 (see below).

Rabbit Proof Fence Road; Locality 16, Figure 3.—One hundred Sherman traps were set for 4 consecutive nights from 28 January alongside 1 km of the Rabbit Proof Fence Road. The trap line commenced 1.3 km to the south of Quaalup Road North.

Rabbit Proof Fence Track; Locality 17, Figure 3.—Seventy-five Elliott traps were set for 4 consecutive nights from 29 January alongside 0.8 km of the Rabbit Proof Fence Track. The trap line commenced 0.8 km to the north of Colletts Road.

Gairdner Road; Locality 18, Figure 3.—Two lines of traps each 0.9 km long were set alongside Gairdner Road to the north of "Quaalup". Line A (100 Elliott traps) was set for 3 consecutive nights from 31 January and Line B (100 Sherman traps) for 2 nights from 1 February. Line A commenced 0.75 km and line B, 6.1 km, from entrance gate to "Quaalup" on Gairdner Road.

"Quaalup"; Locality 19, Figure 3.—Seventy-two Sherman traps were set for 4 consecutive nights from 30 January in an uncleared area on "Quaalup" close to the boundary of the Fitzgerald River National Park.

Five species of mammals were trapped in the Fitzgerald River National Park and at "Quaalup". They were *R. fuscipes*, *T. spencerae*, *M. musculus*, *Sminthopsis murina* and *Pseudomys albocinereus*. It can

be seen from Table 3 that *R. fuscipes* was trapped in much larger numbers than the other 4 species and it was found in all localities. The *R. fuscipes* were marked with semi-permanent ink and released at the site of capture. The number of recaptures is shown in Table 3. Five specimens which were found dead in the traps were lodged in the Western Australian Museum (2 females, numbers M15465 and M15466; 3 males, numbers M15464, M15467 and M15468). The body weights (at first capture) ranged from 12 g to 117 g for the 54 females captured and from 12 g to 110 g for the 65 males. The one *Tarsipes* female captured, with 3 large young in the pouch (total weight of female and young 12 g), was released at the site of capture. The 2 *T. spencerae* males and 2 *S. murina*, which were found dead in the traps, the 2 male *M. musculus* and the *P. albocinereus* were lodged in the Western Australian Museum (*T. spencerae* male M15459 body weight 7 g, male M15460 body weight 10 g; *S. murina* juvenile male M15458, body weight 11 g; adult female M15457, body weight 15 g; *M. musculus* 2 males, M15469, body weights 13 g and 15 g; *P. albocinereus* female M15463, body weight 22 g).

Discussion

Trapping carried out at Cheyne Beach late in 1976 confirmed that Dibblers were extant in the area in which they were rediscovered in 1967, and brought to 9 the total number trapped there. Because of the very low trapping success the experiment to test the effectiveness of a new type of trap and different baiting procedures was not conclusive.

Table 3

Results of trapping in the Fitzgerald River National Park and at "Quaalup", January/February, 1978

Locality	No. Trap-Nights	Animals trapped								
		Total	<i>R.f.</i>			<i>T.s.</i>	<i>M.m.</i>	<i>S.m.</i>	<i>P.a.</i>	Rep-tiles
			♀ (R)	♂ (R)	Individuals					
15A	200	2	1	1	2	....	....	....	....	....
15B	80	1	....	1	1	....	....	....	....	....
15C	420	29	16 (2)	13 (3)	24	1♀	....	....	....	2
15D	100	5	2	3	5	....	....	....	....	....
15E	375	24	7 (1)	17 (6)	17	1♂	2♂	1♀	1♀	....
16	400	41	16 (3)	25 (6)	32	1♂	....	1♂	....	....
17	300	4	1	3	4	....	1	....	....	3
18A	300	19	11 (3)	8 (2)	14	....	....	....	....	....
18B	200	7	4	3	7	....	....	....	....	....
19	288	17	6 (1)	11 (3)	13	....	....	....	....	....
Total	2663	149	64 (10)	85 (20)	119	3	3	2	1	5

R.f. = *Rattus fuscipes*, *T.s.* = *Tarsipes spencerae*, *M.m.* = *Mus musculus*, *S.m.* = *Sminthopsis murina*, *P.a.* = *Pseudomys albocinereus*, R = recapture.

Further attempts to trap the Dibbler in the Jerdacuttup region have been unsuccessful. In another 2715 trap-nights, including 600 in December 1976 to test the hypothesis that there might be seasonal variation in trapping success in relation to the time at which the Dibblers breed, the only mammals captured were *R. fuscipes*, *T. spencerae* and *M. musculus*. This failure to trap the Dibbler in the Jerdacuttup region is puzzling. Trapping has been carried out in a variety of vegetation associations in practically all areas of uncleared land in proximity to the 2 sites where Dibblers have been reported and in other nearby localities.

If the vegetation in the one known habitat at Cheyne Beach is typical of the requirements of the Dibbler then the most likely areas in the Jerdacuttup region would seem to be the uncleared block on Oldfield Location 829 (Locality 7) and Government Requirements Reserve No. 28110 (Locality 9). However, trapping in these areas (a total of 885 trap-nights in Locality 7 and 580 around the perimeter of Locality 9) has not been successful. The area of the known habitat at Cheyne Beach is small (approximately 10 ha) so it is possible that the Dibblers may be restricted to areas in which trapping has not been carried out within the above localities. This explanation for the lack of success seems less likely in the case of Locality 7, where trap lines have been set through the block of uncleared land which has an area of about 300 ha, than in the case of Locality 9, a much larger area of approximately 900 ha where traps have only been set around the perimeter.

Another factor which may be of importance in determining the distribution of the Dibbler is the fire history of the area. In 1964 a fire swept through much of the region in which trapping has been carried out. The areas not burnt in this fire can be seen in a mosaic map prepared from aerial photographs taken in 1968 and 1969 (Sheet 610, Ravens-thorpe; Department of Lands and Surveys, Perth, Western Australia). They include the southern part of the uncleared block on Oldfield Location 829 in Locality 7 and the south-western part of Reserve No. 28110 (Locality 9). Trapping in the unburnt area of Locality 7 (375 trap-nights in February 1978) was unsuccessful but very little trapping has been carried out in the unburnt area of Locality 9. What little has been done (80 trap-nights in February 1976)

was along part of the western and southern boundaries; no trapping has been done in the interior of the south-western part because of the density of the vegetation and the absence of tracks. Given that Reserve No. 28110 is a large area of apparently suitable habitat, some of which has not been burnt since 1964, and that it is roughly equidistant from the 2 sites at which Dibblers have been reported, it is considered to be the most likely of the areas investigated in which the Dibbler could be found.

No Dibblers were caught in the Fitzgerald River National Park but 5 other species of mammals including one (*Pseudomys albocinereus*) not previously recorded from the Park were trapped.

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A collection of fishes from the Jardine River, Cape York Peninsula, Australia

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Abstract

Collections of freshwater fishes were obtained by the authors from the Jardine River at the northern tip of Cape York Peninsula on two expeditions during 1978 and 1979. An annotated checklist is presented which includes 30 species belonging to 24 genera and 16 families. The fish fauna of the Jardine River is most similar to that of the central coastal plain of southern New Guinea; at least 63% of the Jardine River fishes occur in the latter region. In addition, a similarity exists between the fish faunas of the Jardine River and Arnhem Land, Northern Territory. The zoogeographic relationships of these faunas are discussed in detail.

Introduction

The long neglected freshwater fish fauna of Australia, comprised of approximately 180 species, has commanded considerable attention from taxonomists during the past decade and as a result most major groups have been studied or are currently being reviewed. Important revisions include those of Nelson and Rothman (1973) on the Dorosomatinae, Vari (1977) on the Teraponidae, Ivantsoff (1978) on the Atherinidae, Allen (1978) on the Toxotidae, McDowall and Frankenberg (in press) on the Galaxiidae, and Thomson (in press) on the Mugilidae. In addition, the freshwater fish fauna was partially summarised by Lake (1971 and 1972) and various authors are now revising the Ambassidae, Eleotridae, Melanotaeniidae, and Plotosidae. However, in spite of this attention there still remains a need for collections from certain areas which are critical when attempting to define the distributions of various species. One such area is the remote northern tip of Cape York Peninsula, particularly the Jardine River which represents the northernmost large watercourse in Australia. During September 1978 Mr. Roger Steene and the senior author made a series of fish collections and underwater observations on the Cape York Peninsula including 2 stations at the Jardine River (see Fig 1). One year later the authors made a second series of collections at this locality. These represent the first comprehensive collections from this area. The 1978-79 collections and supplementary visual records include 30 species which represents the largest number of fishes from a single site in Australian freshwater. These collections are reported below together with a small number of fishes taken at the Jardine River by Graham Webb of Sydney University during a crocodile survey in 1972.

Methods

Fish specimens were obtained by the use of a small seine and also with dipnets after being stricken with rotenone. Most specimens were obtained in a small unnamed tributary of the Jardine River from where the stream entered the main river to a point about 400 m upstream. In addition, several species were recorded on the basis of sight records obtained while swimming with a face mask in the main river. The collections were made about 25-30 km upstream from the sea and the main Jardine River was exceptionally clear and flowing at this point with a width of approximately 100 metres. The collection data were as follows:

J-1.—Small tributary of Jardine River in vicinity of wooden bridge on Cape York road about 1 km SW of Jardine Crossing (approximately 11°10'S, 142°22'E); small shrimp seine over sand and mud bottom with aquatic vegetation to depths of 0.3 m; water fresh and clear with pH 5.5 and temperature 30°C; G. Allen on 20 September 1978.

J-2.—Same tributary as above, but deep (approximately 5 m) pool about 4 x 20 m adjacent to main Jardine River channel; rotenone and dipnets; water fresh and clear with pH 5.5 and temperature 29°C; G. Allen and R. Steene on 21 September 1978.

J-3.—Same tributary as above from main river to point approximately 400 m upstream; rotenone and dipnets at depths ranging to about 3-5 m; water fresh and clear with pH 5.4 and temperature 25.2-27.5°C; G. Allen and D. Hoese on 29 August 1979.

J-4.—Jardine River, about 4 km upstream from Cape York Road crossing, swampy area under overhanging paper-bark trees along edge of river; small shrimp seine over sand and mud bottom with aquatic vegetation; water fresh and clear with pH 5.8 and temperature 28.5°C; D. Hoese on 30 August 1979.

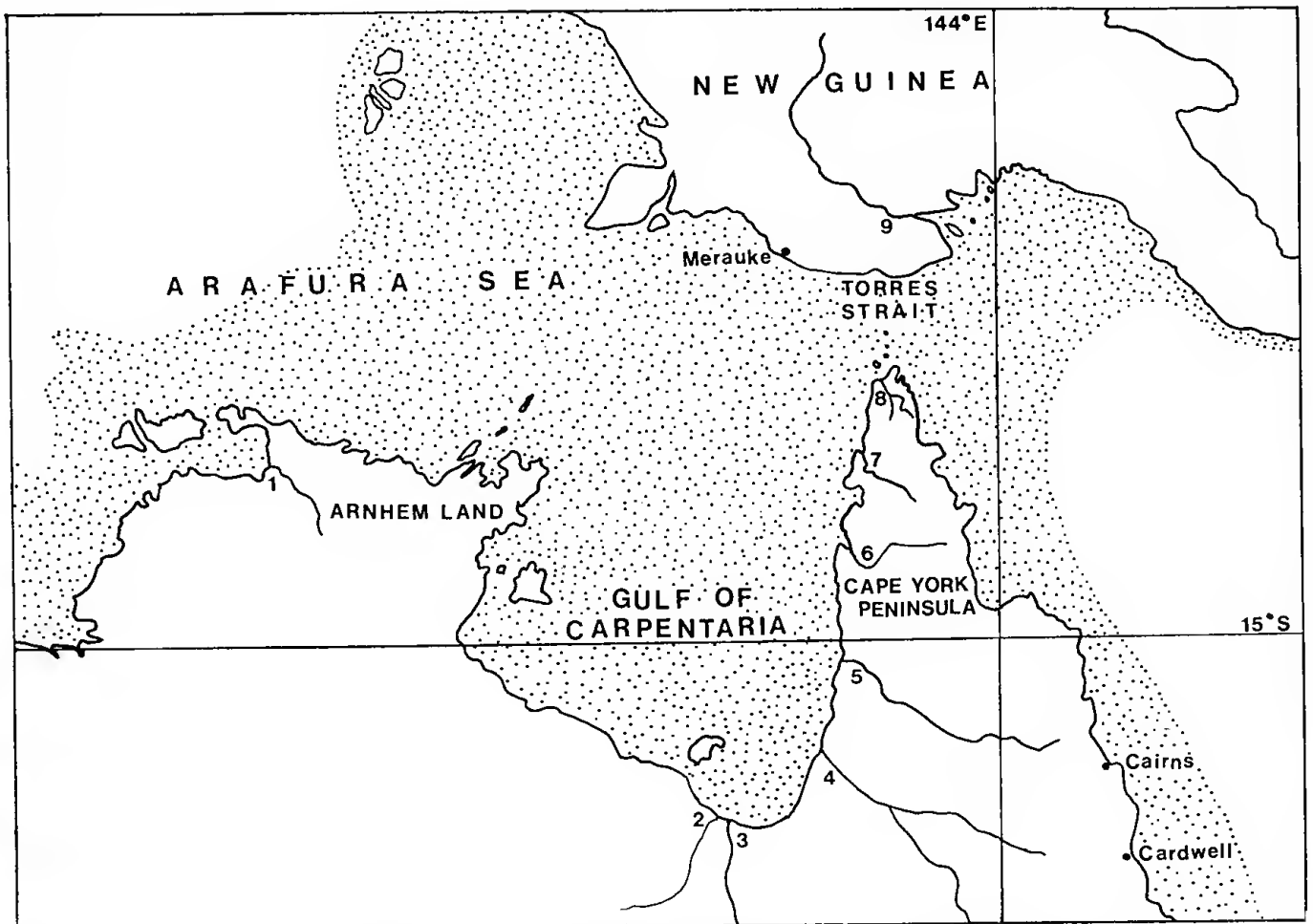


Figure 1.—Map of northern Australia and south-central New Guinea. The stippled area represents the emergent land of the Pleistocene at approximately 20 000-14 000 years B.P. Numbers refer to rivers which are mentioned in the text: 1, East Alligator River; 2, Gregory River; 3, Leichardt River; 4, Gilbert River; 5, Mitchell River; 6, Archer River; 7, Wenlock River; 8, Jardine River; 9, Fly River.

J-5.—Packsaddle Creek, at junction with Jardine River about 3 km upstream from Cape York Road crossing; rotenone and dipnets along mud bank among aquatic vegetation; water fresh and clear with pH 5.2 and temperature 28.5°C; G. Allen and D. Hoese on 30 August 1979.

J-6.—Lily pond adjacent to *J-5*, approximately 10 x 25 m with depths to 1.8 m; rotenone and dipnets among aquatic vegetation on soft mud bottom; water fresh and clear with pH 5.2 and temperature 28.5°C; G. Allen and D. Hoese on 30 August 1979.

J-7.—Lily pond adjacent to *J-1* tributary; small shrimp seine over mud bottom with aquatic vegetation; water fresh and clear; D. Hoese on 31 August 1979.

GW-1.—Small lagoon 200 m off Jardine River, drum nets over mud bottom to depths of 0.6-1.5 m; G. Webb in September 1972.

B-1.—Bridge Creek, tributary of Jardine River at crossing on Cape York Road approximately 8 km south of Jardine River, collection made in small

tributary of Bridge Creek in swampy area; rotenone and small shrimp seine over sand and mud bottom with aquatic vegetation; water fresh and clear with pH 5.2 and temperature 29.3°C; G. Allen and D. Hoese on 28 August and 1 September 1979.

Results

A total of 30 species belonging to 24 genera and 16 families was recorded. An annotated list of the species is presented below. Abbreviated literature citations are given for original descriptions, which include the author, year of publication, page or plate number, and locality. This information is followed by a list of the material collected and general remarks. Specimens are deposited at the Australian Museum, Sydney (AMS) and the Western Australian Museum, Perth (WAM). In addition to the specimens listed below representative collections of most species have been lodged at the Australian Museum and Queensland Museum, Brisbane.

Annotated list of species

Family Megalopidae—Oxeye Herrings

Megalops cyprinoides (Broussonet)

Clupea cyprinoides Broussonet, 1782: plate ix (Jamaica, Antigua, Brazil, and New Hebrides).

J-3 (WAM P26717-006), 1 specimen, 148 mm SL. In addition, several individuals were observed by the senior author in 1978 while swimming with a face mask in the main river channel. Circumtropical distribution, occurring in the sea and estuaries, but frequently entering freshwater.

Family Anguillidae—Freshwater Eels

Anguilla reinhardtii Steindachner

Anguilla reinhardtii Steindachner, 1867: 15 (Fitzroy River at Rockhampton, Queensland).

J-3 (WAM P26717-033), 7 specimens, 205-510 mm TL. J-5 (WAM P26718-006), 1 specimen, 150 mm TL. This species is known from eastern Australia (Tasmania to Cape York), Lord Howe Island, and New Caledonia.

Family Osteoglossidae—Bony Tongues

Scleropages jardini (Kent)

Osteoglossum jardini Kent, 1892: 105 (Batavia River, Cape York, Queensland).

J-3 (WAM P26717-002), 2 specimens, 242 and 250 mm SL. This primitive teleost was first described from the Wenlock River (formerly Batavia River) which lies approximately 120 km south of the Jardine River. It is also known from Arnhem Land (Northern Territory) and the central portion of southern New Guinea.

Family Ariidae—Fork-tail Catfishes

Arius australis Günther

Arius australis Günther, 1867a: 103 (Hunter River, N.S.W.).

One individual, approximately 30 cm was observed by the senior author in 1978 while swimming with a face mask in the main river channel. Widely distributed in northern Australian freshwater and estuaries.

Family Plotosidae—Eel-tail Catfishes

Porochilus obbesi Weber

Porochilus obbesi Weber, 1913: 523 (Lorentz River, New Guinea).

J-2 (WAM P26381-011), 5 specimens, 55-60 mm SL. J-3 (WAM P26717-011), 14 specimens, 45-85 mm SL. J-5 (WAM P26718-001), 6 specimens, 58-66 mm SL. This species is also known from Arnhem Land and the Fly and Lorentz Rivers of southern New Guinea.

Porochilus rendahli (Whitley)

Copidoglanis obscurus (non Günther) Rendahl, 1922: 173 (Glencoe and Hermit Hill, Northern Territory).

Copidoglanis rendahli Whitley, 1928: 214 (substitute name for *Copidoglanis obscurus* Rendahl).

J-3 (AMS I.21237-006), 1 specimen, 86 mm SL. Feinberg and Nelson, who are revising the freshwater Plotosidae, include this species in the genus *Porochilus*. It is also known from the Kimberley region of Western Australia and the Northern Territory (primarily Arnhem Land).

Tandanus ater (Perugia)

Lambertia atra Perugia, 1894: 551 (Inawi, Papua).

J-3 (WAM P26717-014), 5 specimens, 77-300 mm SL. This species is also known from the Kimberley region of Western Australia, Northern Territory (primarily Arnhem Land), and the central portion of southern New Guinea.

Tandanus brevidorsalis (Günther)

Copidoglanis brevidorsalis Günther, 1867b: 66 (Cape York, Queensland).

J-3 (WAM P26717-015), 1 specimen, 60 mm SL. Several specimens also collected in 1979 from McDonnell Creek, a tributary of the Jackson River system, approximately 45 km south of the Jardine River. This species is also known from the central portion of southern New Guinea.

Family Belonidae—Long Toms

Strongylura krefftii (Günther)

Belone krefftii Günther, 1866: 250 (Australia).

GW-1 (AMS un-registered), 1 specimen, 404 mm SL. Several individuals were also observed by the senior author in 1978 while swimming with a face mask in the main river channel. Known from freshwater streams of northern Australia and New Guinea.

Family Atherinidae—Hardyheads

Craterocephalus randi Nichols and Raven

Craterocephalus randi Nichols and Raven, 1934: 3 (Kubuna, New Guinea).

J-3 (WAM P26717-018), 6 specimens, 19-41 mm SL. Ivantsoff (1978) reviewed the Australian and New Guinean species of *Craterocephalus*. He considered *C. randi* of southern New Guinea to be closely related to *C. stercusmuscarum* (Günther) of Queensland and the Northern Territory. He separated these species mainly on the basis of average number of gill rakers on the first arch, midlateral scales, and interdorsal scales. However, the range of counts for these characters are overlapping between the species and the differences are not convincing. We base our identification of this species on a comparison with 29 specimens, 33-52 mm SL of *C. randi* from the Morehead River of southern Papua New Guinea (WAM P26779-001). There are significant colour pattern differences between *C. stercusmuscarum* and *C. randi*: the former species has large dark spots, one per scale, covering most of the side, whereas *C. randi* has a broad, black midlateral stripe extending from the eye to the caudal fin base. This species also occurs in Arnhem Land (Northern Territory) and was first reported from there by Taylor (1964) as *C. fluviatilis* (non McCulloch). We have also collected specimens from the Jackson River system, about 45 km south of the Jardine River.

Family Melanotaeniidae—Rainbowfishes

Iriatherina weneri Meinken (Fig. 2)

Iriatherina weneri Meinken, 1974: un-numbered (near Merauke, Irian Jaya).

J-2 (WAM P26381-001), 6 specimens, 18-21 mm SL. J-2 (AMS I-20585-001), 3 specimens, 14-17 mm SL. J-3 (WAM P26717-001), 76 specimens, 14-21 mm SL. J-3 (AMS I.21237-001), 37 specimens,

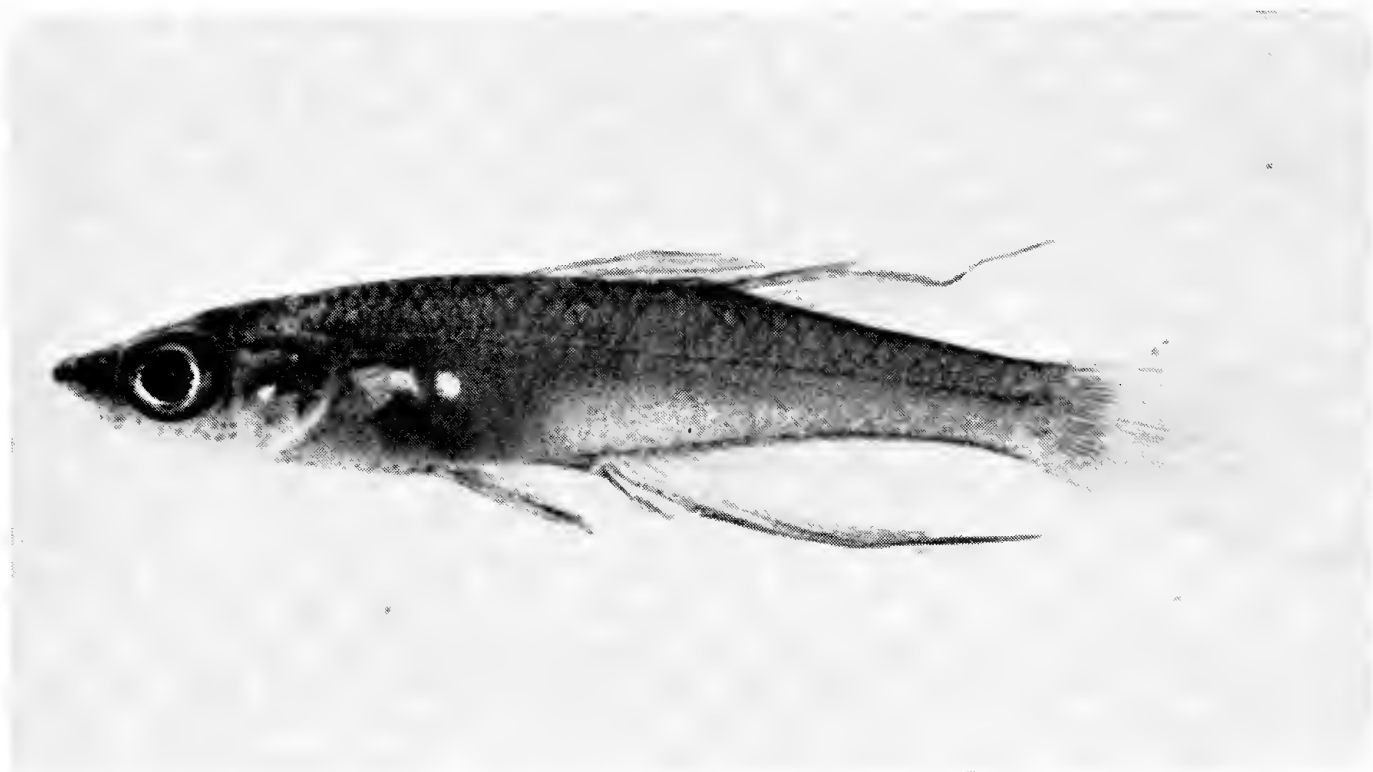


Figure 2.—*Iriatherina wernerii*, 19.1 mm SL, Jardine River.

13-24 mm SL. J-5 (WAM P26718-008), 5 specimens, 16-22 mm SL. J-5 (AMS I.21240-004), 10 specimens, 9-17 mm SL. We observed *I. wernerii* at J-3 with the aid of a face mask. The fish were very abundant at this locality and other areas along the main river where there was an abundance of water-lily plants. Both pairs and aggregations of 20 or more individuals were encountered among plants near the surface. Most adult males which were observed underwater or viewed after being freshly collected, had very elongate dorsal and anal filaments (Fig. 2). However, these appendages are not evident on most preserved specimens as they are fragile and easily broken.

The monotypic *Iriatherina wernerii* was described by Meinken (1974) on the basis of two specimens collected at Merauke (see map, Fig. 1) on the southern coast of New Guinea (Irian Jaya). Although Meinken gave an adequate description of the species he gave no indication of the familial classification for *Iriatherina*. He simply mentioned that it was similar to *Telmatherina*, but differed greatly in head shape. *Telmatherina*, containing 3 lake-dwelling species from the Celebes, is considered a member of the family Atherinidae (Weber and de Beaufort 1922). The overall morphology, particularly the structure of the jaws, and shape of the head, body, and fins does not support a close relationship between *Telmatherina* and *Iriatherina*. A recent study by the senior author (Allen, in press) indicates that the latter genus is a member of the Melanotaeniidae.

We have examined all the known specimens of *I. wernerii* except for the types including the following lots: USNM 217156, 30 specimens, 20-32 mm SL (Lake Boset and Middle Fly River, Papua New

Guinea); WAM P26749-001, 3 specimens, 25-31 mm SL (Morehead River, Papua New Guinea); WAM P26765-001, 7 specimens, 23-31 mm SL (Pahoturi River, Papua New Guinea). Thus, its known distribution includes the Jardine River and the central portion of southern New Guinea between the Merauke and Fly Rivers. The specimens reported above constitute a new record for Australia.

Melanotaenia maccullochi Ogilby

Melanotaenia maccullochi Ogilby, 1915: 118 (Barron River, Queensland).

J-2 (WAM P26381-004), 1 specimen, 22 mm SL. J-3 (WAM P26717-019), 3 specimens, 18-20 mm SL. B-1 (WAM P26719-005), 21 specimens, 21-29 mm SL. This species appears to be relatively rare in the Jardine River system and only small juveniles have been collected. It also occurs on the coastal plain between Cairns and Cardwell, northern Queensland, the McIvor River, about 60 km north of Cooktown, and southern Papua New Guinea between the Bensbach and Fly Rivers.

Melanotaenia nigrans (Richardson)

Atherina nigrans Richardson, 1843: 180 (near Darwin).

J-1 (WAM P26377-002), 5 specimens, 23-37 mm SL. J-2 (WAM P26381-005), 15 specimens, 18-43 mm SL. J-3 (WAM P26717-008), 39 specimens, 15-40 mm SL. B-1 (WAM P26719-006), 7 specimens, 17-32 mm SL. This species was relatively abundant in small swampy tributaries of the Jardine, but was not seen in the main river. Known in Australia from the Northern Territory in coastal streams between Darwin and Groote Eylandt, and from the tip of Cape York Peninsula north of the Jardine

River. It also occurs at Prince of Wales Island in the Torres Strait. Records of this species from New Guinea are referable to *M. goldiei* (Macleay).

Melanotaenia splendida (Peters)

Nematocentris splendida Peters, 1867: 516 (Fitzroy River, Queensland).

J-1 (WAM P26377-001), 1 specimen, 70 mm SL. J-2 (WAM P26381-007), 19 specimens, 28-75 mm SL. J-3 (WAM P26717-010), 7 specimens, 27-49 mm SL. J-5 (WAM P26718-009), 7 specimens, 20-34 mm SL. This species was abundant in tributaries and along the edge of the main river channel. The Jardine River variety is similar to that found from Darwin eastward and throughout the Gulf of Carpentaria drainage. It has previously been referred to as a distinct species, *M. maculata*, but a revision of the Australian Melanotaeniidae currently in progress by the senior author indicates that *australis* (Western Australia), *solata* (Northern Territory), *tatei* (Lake Eyre drainage), *maculata*, and *splendida* (coastal Queensland) are merely varieties of the latter species. This species also occurs in southern New Guinea between the Merauke and Fly Rivers and at Badu Island, Torres Strait.

Melanotaenia trifasciata (Rendahl)

Rhombosoma trifasciata Rendahl, 1922: 182 (Mary River, Northern Territory).

J-2 (WAM P26381-006), 15 specimens, 42-68 mm SL. J-3 (WAM P26717-009), 3 specimens, 44-70 mm SL. This species was abundant in tributaries and along the edge of the main river channel. Known from the Mary, Giddy, and Goyder Rivers of northern Territory and the western side of Cape York Peninsula from the Archer River system northwards. It also occurs on the eastern watershed of Cape York Peninsula as far south as the McIvor River about 60 km north of Cooktown. A closely related species, *M. goldiei* (Macleay) is found in southern New Guinea.

Pseudomugil gertrudae Weber

Pseudomugil gertrudae Weber, 1911: 23 (Aru Islands).

J-2 (WAM P26381-003), 11 specimens, 14-17 mm SL. J-3 (WAM P26717-021), 50 specimens, 12-23 mm SL. J-5 (WAM P26718-007), 1 specimen, 15 mm SL. B-1 (WAM P26719-004), 12 specimens, 17-21 mm SL. B-1 (WAM P26716-001), 22 specimens, 13-19 mm SL. Specimens from the Jardine River agree well with those reported from Groote Eylandt by Taylor (1964). However, there is some doubt as to whether Australian specimens are conspecific with the species originally described by Weber from the Aru Islands. There is a critical need for revision of the subfamily Pseudomugilinae. This group has been frequently placed in the Atherinidae or accorded separate family status, but Allen (in press) provides evidence which indicates a relationship with the Melanotaeniidae. *P. gertrudae* is known in Australia from Arnhem Land, Groote Eylandt, the Jardine River, and the coastal plain between Cardwell and Cairns in Queensland. Roberts (1978) also recorded it from the Fly River drainage of southern New Guinea.

Family Synbranchidae—Swamp Eels

Ophisternon gutturale (Richardson)

Synbranchus gutturalis Richardson, 1844 (Dampier Archipelago, Western Australia).

J-3 (WAM P26717-016), 3 specimens, 146-160 mm TL. We follow Rosen and Greenwood (1976) in using the name *gutturale* for this species. It is closely related to *O. bengalense* McClelland from the Indo-Malayan region. It is possible that records (see Munro 1958) of the latter species from New Guinea are actually referable to *O. gutturale*. Also known from Arnhem Land (Northern Territory). The type locality of Dampier Archipelago is questionable because this area is composed of desert islands without permanent freshwater. However, it is possible that the type specimen was collected from the mainland opposite the Dampier Archipelago, although this species has not been taken there on WAM collecting expeditions.

Family Centropomidae—Barramundi

Lates calcarifer (Bloch)

Holocentrus calcarifer Bloch, 1790: 100 (Japan).

One individual, approximately 500 mm SL, was observed by the senior author in 1978 while swimming with a face mask in the main river channel. Widely distributed in estuaries and freshwater streams from the Persian Gulf eastward to southern China and the Indo-Australian Archipelago.

Family Ambassidae—Glassfishes

Ambassis elongatus (Castelnau)

Pseudoambassis elongatus Castelnau, 1878: 44 (Norman River, Queensland).

J-2 (WAM P26381-009), 11 specimens, 22-35 mm SL. J-3 (WAM P26717-017), 6 specimens, 21-31 mm SL. J-5 (WAM P26718-003), 10 specimens, 19-28 mm SL. B-1 (WAM P26719-003), 1 specimen, 22 mm SL. This species was relatively common in tributaries and along the edge of the main river. Known only from streams draining into the Gulf of Carpentaria.

Ambassis macleayi (Castelnau)

Pseudoambassis macleayi Castelnau, 1878: 43 (Norman River, Gulf of Carpentaria, Queensland).

J-5 (WAM P26718-012), 2 specimens, 34 and 36 mm SL. This species is relatively widespread in northern Australia, ranging from Cape York Peninsula to the Carson River in Western Australia. It also occurs in the central portion of southern New Guinea.

Denarius bandata Whitley

Denarius bandata Whitley, 1948: 92 (Arnhem Land, Northern Territory).

J-2 (WAM P26381-010), 9 specimens, 18-27 mm SL. J-3 (WAM P26717-007), 12 specimens, 13-26 mm SL. J-5 (WAM P26718-002), 2 specimens, 18 and 23 mm SL. B-1 (WAM P26719-002), 1 specimen, 29 mm SL. This species was moderately common among aquatic vegetation, particularly in swampy tributaries. Known also from coastal

streams of the Northern Territory east of the Alligator Rivers system to Groote Eylandt and from a single specimen collected from the Murray Swamps near Innisfail on the east Queensland coast by S. H. Midgley (pers. comm.). Roberts (1978) also recorded it from the Fly River system of Papua New Guinea.

Family Apogonidae—Cardinalfishes

Glossamia aprion (Richardson)

Apogon aprion Richardson, 1842: 16 (near Darwin).

J-2 (WAM P26381-012), 5 specimens, 34-62 mm SL. J-3 (WAM P26717-005), 16 specimens, 43-140 mm SL. J-5 (WAM P26718-010), 4 specimens, 30-50 mm SL. This species was frequently observed among shoreline vegetation. Known from coastal streams of northern Australia and southern New Guinea.

Family Teraponidae—Grunters

Hephaestus carbo (Ogilby and McCulloch)

Therapon carbo Ogilby and McCulloch, 1916: 116 (Gregory River, Queensland).

J-2 (WAM 26381-014), 1 specimen, 181 mm SL. J-3 (WAM P26717-004), 4 specimens, 101-195 mm SL. This species was relatively common in the small tributary where collections J-1, J-2, and J-3 were made. Vari (1978) recognised *H. suavis* Whitley, known on the basis of two specimens, 51 and 65 mm SL from Cape York Peninsula, as a distinct species. However, it is our opinion that *H. suavis* represents the young of *H. carbo*. The adults which were collected agree in preserved colouration with *H. carbo* as illustrated by Vari, while young specimens (under about 100 mm SL) exhibited the typical *suavis* pattern of irregular pale stripes on a dark ground. Known from the Goyder River of Arnhem Land, the Gregory River of Western Queensland (Gulf of Carpentaria drainage), and the Cape York Peninsula north of the Archer River system.

Pingalla lorentzi (Weber)

Helotes lorentzi Weber, 1910: 326 (Lorentz River, New Guinea).

J-2 (WAM P26381-013), 2 specimens, 53 and 75 mm SL. J-3 (WAM P26717-022), 18 specimens, 46-130 mm SL. We provisionally identify this species as *P. lorentzi*, known previously from the central portion of southern New Guinea. The specimens differ from New Guinea material in having 3 to 5 rows of teeth in the jaws instead of 2 rows, and in having the mouth terminating below the posterior nostril instead of between the anterior and posterior nostrils. One of the juvenile specimens has a single vomerine tooth. We also collected this species in Cockatoo Creek, a tributary of the Jackson River about 45-50 km south of the Jardine River. A new record for Australia. A related species, *Pingalla gilberti*, is known from the Gilbert, Flinders, and Norman Rivers of Queensland and the South Alligator River in the Northern Territory.

Family Toxotidae—Archerfishes

Toxotes chatareus (Hamilton)

Coilus chatareus Hamilton, 1822: 101 and 370 (Ganges River, India).

Several individuals were observed along the edge of the main river channel. Known from estuaries and freshwater streams of Southeast Asia (India to China), Malaysia, Indonesia, and New Guinea. In Australia it is found in northern coastal streams from the Fitzroy River of Western Australia to the vicinity of Townsville. Breeding populations are sometimes encountered more than 100 km upstream from the sea (Allen 1978).

Family Gobiidae—Gobies

Glossogobius sp.

J-2 (WAM P26381-019), 2 specimens, 24 and 25 mm SL. J-3 (AMS I.21237-002), 6 specimens, 10-27 mm SL. J-4 (AMS I.21238-001), 16 specimens, 12-21 mm SL. J-5 (AMS I.21241-001), 17 specimens, 11-24 mm SL. J-5 (WAM P26718-004), 2 specimens, 18 and 25 mm SL. J-6 (AMS I.21240-001), 13 specimens, 10-27 mm SL. Dorsal rays VI-1,8; anal rays I,6-7; pectoral rays 14-15; vertical scale rows 24-26. The midline of the nape is naked, but the sides scaled to above the operculum. There are no head pores above the operculum. The jaws end under the anterior margin of the eye. The gill opening ends below and behind the posterior preopercular margin. The tongue is bilobed. There is a distinct black spot at the posterior end of the first dorsal fin. The dorsals have small spots forming two to four rows, and the caudal has similar spots forming wavy bands. The anal, pectoral, and pelvic fins are clear to dusky. There is a black stripe on the side of the body formed by a series of elongate spots. There is a black stripe from the front of the eye to below the anterior nostril.

This species, which is possibly new, is distinctive from other species of *Glossogobius* in colouration, the absence of pores above the operculum, in the low fin ray and scale counts, and the absence of scales on the midline of the nape. The species is known from creeks and rivers of the Gulf of Carpentaria drainage system on Cape York Peninsula between the Jardine and Archer River systems.

Family Eleotridae—Gudgeons

Hypseleotris compressa (Kreffft)

Eleotris mogurnda Richardson, 1844: 4 (vicinity of Darwin, Denison, Australia).

J-2 (WAM P26381-015), 2 specimens, 38 and 41 mm SL. J-3 (WAM P26717-012), 1 specimen, 53 mm SL. This species is widely distributed in northern and eastern Australia and also occurs in southern New Guinea.

Mogurnda mogurnda (Richardson)

Eleotris mogurnda Richardson, 1844: 4 (vicinity of Darwin).

J-2 (WAM P26381-017), 2 specimens, 18 and 38 mm SL. J-3 (WAM P26717-013), 3 specimens, 21-33 mm SL. B-1 (WAM P26719-001), 3 specimens, 26-47 mm SL. This is another widespread eleotrid species occurring in coastal streams of northern Australia and southern New Guinea.

Oxyeleotris sp. A

J-2 (WAM P26381-016), 2 specimens, 38 and 51 mm SL. J-3 (AMS I.21237-001), 3 specimens, 60-73 mm SL. Dorsal rays VI-I,12; anal rays I,10; pectoral rays 14-15; vertical scale rows 53-55. The head pores are large and conspicuous; there is a pair of pores adjacent to each posterior nostril; there are two pairs of interorbital pores. There are 6-7 short stubby rakers on the lower part of the first gill arch. The colouration is dark brown to black; there is no conspicuous black bar before the eye. The second dorsal and caudal fins are spotted, but the other fins dusky. There is no white margin around the caudal fin. The tip of the anal fin is lighter than the rest of the fin. There is a faint black spot, about equal to pupil in size, at the upper base of the caudal fin.

A closely related species, occurs in the Jackson River Drainage about 40-50 km south of the Jardine River. It differs in having large head pores, with only a single pore near each posterior nostril and a single median posterior interorbital pore. It also has one fewer dorsal and anal rays, and has the back much lighter than the sides. Both species are similar to *O. fimbriatus*, but as Roberts (1978) noted, there are at least 2 species, which have been confused under the name *O. fimbriatus*. A re-examination of the types of *Eleotris fimbriatus* Weber, *E. mertonii* Weber, and *E. auruensis* Weber is necessary to clarify the identity of the Australian species.

Oxyeleotris sp. B

J-2 (WAM P26381-018), 2 specimens, 17 and 20 mm SL. J-3 (AMS I.21237-003), 152 specimens, 13-31 mm SL. J-3 (WAM P26717-020), 17 specimens, 15-27 mm SL. J-4 (AMS I.21238-002), 7 specimens, 17-27 mm SL. J-5 (AMS I.21240-003), 14 specimens, 11-26 mm SL. J-5 (WAM P26718-005),

1 specimen, 26 mm SL. J-6 (AMS I.21239-001), 23 specimens, 15-26 mm SL. J-7 (AMS I.21241-003), 75 specimens, 16-30 mm SL. B-1 (AMS I.21236-002), 2 specimens, 21 and 25 mm SL. Dorsal rays VI-I,10-11; anal rays 1,7-9; pectoral rays 11-12; segmented caudal rays 17; branched caudal rays 13; vertical scale rows 30-37; rakers on lower part of first arch 8-9. The preserved colouration is overall dusky, paler ventrally with a vertical blotch below and a similar blotch above at the base of the caudal fin. The dorsal fins have small spots forming longitudinal stripes. The caudal has small spots forming wavy bands. There is a dark spot, with a white centre above the pectoral base. In some specimens there are irregular blotches on the body forming chevrons. There are 3 dark bands radiating posteriorly from the eye, but these are obscure in dark specimens.

This species is also known from Arnhem Land and creeks north of Jardine River. It is possibly identical with *O. nullipora* Roberts from New Guinea. However, New Guinea material apparently lacks spots on the caudal fin. The small mouth and low scale counts of these species and *O. paucipora* are distinctive from other species of *Oxyeleotris*, and further studies are necessary to clarify the generic relationships of this group.

Discussion

The known fish fauna of the Jardine River is summarised in Table 1. Undoubtedly further collecting efforts will add several other fishes to the list. Such species as the freshwater sawfish (*Pristis*), the mangrove jack (*Lutjanus argentimaculatus*), mullet (Mugilidae), and freshwater soles (Soleidae) were not recorded during the present survey, but most likely inhabit this stream.

The Jardine River area lies approximately 205 km south of New Guinea. The two areas are separated primarily by the shallow (average depth about 13 m) waters of Torres Strait. However, this separation is of relatively recent origin (geologically speaking), most likely having existed continuously for only the past 6500-8000 years. Prior to this time the two regions were usually connected by a land bridge which existed for at least 200 million years (see Walker 1972). The Torres Strait is so shallow that it would have been land during the time of Pleistocene low sea levels, for periods totalling perhaps 500 000 years (see map, Fig. 1). Thus, it is not surprising that the fish fauna of the Jardine River bears a strong resemblance to that of the coastal lowlands of southern New Guinea opposite Torres Strait. At least 63% of the Jardine River species (Table 1) are found in New Guinea and this figure will probably be increased with further collections in both areas and clarification of taxonomic problems (particularly in the Ariidae, Synbranchidae, Ambassidae, Gobiidae, and Eleotridae). A similar relationship between the frog fauna of Cape York Peninsula and southern New Guinea was noted by Tyler (*in* Walker 1972). Munro (1964) listed 24 fish species (excluding those occurring in brackish water) common to northern Australia and New Guinea. However, current studies by the senior author indicate that 2 of the melanotaeniids (*Melanotaenia goldiei* and *M. ogilbyi*) included in this category are not found in Australia, and a third melanotaeniid,

Table 1

Summary of the fishes of the Jardine River

Family	Species
Megalopidae	* <i>Megalops cyprinoides</i>
Anguillidae	<i>Anguilla reinhardtii</i>
Osteoglossidae	* <i>Scleropages jardini</i>
Ariidae	<i>Arius australis</i>
Plotosidae	* <i>Porochilus obbesi</i>
Plotosidae	<i>P. rendahli</i>
Plotosidae	* <i>Tandanus ater</i>
Plotosidae	* <i>T. brevidorsalis</i>
Belontiidae	* <i>Strongylura krefftii</i>
Atherinidae	* <i>Craterocephalus randi</i>
Melanotaeniidae	* <i>Iriatherina wernerii</i>
Melanotaeniidae	* <i>Melanotaenia naccullochi</i>
Melanotaeniidae	<i>M. nigrans</i>
Melanotaeniidae	* <i>M. splendida</i>
Melanotaeniidae	<i>M. trifasciata</i>
Melanotaeniidae	* <i>Pseudomugil gertrudae</i>
Synbranchidae	<i>Ophisternon gutturale</i>
Centropomidae	* <i>Lates calcarifer</i>
Ambassidae	<i>Anubassis elongatus</i>
Ambassidae	* <i>A. macleayi</i>
Ambassidae	* <i>Denariusa bandata</i>
Apoгонidae	* <i>Glossamia aprion</i>
Teraponidae	<i>Hephaestus carbo</i>
Teraponidae	* <i>Pingalla lorentzi</i>
Toxotidae	* <i>Toxotes chatareus</i>
Gobiidae	<i>Glossogobius sp.</i>
Eleotridae	* <i>Hypseleotris compressa</i>
Eleotridae	* <i>Mogurnda mogurnda</i>
Elcotridae	<i>Oxyeleotris sp. A</i>
Eleotridae	<i>Oxyeleotris sp. B</i>

*denotes also recorded from southern New Guinea.

M. nigrans, does not occur in New Guinea. Similarly, Vari (1978) has shown that *Hephaestus romeri*, a teraponid listed by Munro, is confined to southern New Guinea.

Another major facet of the Jardine fish fauna, and one which has previously been overlooked, or at least misinterpreted is a relationship between this region (i.e., northern tip of Cape York Peninsula) and the northernmost section of the Northern Territory, particularly Arnhem Land (Fig. 1). Previous workers have frequently assumed that fishes occurring in these 2 regions have continuous distributions, occurring throughout the Gulf of Carpentaria drainage. However, on the basis of museum records and a series of collections by the senior author between the Gregory and Mitchell Rivers (Fig. 1), we are convinced that certain species common to Cape York and Northern Territory exhibit disjunct distributions. Species which fall in this category include *Porochius obbesi*, *P. rendahli*, *Tandanus ater*, *Melanotaenia nigrans*, *M. trifasciata*, *Pseudomugil gertrudae*, *Craterocephalus randi*, *Denariusa bandata*, *Ambassis elongatus*, *Oxyeleotris* sp. B, and possibly *Ophisternon gutturale*. In addition, *Scleropages jardini* and *Hephaestus carbo* are absent from the portion of the gulf drainage between the Gregory and Mitchell Rivers (Fig. 1).

The reason for these distributional discontinuities is probably related to the inundation of the Gulf of Carpentaria basin during the Pleistocene and associated temperature regimes during that period. There is good evidence (see Nix and Kalma in Walker 1972) that the connecting land mass between Australia and New Guinea was very broad for perhaps 3000-6000 years during the late Pleistocene (about 20 000-14 000 years B.P.) and covered the area now occupied by the Torres Strait, Gulf of Carpentaria, and the easternmost portion of the Arafura Sea (Fig. 1). It is not difficult to imagine that the freshwater fish fauna inhabiting the swamps and streams of this now inundated land was very similar in composition to the present day fauna. From what is known about evolutionary rates of fishes it would be safe to say that many if not all of the species which presently occur in the Jardine River were extant during the last stages of the Pleistocene. It seems likely that a more or less continuous fauna may have occurred across this region north of approximately 15° south latitude. The southward distributions of many of the species was probably limited by cooler temperature regimes. Recent data (Table 2) indicates a marked temperature gradient during late winter ranging from 27-32°C in the Northern Territory and northern portion of Cape York Peninsula to 22-23°C in streams running into the lower portion of the Gulf of Carpentaria. Certainly this same sort of gradient existed at the time of the Gulf of Carpentaria-Arafura land bridge during the late Pleistocene and it was probably of greater magnitude because of the more inland position of the major river systems flowing through the southern half of what is now the Gulf of Carpentaria. Nix and Kalma (in Walker 1972) estimate that present-day temperature regimes were probably lowered by 3-4°C at sea level during Pleistocene times. Their data is based on a 5-6°C reduction necessary to account for the lowering of the New Guinea snowline which occurred during the Pleistocene, and corresponds with a 3-9°C reduction in global mean

Table 2

Temperature data for northern Australian streams

Locality	Date	Temperature (°C)
Jardine River (11°10'S, 142°22'E)	21 Sept. 1978	28
Wenlock River (12°27'S, 142°33'E)	22 Sept. 1978	29
Archer River (13°26'S, 142°57'E)	18 Sept. 1978	27
Mitchell River (16°32'S, 143°36'E)	12 Sept. 1978	26
Staaten River (16°25'S, 142°02'E)	12 Sept. 1978	27
Einsleigh River (18°10'S, 144°00'E)	6 Sept. 1978	25
Gilbert River (18°26'S, 142°43'E)	7 Sept. 1978	24
Norman River (18°05'S, 141°15'E)	7 Sept. 1978	23
Leichardt River (18°07'S, 139°53'E)	9 Sept. 1978	23
Gregory River (18°38'S, 139°15'E)	9 Sept. 1978	22
East Alligator River System (12°30'S, 133°30'E)	Sept.-Oct. 1972	26-32

temperatures postulated by Flint and Brandtner (1961). Thus a lowering of minimum temperatures to at least 18-19°C in the lower Gulf area probably prevented the southward dispersal of some fishes. Temperatures were probably even lower in these areas as cooler, drier air masses appeared to have dominated northern Australia at the time of maximum lowering of the sea during Pleistocene glaciations (Webster and Stratton in Walker 1972). Minimum winter temperatures may have been similar to the 13°C recorded by S. H. Midgley (pers. comm.) in July 1971 in the Georgina River at Camooweal, Queensland (19°55'S, 138°07'E).

Another pattern of disjunction is evident in 3 of the Jardine River fishes, *Melanotaenia maccullochi*, *Pseudomugil gertrudae*, and *Denariusa bandata*. Although additional collections are needed on the eastern coast of Cape York Peninsula there appears to be a genuine gap in the distributions of these species, roughly extending along the Pacific coast between Cairns and the vicinity of the Jardine River, although *M. maccullochi* was recently taken by the junior author near Cooktown. Possible relict populations of these species are found in a relatively narrow coastal belt between Cardwell and Cairns. It is difficult to account for this pattern of discontinuity, although post-glacial flooding of coastal plain habitat and climatic changes may have been contributing factors.

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Obituary

Laurence John Hartley Teakle 1901-1979

Emeritus Professor Laurence John Hartley Teakle, C.M.G., B.Sc.(Agric), Ph.D., F.A.I.A.S. died in Brisbane, December 8, 1979 after several months affliction with a brain tumour. He was aged 78.

Dr. Teakle had a long association with the Royal Society of Western Australia which he joined in 1928 soon after returning to Western Australia from post-graduate studies in plant nutrition at the University of California, Berkeley, where he earned his Ph.D. He was a member of the Society's Council from 1929 to 1943 and was President in 1937-38 when he contributed "A Regional Classification of the Soils of Western Australia" as his Presidential address. He served as Treasurer for several years and in 1971 Honorary Life Membership was conferred on him.

Hartley Teakle was born in South Australia but came to Western Australia as an infant when his parents became farmers at Isseka north of Geraldton. From Isseka State School he proceeded to Perth Modern School and to the University of Western Australia where he graduated B.Sc.(Agric) in 1923 and won the Amy Saw Scholarship. He was at the University of California from 1924-27. In 1928 he was appointed Plant Nutrition Officer in the Western Australian Department of Agriculture and soon became involved in soil salinity work in the Salmon Gums district and in the proposed 3 500 Farms Scheme area between Southern Cross, Lake King and Salmon Gums. Controversy developed when he reported that soil salinity might restrict agricultural productivity on the proposed farms. The scheme was abandoned in 1930 when the economic depression of that time intensified. From 1930-36 soil survey parties directed by Dr. Teakle made soil and salinity surveys of 400 000 hectares of land in the north-eastern wheatbelt, the Lake King area and at Salmon Gums. In 1937 he began trace element trials using copper and manganese with potatoes and vegetables at Albany and demonstrated responses. In 1939-41 trials with copper gave benefits with cereals in a number of wheatbelt areas. Manganese and zinc responses with cereals were also demonstrated. He also worked on the phosphate requirements of cereals and pastures.

During the Second World War Dr. Teakle controlled the rationing of superphosphate and other fertilisers and was associated with soil conservation problems including the Ord River catchment. In 1946 he became the first Commissioner of Soil Conservation under the Soil Conservation Act 1945, and early in 1947 he accepted appointment as Professor of Agriculture in the University of Queensland. The remainder of his professional career was at that University where he became President of the Professorial Board in 1960, Deputy Vice-Chancellor in 1963 and was later Acting Vice-Chancellor. He retired in 1970 and was made a C.M.G.

In Queensland he developed wide ranging interest in the agricultural and pastoral industries and their associated soils and encouraged research to elucidate problems. He was elected Chairman of the Queensland Wheat Industry Research Committee in 1957 and remained Chairman till 1963 when he was appointed Deputy Vice-Chancellor of the University of Queensland. The Wheat Research Committee sponsored the development of a successful Wheat Research Institute at Toowoomba.

In 1951 he was awarded the Farrer Medal in Agricultural Science and was later elected a Fellow of the Australian Institute of Agricultural Science. The Australian Society of Soil Science made him an Honorary Member for life and he had a Fellowship of the Australian College of Education. The University of Queensland gave him the title of Emeritus Professor and the degree of Doctor of Laws (LL.D. *Honoris causa*). A new university building for agriculture was named "Hartley Teakle Building".

After retiring Dr. Teakle spent much time tracing the activities of his forebears, commencing with David Teakle an English migrant who attended the Proclamation of the Colony of South Australia on 28 December, 1836. The result was a book "The David Teakle Saga" published in 1979 shortly before the author's final illness.

Throughout his life, Hartley Teakle was a sincere and ardent worshipper at, and supporter of, the Methodist Church. He is survived by a widow, three sons and a daughter who may reflect with pride on his life and his contribution to science, to education and to church and family life.

G.H.B.



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Quaternary stratigraphy of the tidal flats, King Sound, Western Australia

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Manuscript received 19 June 1979; accepted 19 June 1979

Abstract

Six new stratigraphic units are recognised in the Quaternary sequence underlying the tidal flats of the southern portion of King Sound. The youngest, the Point Torment Sand, is a Holocene sequence of shoreline sandy spits; it overlies and interfingers with the Holocene Doctors Creek Formation (10–12 m thick) which is a shoaling-tidal-flat sequence comprising sands, sand/mud laminites and bioturbated mud. The Doctors Creek Formation unconformably overlies the Christine Point Clay (4–6 m thick), which is a Pleistocene mangrove-sediment unit. The Christine Point Clay rests on a thin palaeosol, termed the Double Nob Formation, which in turn rests on the oldest Pleistocene marine unit in the area, the Airport Creek Formation. This formation is composed of semi-lithified to indurated, tidal sand and mud laminites and beds. The Mowanjum Sand is the oldest Quaternary unit in the area; it rests unconformably upon lateritised Mesozoic rocks and underlies the Airport Creek Formation. Its margin has been reworked during later transgressive phases and it extends as tongues across the unconformity interfaces that separate the other Quaternary units. The tidal flats at present are undergoing rapid erosion and most of the Pleistocene and Holocene units crop out across vast, tidally-scoured surfaces. These surfaces are frequently covered by a thin, ephemeral sedimentary blanket termed the Modern Veneer. The Quaternary stratigraphy in the King Sound area reflects the sedimentary accumulation during 3 marine inundations. The Airport Creek and Christine Point Formations accumulated during 2 separate Pleistocene marine incursions. The Doctors Creek and Point Torment formations accumulated, and are accumulating, during the Holocene incursion.

Introduction

The Quaternary stratigraphy of the King Sound area in Western Australia has been left undifferentiated (Casey 1958; Gellatly and Sofoulis 1973). During the course of recent ecological and geological research on the tidal flats of King Sound the author subdivided the Quaternary sediments into numerous stratigraphic units. This paper describes the Quaternary sedimentary sequence underlying both the tidal flats and the adjoining hinterland and proposes stratigraphic nomenclature for the new units. The data and the stratigraphic framework are provided to the detail required for future work on sedimentology, geomorphic development and description of biological habitats of this area.

Methods

The stratigraphy of the area was investigated firstly along selected transect lines. The transects were profiled and levelled with respect to Australian Height Datum (AHD) which enabled later location of various stratigraphic levels relative to datum tide. Conventional methods of hand augering (to 5 m depth), vibrocoring (to 7 m depth) and augering with a Gemco rig (to 16 m depth) were used to explore stratigraphy along the transects. Location of transects and bore and core sites are shown on Figure 1.

At many localities however, stratigraphic units and their relationships are well exposed for direct observation and measurement. This is the case along the banks and walls of deeply incised tidal creeks where

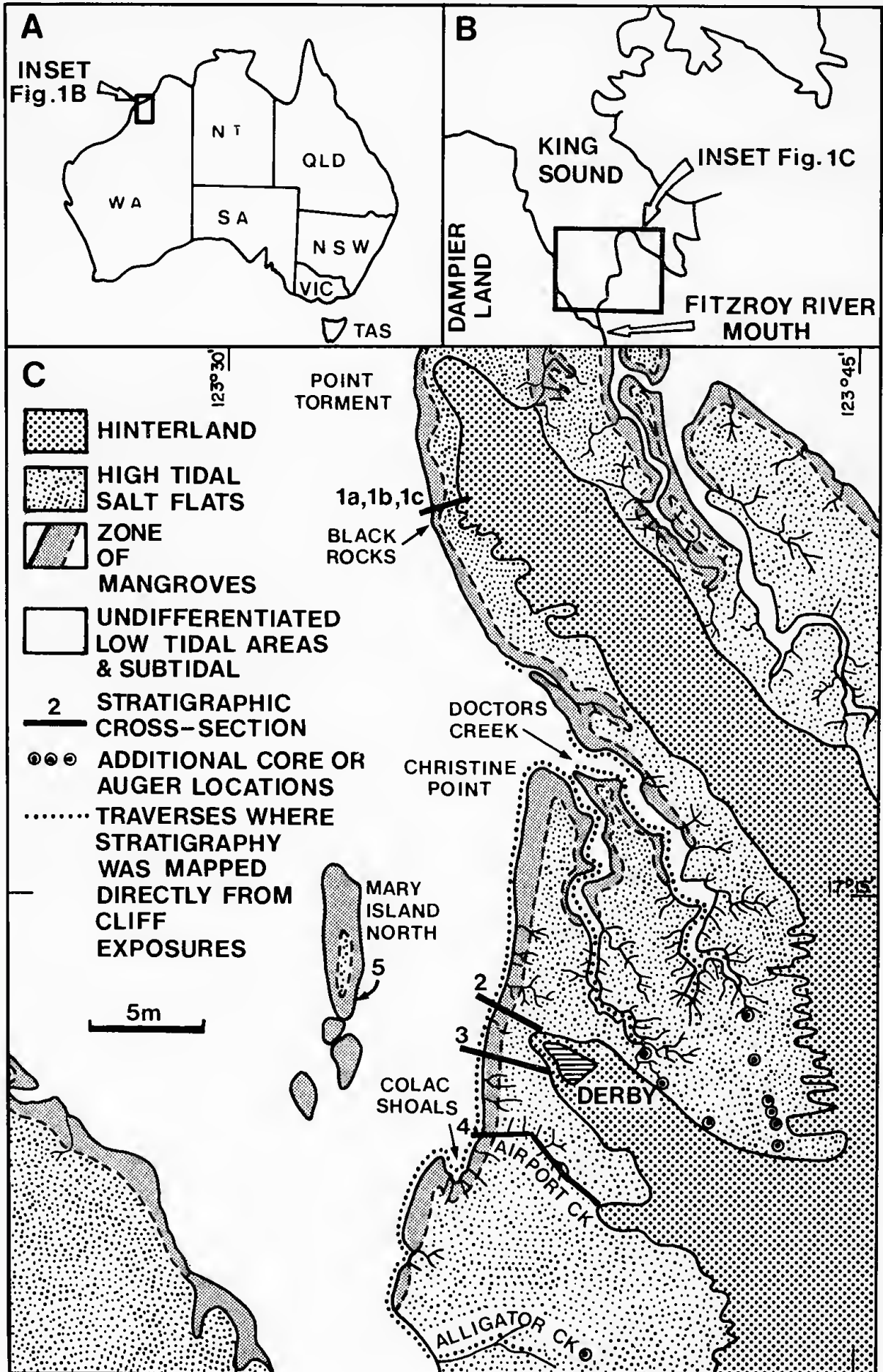
hundreds of metres of cliff section are exposed and washed clean by tidal waters. Extensive stratigraphic sections also are well exposed along cliffs parallel to the shore and across vast, tidally-scoured surfaces from which the sedimentary veneer has been stripped. Creeks and cliffs, where well exposed stratigraphic units were studied in detail, are located on Figure 1.

Geological setting

King Sound is a large marine embayment, of approximately 5 000 km², and is located in the Kimberley region of north Western Australia. Geologically, King Sound is a Quaternary depositional embayment within the Canning Basin. To the north King Sound is flanked by pre-Quaternary (Proterozoic to Tertiary) rocks and vegetated Quaternary red sand dunes and a rocky coastline with narrow tidal flats is developed (Casey 1958; Gellatly and Sofoulis 1973). To the south it is flanked by Quaternary sediments, such as vegetated red sand dunes, grassy alluvial plains and broad tidal flats; these Quaternary sediments overlie, at shallow depths, Mesozoic rocks and Tertiary ironstone (Casey 1958).

In the southern localities the tidal flats and adjoining hinterland are clearly zoned into several units using geomorphology and associated vegetative communities. From landward the units are:

- 1.—hinterland of vegetated red sand dunes and/or Mesozoic rock, or ironstone outcrops.
- 2.—supratidal and salt marsh flats, inundated by storm water and the highest tides.



- 3.—salt flat, occurring above mean high water spring.
- 4.—mangrove and salt marsh flats, which are vegetated surfaces occurring between mean sea level and mean high water spring.
- 5.—an inclined slope, occurring between mean sea level (or high water neap) and low water neap.
- 6.—low-tidal flats exposed by low water spring tides.

Mainly as a result of tidal erosion, modifications of the basic zonal sequence occur. Firstly, a small sea cliff may separate the inclined slope from the mangrove flats so that their junction then occurs at high water neap rather than at mean sea level. A small cliff may also separate the inclined slope from the low tidal flats. Secondly, rocky islands, rocky "reefs" and sand bars are present locally. Thirdly, tidal creeks are common on the flats and incise all but the highest tidal and supra-tidal levels.

Stratigraphy

Six Quaternary stratigraphic units are recognised underlying the tidal flats and onshore hinterland of the King Sound area. They are (in descending order):

- 6.—Point Torment Sand
- 5.—Doctors Creek Formation
- 4.—Christine Point Clay
- 3.—Double Nob Formation
- 2.—Airport Creek Formation
- 1.—Mowanjum Sand

In addition much of the eroded surface of the tidal flats is covered by an ephemeral, thin blanket or veneer of sediment termed the Modern Veneer.

Mowanjum Sand

The Mowanjum Sand is a unit of red dune sand that forms the onshore hinterland bordering most of the tidal flats of King Sound. The dunes are east-west oriented longitudinal forms fixed by *Eucalyptus* and *Acacia* shrublands and woodlands.

Derivation of name.—Mowanjum Mission; grid reference 130813, Derby 1:250 000 sheet.

Type section.—The type section is designated in a sand quarry (grid reference 128820, Derby 1:250 000 sheet) on the northern margin of Derby townsite. Here a section, 6 m thick, is well exposed and a further 1 m was penetrated by auger.

Distribution.—The Mowanjum Sand forms an extensive undulating plain over 20 km wide bordering both eastern and western margins of King Sound for over 200 km; the areal extent of the Mowanjum Sand is well over 4 000 km². Locally, as at Black Rocks, the unit is cliffed and exposed on the low tidal flats. Numerous road-cuts expose cross sections of the longitudinal dunes along the Derby-Broome Highway. The formation is also penetrated in the numerous water bores in the Derby area.

Geometry and thickness.—The Mowanjum Sand is a sheet deposit that blankets Mesozoic and Tertiary rocks. Thickness varies depending on undulations in the underlying rocks. Maximum recorded thickness is 15 m in a small embayment on the west shore of King Sound (grid reference 688805, Derby 1:250 000 sheet) opposite

Alligator Creek (Jennings 1975). Locally because of subcropping Tertiary rock highs, its thickness is less than 1 m.

Lithology.—The formation is composed mainly of red to orange quartz sand; locally the sand is white. There are sheets and wedges of white sand, ferruginised sand and root-structured sand interlayered locally with the main red sand. The structure is homogeneous to mottled (locally) root-structured; animal burrows are common in the upper parts. Fe-oxide mottles and/or orange clay mottles are scattered but abundant in some areas. Parts of the formation have been cemented by Fe-oxide forming ferruginous sandstone as sheets and along former root casts.

Fossils.—The formation contains only trace fossils (animal burrows, root casts) and scattered plant detritus.

Stratigraphic relationships.—The Mowanjum Sand rests unconformably on Tertiary laterite and other pre-Quaternary rocks. The formation can be observed beneath all other Quaternary formations where it is well exposed in low tidal areas. Coring indicates that the Mowanjum Sand preceded the younger Quaternary formations (Figs. 2 and 7). The depositional breaks between the younger formations are marked by sheets of red sand, white sand (= marine reworked red sand), or bioturbated muddy sand (= marine reworked Mowanjum Sand bioturbated by a mangrove community). These sand (or muddy sand) sheets are extensions of the main Mowanjum sand body (Fig. 2) and pinch out seaward. In many localities successive marine incursions during the Quaternary have completely eroded the seaward edge of the Mowanjum Sand and the younger formations rest directly on Tertiary rocks (Fig. 7).

Discussion.—The Mowanjum Sand is essentially a sand-plain (terrestrial) formation probably of aeolian origin. Its present geomorphic surface has been shaped by aeolian activity. Along the shores of King Sound the top of the unit occurs from levels of over 30 m above high tide down to the low spring tidal zone. On its seaward margin the Mowanjum Sand has been reworked by successive marine transgressions and there are ribbon to sheet extensions intercalated with marine units. The extensions (reworked margins) were formed by a combination of sheet-washing of sand across plains during wet seasons and marine reworking of the exposed edge of a sand plain.

Airport Creek Formation

The Airport Creek Formation is a unit of semi-lithified and nodular-cemented interlayered sand and mud deposited in Pleistocene tidal environments. The unit forms extensive sheet outcrops exposed at low spring tides.

Derivation of name.—Airport Creek, which is a tidal creek draining high tidal flats west of Derby airport and Mowanjum Mission. Grid reference (for mouth of creek): 121817, Derby 1:250 000 sheet.

Type section.—The type section is designated as the mouth and banks of Airport Creek; here 3 m of section and the contact with the overlying formation are well exposed. The base of the unit is not exposed.

Distribution.—The formation crops out over 8 km² of tidal flat exposed at low tide between the mouth of Airport Creek and Nob Hillock. The unit is observed

Figure 1.—Map showing location of study area. Inset C shows transect lines, position of additional core or auger sites and traverses.

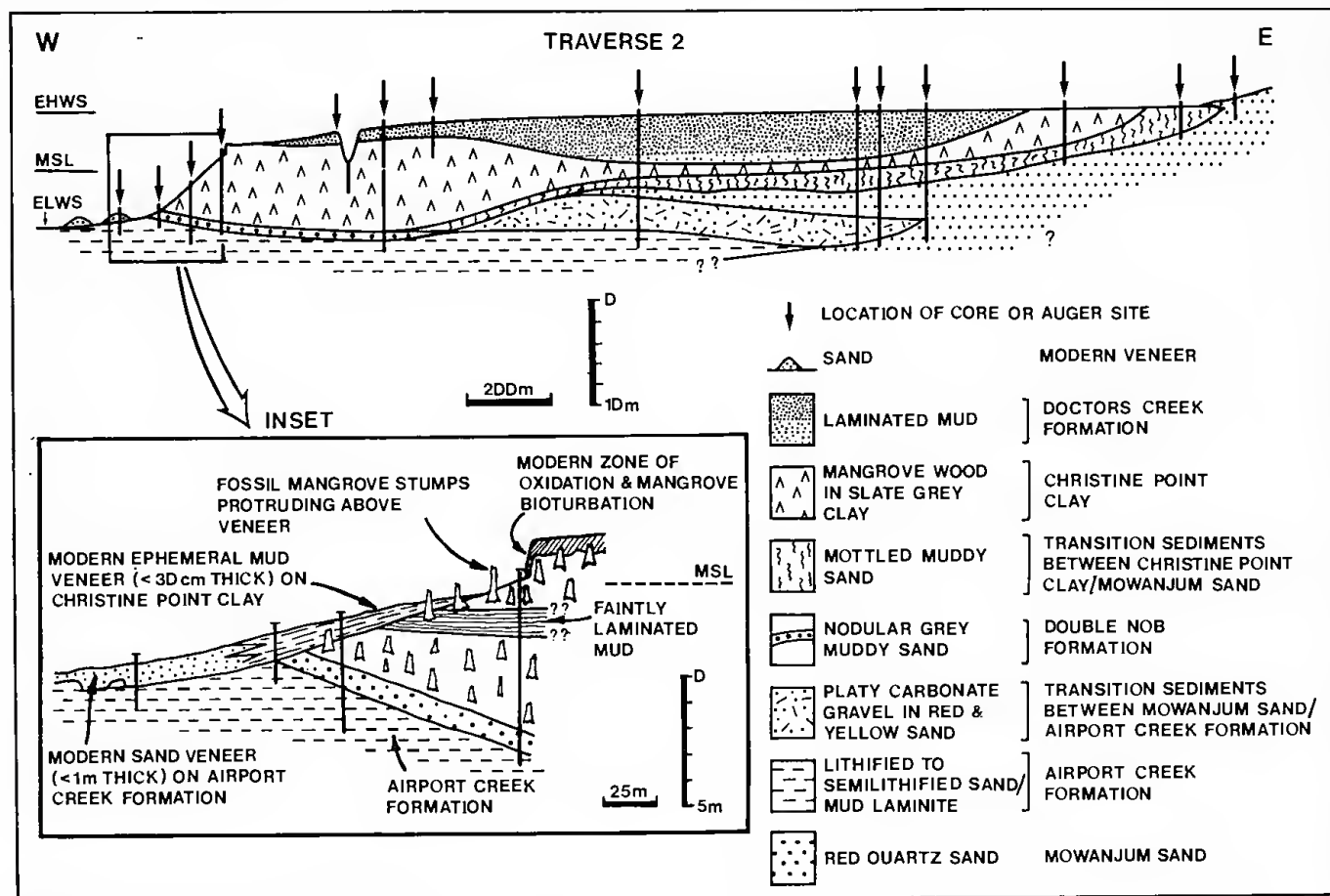


Figure 2.—Stratigraphy along transect 2 showing relationship of Mowanjum Sand to other stratigraphic units. Inset shows detail of profile exposed on shore face at Derby Jetty.

in small outcrops several kilometres offshore from Derby during periods of the lowest tides. It crops out on the floor and banks of Airport Creek and Doctors Creek where the Modern Veneer is stripped away. Additionally the formation has been intersected in cores at various sites (transects 2, 3 and 4). It is inferred from its distribution pattern that the formation underlies most of the tidal flats and that it covers an area of over 200 km².

Geometry and thickness.—The geometry of the Airport Creek Formation is incompletely known because the total thickness is unknown except for onshore sections. Numerous cores and outcrops, however, show that the top of the formation is extensively eroded with broad scours up to 4 m deep.

The unit typically is exposed between intervals of low water neap and shallow subtidal, i.e. over 3 m, which is its average exposed thickness. Coring along transect 2 (Fig. 2) shows that the unit is at least 8 m thick; the base however was not reached.

Lithology.—The formation is composed of a grey to buff, semi-lithified to indurated, sediment suite that includes: (a) laminated, cross-laminated and ripple-laminated sand; grains are mainly quartz and calcareous skeletons, (b) laminated, cross-laminated and ripple-laminated silt; grains are quartz and skeletons, (c) laminated and bedded clay, (d) burrow-structured to bioturbated sand, silt and clay. The sediments typically are interlayered and interlaminated; sand predominates in the suite. The induration or semi-lithification is due to an interstitial precipitate of low-magnesian calcite.

Fossils.—The formation contains three types of fossils: (a) abundant microfauna, as grain types in the sand and silt, including foraminifers, sponges and mollusc fragments, (b) scattered macrofauna of crab claws and debris (*Uca* spp., *Scylla serrata*), bivalves, (c) an ichnofauna that includes burrow traces of crustaceans and worms.

Stratigraphic relationships.—The Airport Creek Formation appears to rest unconformably on Mowanjum Sand or Tertiary laterite. On low tidal flats in the Derby area the base of the unit is not exposed. Coring further onshore (Figure 2) indicates that the formation rests on Mowanjum Sand; the Airport Creek Formation usually is reduced to an aggregate of reworked nodules (transition sediments of Figure 2) above the Mowanjum Sand. Further north at Black Rocks the same stratigraphic relationship is exposed at low tide, i.e. an aggregate of “limestone” nodules (presumably formed as a lag after erosion of Airport Creek Formation) rests on Mowanjum Sand. The top of the Airport Creek Formation is gradational into the overlying Double Nob Formation. Locally, erosion has removed the Double Nob Formation and the Airport Creek Formation is overlain, with sharp contact, by the Doctors Creek Formation (Figs 2, 3 and 4).

Discussion.—The Airport Creek Formation is essentially a lithified to partly lithified tidal flat sedimentary accumulation. The sediments all have analogs on the modern tidal flats particularly in low to mid tidal levels. The interpretation of the stratigraphic relationships between Airport Creek and other formations in many

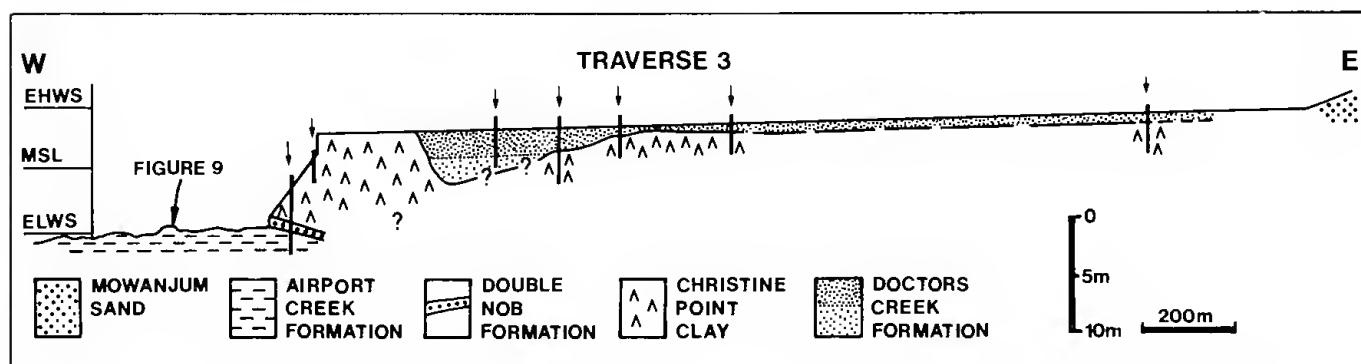


Figure 3.—Stratigraphy along transect 3 showing relationship between Doctors Creek Formation and Christine Point Clay.

areas depends upon recognition of pebbles derived from the formations. Erosion of Airport Creek Formation typically results in a lag of grainstone-lithoclast pebbles that are usually platy. These pebbles represent the indurated parts of the formation that remain as residuals during erosion (Fig. 9). Similar pebble lags develop where nodular-cemented younger formations are eroded but, in contrast, the Airport Creek nodules retain the distinctive lithology and sedimentary structures, and furthermore are indurated by low-magnesian calcite cement. Younger formations are predominantly composed of bioturbated or massive mud and are patchily indurated by magnesian calcite, dolomite and aragonite cements.

Double Nob Formation

The Double Nob Formation is a sheet of black nodular soil that separates the Airport Creek and Christine Point Formations.

Derivation of name.—Double Nob Hillock (grid reference 821121, Derby 1:250 000 sheet).

Type section.—The type section is designated on the low tidal flats 1.5 km south of Derby jetty (traverse 3 on Fig. 1) where the base and top of the unit are well exposed (Fig. 8).

Distribution.—The formation is exposed in over 9 km of cliff section at levels of low tide from the mouth of Airport Creek northwards. It also occurs in scattered outcrops and cliff sections wherever the base of the Christine Point Clay is exposed. Additionally the unit has been intersected in a few core sites (traverses 2, 3 and 4).

Geometry and thickness.—The Double Nob Formation is a thin (sheet) unit that blankets the Airport Creek Formation. Its thickness varies from 30 cm to 1 m.

Lithology.—The unit is composed of homogeneous dark grey muddy sand cemented by low magnesian calcite into granule-sized nodules; sand grains are medium and coarse quartz.

Fossils.—The unit is unfossiliferous.

Stratigraphic relationships.—The Double Nob Formation overlies the Airport Creek Formation with gradational contact. The unit underlies the Christine Point Clay and the contact varies from sharp to gradational; gradational contacts are characterized by a transitional zone (up to 20 cm thick) composed of burrow mottles, root structures, and biogenic mixing of formation boundaries.

Discussion.—The lithology (texture, composition and colour) of the Double Nob Formation is similar to inland black soils on the modern plains bordering lime-

stone ranges of the Kimberleys (Playford and Lowry 1966). The granule-sized nodules in the unit are CaCO_3 indurations and probably are pedogenic. Similar pedogenic CaCO_3 nodules occur locally in black soils inland in the Kimberleys. The Double Nob Formation probably represents a pedogenic unit developed on a calcareous parent (Airport Creek Formation) during a Pleistocene low sea level stand. At the time the King Sound area would have been an extensive undulating savannah plain (some 2.5–3 m below present mean sea level) underlain by black soil.

Christine Point Clay

The formation is composed of a grey clay with abundant *in situ* large mangrove stumps. It is a distinctive unit well exposed on the eroding tidal flats around Derby.

Derivation of name.—Christine Point (grid reference 123834, Derby 1:250 000 sheet).

Type section.—The type section is designated on the mid to low tidal flats 1.5 km south of Derby jetty (Traverse 3, Fig. 1) where the base and most of the unit are exposed (Fig. 8).

Distribution.—The formation is exposed in cliff sections at numerous localities along the coast between the mouth of Airport Creek and Christine Point and in Airport Creek, Doctors Creek and the creeks north of Derby jetty. The formation has been intersected in numerous cores in traverses 1–4, and occurs over 100 km² in outcrop and subsurface on the eastern shore of King Sound.

Geometry and thickness.—The geometry of the formation is incompletely known because its seaward extremity has been eroded away; the unit also has been extensively eroded and scoured prior to deposition of the overlying formations. The Christine Point Clay largely appears now as isolated buried islands or hinterland-fringing platforms (Fig. 6). From a consideration of the enveloping surface of its base and top, it appears that the unit was deposited on a sloping to undulating surface. The maximum thickness of the unit is 7.5 m. Generally the unit is 4–6 m thick at its present western (eroded) margin and it thins toward the hinterland (Figs. 2, 3, and 4). The formation was essentially wedge-shaped and fringed the hinterland prior to extensive erosion.

Lithology.—The formation is mostly uniform throughout its thickness and is composed of slate grey, homogeneous to mottled clay; large *in situ* mangrove stumps (up to 1.2 m diam), rootlets and plant detritus are abundant; locally there are filled burrow structures. There is local development of nodules by precipitates

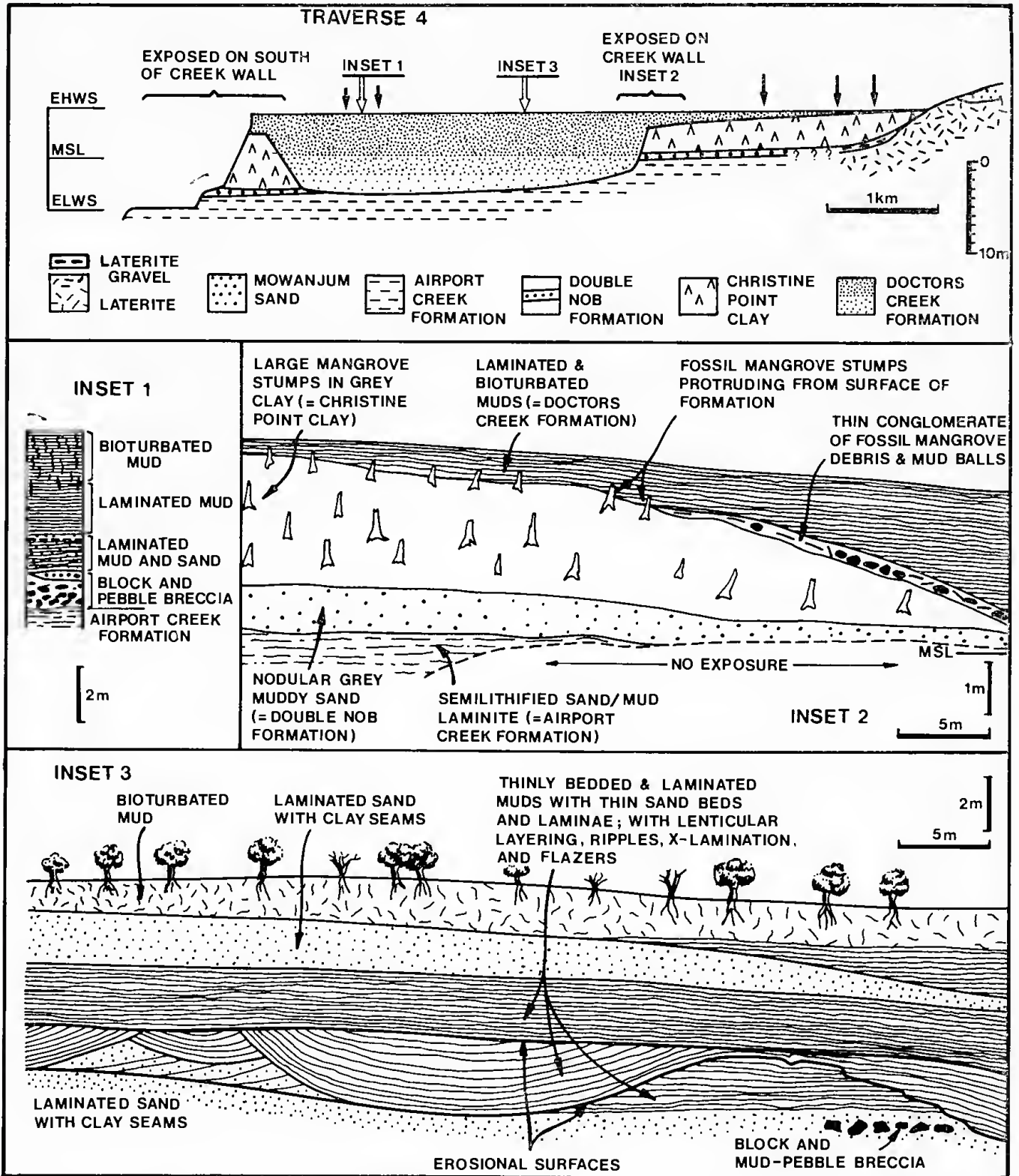


Figure 4.—Stratigraphy along transect 4 (Airport Creek); arrows show locations along the creek where more detailed study was made of stratigraphic sequence. Insets show detail of stratigraphic relationships at various localities along the profile. Inset 2 is a view to the south of the creek wall.

of dolomite and magnesian calcite. A transitional sediment is developed between the contact of the Christine Point Clay and Mowanjum Sand. It is a grey, brown to orange, colour-mottled and burrow-mottled mixture of sand, muddy sand and mud. At about the middle of the formation there is a 1 m thick band of crudely laminated light grey clay without *in situ* rootlets and without the bioturbation features so typical of the rest of the formation (traverse 2, Fig. 2). This clay pinches out to the east.

Fossils.—The Christine Point Clay has yielded a variety of fossils. Imbedded in the formation are abundant *in situ* and reworked mangrove stumps and trunks (Figs. 8B and 8C), and calcareous to dolomitic nodules that contain a varied invertebrate fauna. The mangrove trunks and stumps have been identified as *Avicennia marina*, *Rhizophora stylosa* and *Ceriops tagal* (using root morphology, Field Key 2 of Semeniuk *et al.* 1978). The stumps and trunks of *Avicennia marina* are commonly riddled with carbonate-cemented borings referable to *Teredo* spp.; the mangrove wood is locally impregnated with dolomite and/or magnesian calcite. Fauna from the nodules includes: *Uca* (fiddler crab), *Scylla serrata* (mangrove crab) and *Thalassina anomala* (mud lobster). Ichno-fauna includes a wide range of indeterminate filled burrows.

Stratigraphic relationships.—The formation generally rests with gradational contact along its hinterland margins on Mowanjum Sand with a transitional zone of orange and grey sand mottled with brown muddy sand and clay. Seaward, the Christine Point Clay unconformably overlies the Double Nob Formation. The contact is sharp but varies locally to gradational with a transitional zone (a few decimetres thick) where sediments of the Christine Point Clay and Double Nob Formation are biogenically mixed by root casts and burrows. Locally *in situ* stumps that grew on the Double Nob soil are preserved.

The contact of the top of the formation with younger formations (Doctors Creek and Point Torment formations) is generally sharp where developed between mean sea level and low tide because biogenic activity is not as pervasive and has not disturbed the contacts. The top of the Christine Point Clay has either a sharp or gradational contact with overlying units at levels between mean sea level and high tide. The contact is usually sharp where it is above the range of modern mangroves, and is often marked by a weathered zone of oxidised clay and oxidised mangrove stumps. However the contact is gradational where root structuring, root casting and animal bioturbation has taken place (usually within the interval of modern mangrove growth *i.e.*, about mean sea level to mean high water spring).

The base of the Christine Point Clay rests on the gently undulating top of the Double Nob Formation, some 2–3 m below mean sea level. Contact relationships indicate that the sea transgressed a soil plain and mangroves encroached upon and colonised the plain as it was inundated. The top of the formation is extensively and deeply scoured. The bulk of the Doctors Creek Formation occurs within these scoured hollows (Fig. 6). The contact is often marked by mud pebble conglomerate and mangrove wood debris.

Discussion.—The Christine Point Clay is a unit deposited largely under mangrove cover. The thin clay unit in the middle of the formation is lithologically and structurally similar to sediment formed today in mid-tidal (front of mangrove) environments. It would appear therefore that the Christine Point Clay represents an accumulation

of sediment under transgressive, followed by regressive, conditions. The height of the transgression is represented by the mid-tidal clays that occur some 1.5–2.2 m below present mean sea level (Fig. 2).

The top of the formation has been weathered and planed to levels of high water spring and overlain by Doctors Creek Formation (Fig. 3). The bulk of the Christine Point Formation however was deeply scoured (probably by the Holocene transgression) and the large erosional hollows became embayments for deposition of Doctors Creek Formation (Figs. 2, 3, 4, 6).

Doctors Creek Formation

This unit is characterised by a shoaling sequence of sand, mud/sand laminite, bioturbated mud, and laminated (to vesicular) mud. The formation occurs locally in depositional embayments, where it is presently accumulating, but it is also undergoing erosion in many other localities where its depositional phase has ceased. The lithologies and their levels relative to datum can be correlated with modern tidal facies.

Derivation of name.—Doctors Creek (grid reference 125835 to 129821, Derby 1:250 000 sheet) where the unit is well exposed.

Type section.—The type section is designated along the banks of Doctors Creek between (grid reference) 125835 and 126830 (Derby 1:250 000 sheet).

Distribution.—The formation is exposed over 180 km² (Fig. 6). It is well exposed on the coastline and creeks south of Airport Creek, along most of the length of both channels of Doctors Creek and at the margins of Mary Island North. The formation occurs as a contemporary depositional unit in the Colac Shoals area (Fig. 1), in the stretch of coastline between Christine Point and Point Torment, and also in local embayments along the shore of Mary Island North. It has been intersected in core in traverses 2, 3, 4, 5 (Figs. 2, 3, 4, 5).

Geometry and thickness.—The formation occurs as large lensoid bodies 10 km x 10–15 km x 12 m as sedimentary fill in older tidal embayments; it occurs as ribbon to wedge-shaped bodies 10–15 km long, 2–4 km wide and up to 12 m thick fringing the coastline where it is currently accumulating; it also forms offshore lensoid shoals up to 10–15 km long, 4 km wide and 12 m thick as at Mary Island North, Mary Island South and Colac Shoals (Fig. 1).

Lithology.—There are essentially five main facies in the formation: (a) sand and shelly sand (b) sand/mud laminite (c) bioturbated mud (d) laminated mud (e) conglomerate.

The sand and shelly sand facies are laminated to cross-laminated, medium to coarse, quartz skeletal sediments; locally they are lithoclastic. Shells are abundant in bands and along laminae. Vertical burrows are scattered in occurrence.

The sand/mud laminite facies consists of interlayered sand and mud (Fig. 8D); the layers are centimetres to millimetres apart. Wavy lamination, lenticular bedding, flaser bedding, ripple-drift-lamination and cross-lamination (Reineck and Singh 1973) are typically present. Vertical to sub-vertical burrows (filled with sand or mud) are common and cut across layering. The mud bands and laminae are generally homogeneous to crudely laminated. Mangrove roots and scattered stumps are present toward the top of this facies.

The bioturbated mud facies is a root-structured, root-casted, animal bioturbated, to homogeneous mud unit. Locally it is crudely laminated. *In situ* man-

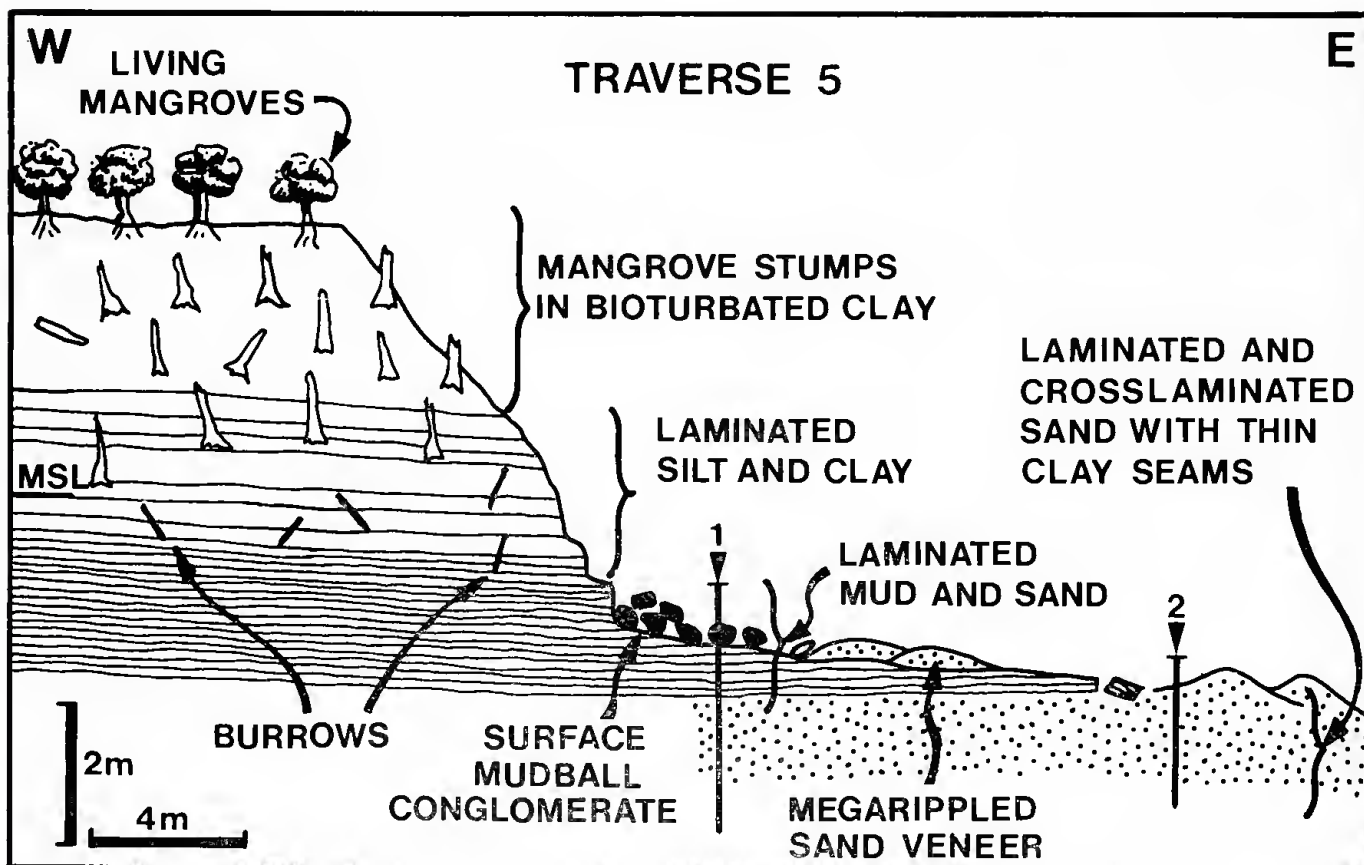


Figure 5.- Stratigraphy of Doctors Creek Formation along transect 5 at Mary Island North.

grove stumps and rootlets are common (Fig. 8D). Locally there are shell and sand lenses generally less than 10 cm thick; sand and shell are present either in discrete patches as burrow fills or scattered through the sediment. Locally there is patchy lithification by dolomite and magnesian calcite forming nodules (up to 20 cm in size).

The laminated mud facies is an interlayered silt and clay sediment. Laminae often are vesicular. Where silt is generally absent clay is crudely laminated and more obviously vesicular. Desiccation cracks and thin mud chip breccias are locally preserved in this facies.

The conglomerate facies forms a minor part of the formation but is important historically. There are three types of conglomerate, limestone-pebble, mud-clast and wood-debris, all with a grain-support gravel framework and interstitial mud. Limestone-pebble conglomerate is an accumulation of nodules eroded from the Airport Creek, Double Nob and Christine Point Formations (Fig. 4). Mud-clast conglomerate is composed of pebble- to boulder-sized clasts of mud eroded from Christine Point Clay, or intraformationally from eroding mud beds in the Doctors Creek Formation (Figs. 4 and 5). Mangrove-wood-debris conglomerate is a chaotic accumulation of mangrove stumps, trunks and branches (ranging in size from a few centimetres to over a metre), mixed with mud clasts and rarer limestone pebbles. The mangrove debris forms a supportive frame with the other pebble types. The facies in the Doctors Creek Formation are in a sequence that is related to modern tidal levels (Figs. 4, 5, 8). The sand and shelly-sand facies generally forms the lower parts of the formation in the interval of shallow subtidal to low

water neap. This facies, with increasing mud content (mud seams), passes gradually up into sand/mud laminite facies which occurs between intervals of low water neap and about mean sea level. Sand/mud laminite facies is, in turn, overlain by bioturbated mud facies the top of which is at mean high water spring; the contact is gradational and reflects decreasing sand and increasing bioturbation. The laminated mud facies occurs between levels of mean high water spring and the highest tides. Each facies thus is essentially sheetlike and stacked one upon the other:

- top: laminated mud facies (< 1 m thick)
- bioturbated mud facies (3-4 m thick)
- sand/mud laminite facies (2-3 m thick)
- bottom: sand and shelly sand facies (3 m or more thick)

Two exceptions to the sequence may be developed. Firstly, sand and shelly sand may form isolated ribbon bodies within the sand/mud laminite facies. This feature has its modern analog where a shoal (ribbon) of sand some 1-2 m thick has migrated into the sand/mud laminite lithotope. Secondly, the bioturbated mud facies locally may be poorly developed and laminated mud facies is present in its place. This relationship has its modern analog along the coast where mangroves are absent or sparse and sediments of the mid to high tidal flats are not intensely burrowed or root structured.

The conglomerate facies occur in the following stratigraphic locations. Limestone-pebble conglomerate generally is present as a lens- to wedge-shaped body (less than 1 m thick) where the Doctors Creek Formation rests on the Airport Creek or Christine Point formations. Mud-clast conglomerate occurs as

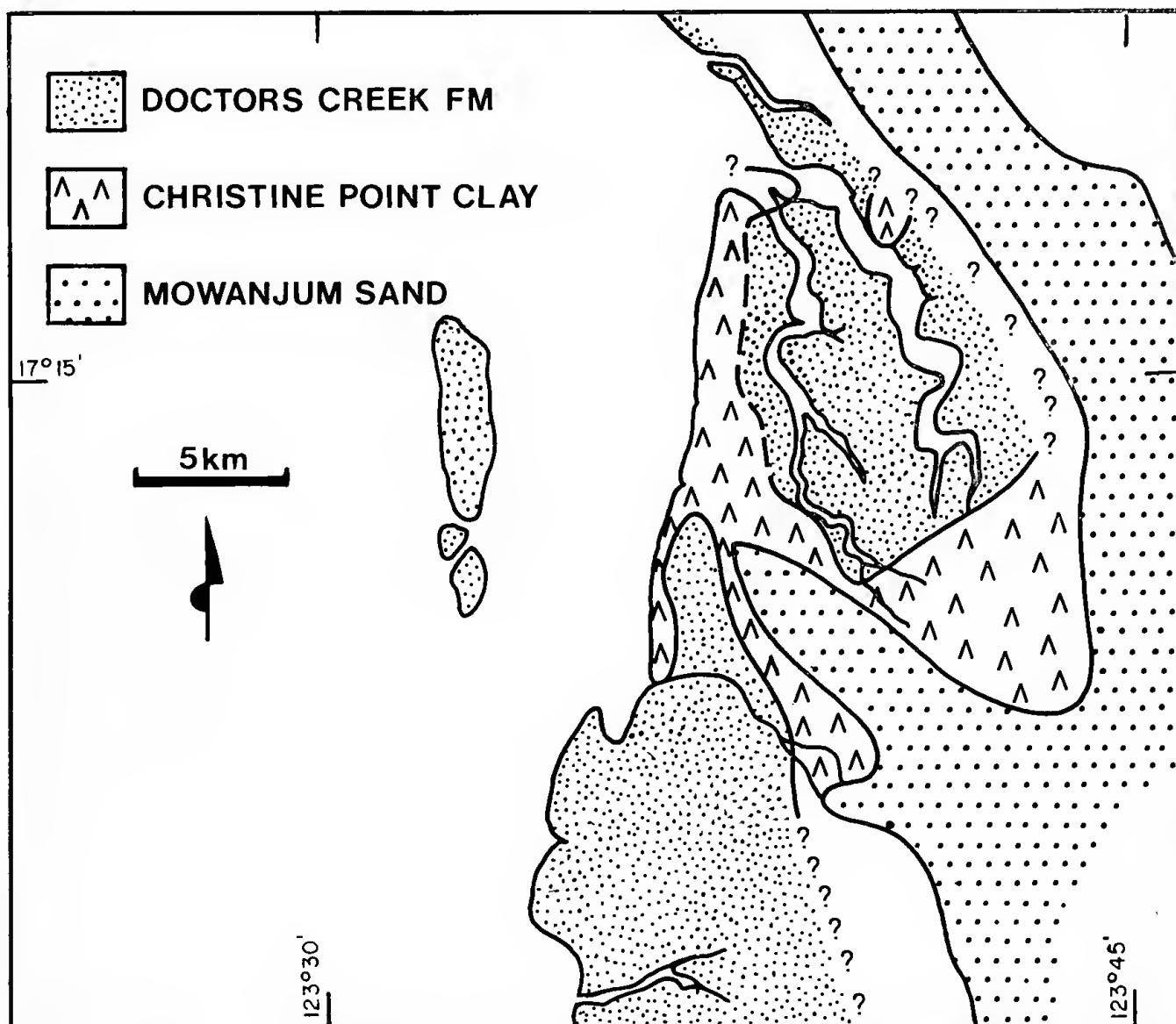


Figure 6.—Map showing distribution of Doctors Creek Formation in the large-scale hollows scoured out of Christine Point Clay. Boundary of Christine Point Clay and Doctors Creek Formation is illustrated in profile of transects 2, 3, 4 and Figure 8 C.

a lens (or wedge) deposit where the Doctors Creek Formation rests on, or abuts against, Christine Point Clay (Fig. 4); the conglomerate also forms as intraformational units where erosion of mud beds has taken place (Fig. 5). Mud clasts of intraformational origin are distinguishable microscopically, texturally and by colour from clasts eroded from the Christine Point Clay. Mangrove debris conglomerate forms lens- to wedge-shaped accumulations along the interface between the Christine Point Clay and the Doctors Creek Formation (Fig. 4) and at the mouths of tidal creeks that erode into a variety of formations.

Fossils.—The Doctors Creek Formation contains a variety of fossils. Flora includes *in situ* stumps of *Avicennia marina*, *Rhizophora stylosa* and *Ceriops tagal*. Diameter of stump rarely exceeds 10–15 cm. *Avicennia* and *Rhizophora* stumps and reworked trunks are often riddled with *Teredo* borings.

The most important and diagnostic fauna includes: (a) sand and shelly sand facies: molluscs *Barbatia*, *Saccostrea* fragments, *Nucula*, *Spisula*, *Solen* and

Zeuxis dorsata; echinoderm tests and fragments; *Scopimerina* crab burrows as ichnofauna, (b) sand/mud laminite facies: sand laminae contains shell fauna as above; ichnofauna of the crabs *Uca* and *Macrophthalmus*, shrimps and worms, (c) bioturbated mud facies: molluscs *Telescopium telescopium*, *Terebralia sulcata*, *Cerithidea*, *Littorina scabra*, *Saccostrea*, *Nerita lineata*; crustaceans *Uca* spp., *Sesarma* spp., *Scylla serrata*, *Thalassina anomala*, barnacles and shrimps; an ichnofauna of borings and burrows of crustaceans, bivalves and worms, (d) laminated mud facies: crab claws, *in situ* bivalve *Glaucomya* sp; ichnofauna of crab, worm and insect burrows.

Stratigraphic relationships.—The Doctors Creek Formation rests erosively and unconformably on all other older formations (Figs. 4, 6, 7, 8). The formation is best developed as sedimentary fill in large-scale hollows scoured into the Christine Point Clay (Fig. 6). The stratigraphic relationship here is erosional; mangrove stumps of the Christine Point Clay protrude into the overlying Doctors Creek Formation (Fig. 8C) and

wedges of conglomerate are present above the contact. The erosional contact between Doctors Creek Formation and the Airport Creek and Double Nob Formations is also marked by conglomerate with debris reworked from the underlying units (Fig. 4).

Discussion.—The sedimentary facies of the Doctors Creek Formation have analogs on the modern tidal flats. Indeed the boundary between each facies corresponds to the tidal levels of the modern facies. Clearly the Doctors Creek Formation developed while sea level remained mostly at its present position. The sedimentary material that fills the large scale embayments (now buried under tidal flats) however is currently being rapidly eroded. It appears that most of the deposition of the formation ceased sometime earlier in the Holocene. Deposition of the formation continues in small, local, (semi-protected) embayments but these are minor features when compared to the large scale erosion occurring along the coastline.

Point Torment Sand

The Point Torment Sand is a unit of sand and shelly sand that generally borders the hinterland at levels of high tide. The formation is developed as shoreline spits typically to the north of Christine Point. The surface of many of the spits is above tidal levels and is colonised by terrestrial coastal vegetation such as *Acacia* and *Spinifex longifolia*.

Derivation of name.—Point Torment (grid reference 117853, Derby 1:250 000 sheet).

Type section.—The unit and its stratigraphic relationships are well developed at Point Torment Light Tower (grid reference 120847, Derby 1:250 000 sheet) and this locality is designated as the type section.

Distribution.—The formation is a discontinuous shoreline deposit along the east shore of King Sound between the north bank of the mouth of Doctors Creek and Point Torment, and north of Point Torment on both east and west shores of King Sound.

Geometry and thickness.—The formation is a series of spits essentially shoestring in shape (Jennings and Coventry 1973). These spits are aligned along the tidally-eroded edge of the Mowanjum Sand. The spits may exhibit splays across the depositional slope but they do not form a continuous north-south body. Individual spits are up to 1.5 km long and their width varies from a few metres to over 20 m. Splays occur over a total width of about 200 m. Maximum thickness of the spits is 3 m; subaerially and tidally degraded spits are less than 1 m thick.

Lithology.—The formation consists of cross-laminated, cross-bedded and, very locally, bioturbated, medium and coarse quartz skeletal sand, shelly sand and lithoclastic sand.

Fossils.—The fauna of this formation includes a large range of molluscs (listed in Doctors Creek Formation), crustaceans and corals. It represents material reworked from tidal communities in mangroves and offshore, as well as shell fragments (oysters and mud whelks) that probably are aboriginal middens.

Stratigraphic relationships.—The Point Torment Sand abuts the Mowanjum Sand (Fig. 7). The formation locally overlies and interfingers with modern sediments of the Doctors Creek Formation (Fig. 7). The Point Torment Sand is developed as spits along an eroding coastline cut into the finger-like extensions of Mowanjum Sand. The sand spits, transported by longshore tidal

currents, migrated north and south from their source and developed three types of stratigraphic relationship with the contemporary Doctors Creek Formation: (a) an interfingering relationship with bioturbated mud (the mangrove lithotope) and laminated mud on west and east margins, (b) a conformable sharp contact where the sand invades established mangrove environments which are underlain by bioturbated mud, (c) a conformable sharp contact where the sand has encroached onto a salt flat underlain by laminated mud.

Discussion.—The Point Torment Sand has been deposited only since tidal erosion has progressed to the stage onshore that Mowanjum Sand has been eroded. Thus it appears that the formation is the youngest in the area.

Modern Veneer

The term, Modern Veneer, is applied here to sediments that form a thin sheet over older units. It is not proposed to give it formational status, rather it is an informal term used here for descriptive purposes since the veneer is largely ephemeral and is commonly stripped away seasonally.

The Mowanjum, Airport Creek, Double Nob and Christine Point formations, as well as Tertiary ironstone, crop out over extensive areas of eroded tidal flats where they are frequently covered seasonally by a veneer of recent sediment. Low tidal areas have a veneer of limestone pebbles that overlie the Airport Creek Formation from which they are derived, (Figs. 8A and 9). Other low tidal areas have a veneer of sand and shelly sand that overlies Airport Creek, Double Nob and (lower parts of) the Christine Point formations (Fig. 2). Low to mid-tidal areas have a veneer of interlayered mud and sand or a sheet of mud that overlies Christine Point Clay. Pockets and hollows in Tertiary rocks or Mowanjum Sand are covered by a veneer of sand, or sand/mud laminite or mud (Fig. 7).

All sedimentary veneers are less than 1 m thick and most are less than 30 cm thick. The veneers in low to mid tidal areas are frequently stripped on a monthly or seasonal basis by spring tides or storms. In the field shallow excavations or augering immediately distinguishes Modern Veneers from shoaling stratigraphic sequences of the Doctors Creek Formation.

Age of the units

The discussion on the ages of the stratigraphic units is best developed by beginning with an account of the youngest unit and proceeding through to progressively older units. The tentative age assignments of older units have necessarily been based on stratigraphic criteria.

Doctors Creek and Point Torment Formations, Modern Veneer.—The youngest units, Point Torment Sand, Doctors Creek Formation and the Modern Veneer are clearly contemporary. The older, buried Doctors Creek Formation that currently is being exposed by erosion is also assigned a Holocene age because its facies correspond to levels of the modern facies, the composition of fauna and flora (particularly type and size of mangrove stumps) are similar to modern biota and the preserved shelly fauna is fresh (i.e. unaltered). It would appear therefore that the Doctors Creek Formation and Point Torment Sand accumulated with mean sea level at about its present position.

Christine Point Clay.—The contact between the Christine Point Clay and Doctors Creek Formation is important stratigraphically and represents a major interval of

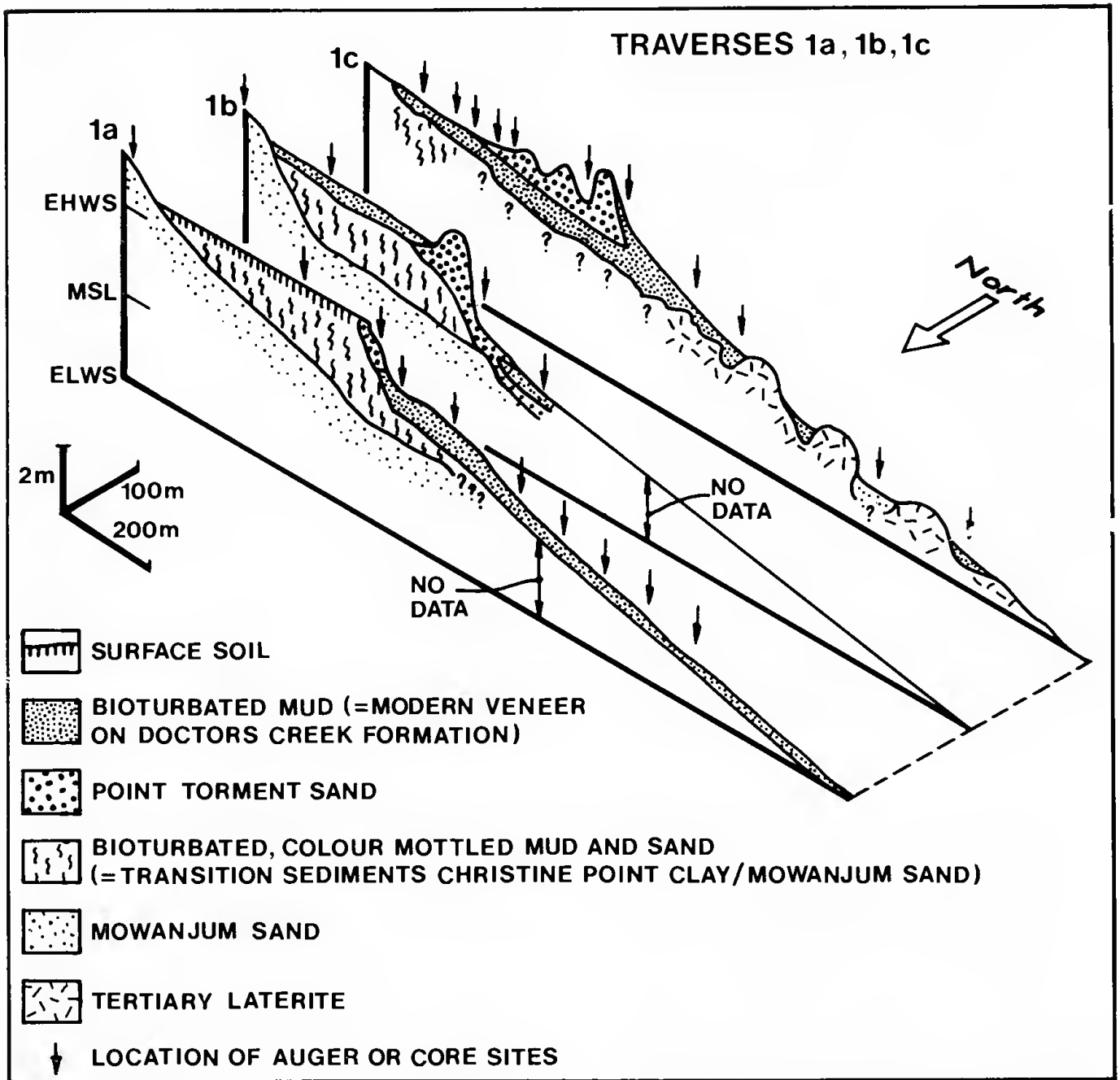


Figure 7.—Stratigraphy along 3 closely spaced transects 1a, 1b, 1c in the Black Rocks area. The profile illustrates the relationship between Point Torment Sand and the older stratigraphic units.

erosion where a large volume of sediment was removed. The following features suggest a pre-Holocene age: (a) it is a transgressive-regressive unit formed marginal to a sea whose mean level reached a maximum height of some 1.5 m *below* present mean sea level, (b) the mangrove stumps are distinctly larger (30 cm–1.2 m diameter) than those occurring both today and in the Doctors Creek Formation, (c) its shells (except for those preserved in carbonate nodules) have been lost through solution.

If both the Christine Point Clay and Doctors Creek Formation were of Holocene age the following sequence of events would be necessary: (a) inundation of a sub-aerial plain during the Holocene transgression, (b) encroachment and deposition of mangrove lithotope

during the transgression to accumulate a 3–4 m thick mangrove mud sequence culminating, at the height of the transgression, in deposition of mid-tidal laminites, (c) a sea level still-stand, with mean sea level at about 1.5 m below present, so that the mangrove lithotope can prograde out over both mid-tidal laminites and the earlier deposited transgressive mangrove lithofacies, (d) local cementation by dolomite and magnesian calcite and selective dissolution of calcareous components in the Christine Point Clay, (e) extensive deep scouring of the now 6–8 m thick mangrove mud wedge and development of lag conglomerate of carbonate nodules, (f) rise of the sea to present mean sea level and deposition of shoaling tidal sequences (Doctors Creek Formation) within the embayments.

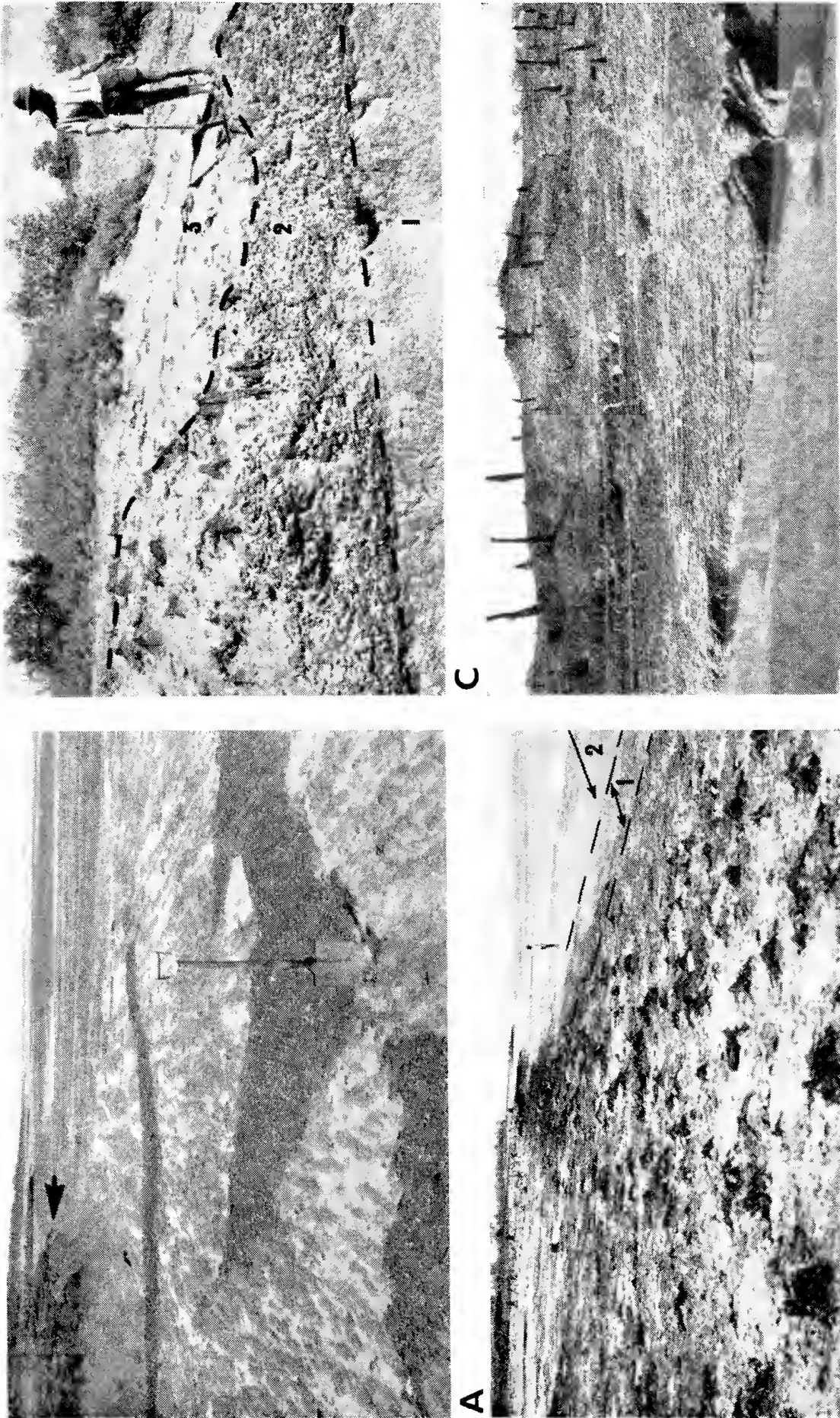


Figure 8—A.—Tidal flats exposed by a low spring tide along transect 3. In the foreground is the Double Nob Formation (linearly scoured by tidal erosion) with a patchy veneer of limestone-
 pebble conglomerate. At the base of the small cliff (Arrow) the Double Nob Formation separates the Airport Creek Formation from the overlying Christine Point Clay. Spade for scale
 is in foreground. B.—Tidal flat exposed by a low spring tide along transect 3. The Christine Point Clay with *in situ* mangrove stumps crops out over the inclined slope. The interval marked
 (1) is outcrop of Double Nob Formation which is exposed by low water neap tides; the interval marked (2) is outcrop of Airport Creek Formation. Man for scale. C.—Stratigraphic relation-
 ships exposed at headwaters of Airport Creek. Lowest exposed unit is Double Nob Formation (1). There is a sharp erosional contact between Doctors Creek Formation (3) and Christine
 Point Clay (2). Note mangrove stumps protruding above the unconformity into the overlying formation; compare this buried surface with Figure 8 B which is a contemporary erosional surface.
 D.—Doctors Creek Formation exposed at low tide on the steep eroding banks of Doctors Creek. A segment of the stratigraphic sequence (sand/mud laminites overlain by bioturbated mud
 with *in situ* *Avicennia* mangrove stumps) is evident here. Height of cliff is approximately 4 m.

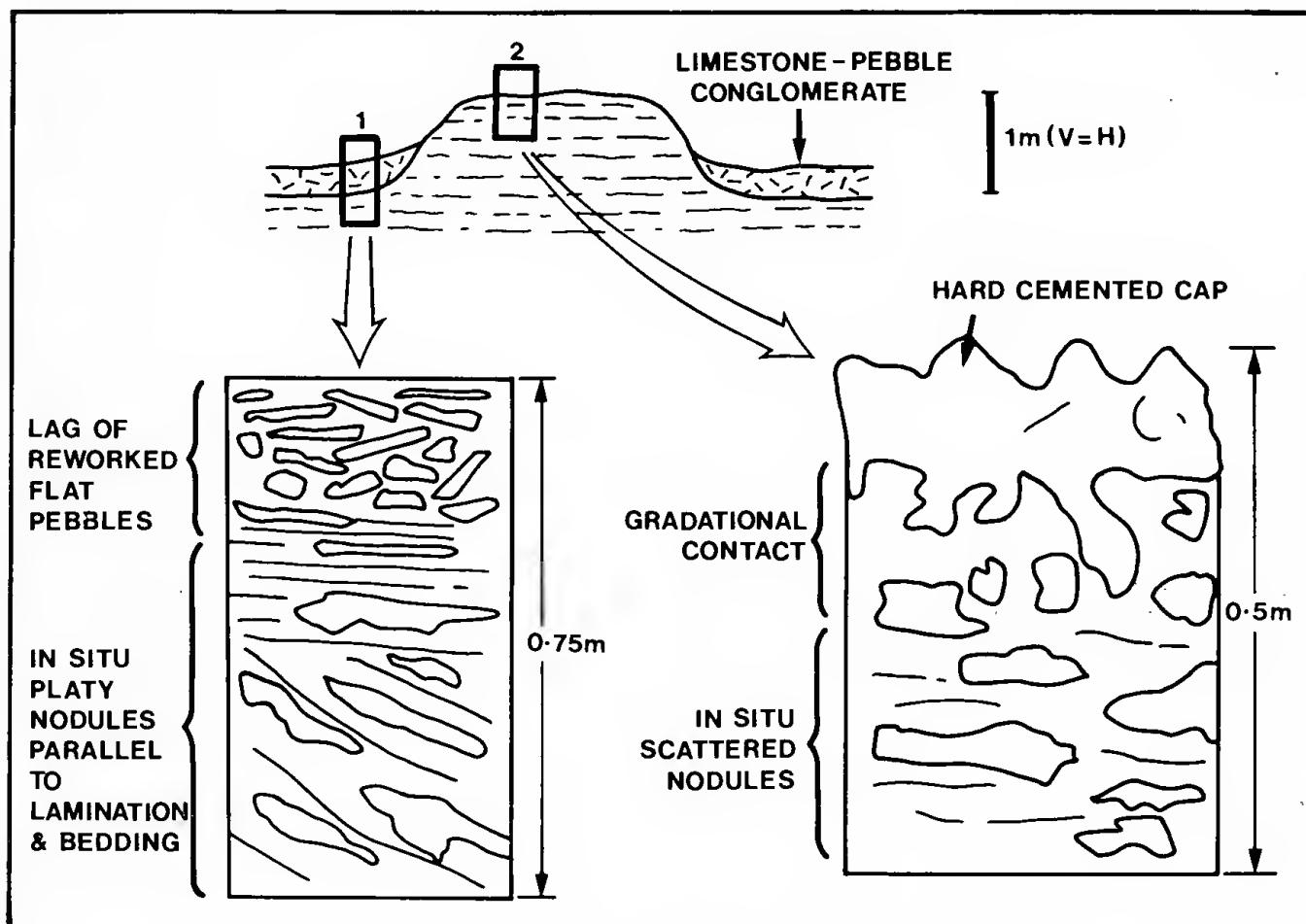


Figure 9.—Field sketch at western margin of transect 3 (Fig. 3) showing detail of geomorphology of tidal flat surface and stratigraphic relationships between Airport Creek Formation and Modern Veneer. Inset 1 shows relationship of Modern Veneer to Airport Creek Formation with *in situ* nodules; inset 2 shows disposition and extent of induration at top of Airport Creek Formation.

In view of the rate of the Holocene transgression determined by other workers (Curry 1965, Fairbridge 1961, Milliman and Emery 1968) and the lack of a mean sea level still stand at approximately 1.5 m below present in the world literature it would appear unlikely that all these events took place in the Holocene. It is concluded here that the Christine Point Clay is a late Pleistocene marine unit and the Doctors Creek Formation is Holocene. The timing of the extensive erosion of Christine Point Clay is unknown. If the erosion was subaerial and developed prior to deposition of Doctors Creek Formation, then subsequent Holocene transgression flooded the subaerially scoured embayments. The Doctors Creek Formation then would have filled the embayments in much the same way it is accumulating today. If on the other hand the scouring was brought about by tidal erosion, then the embayments would have formed during the Holocene transgression and erosion has continued sometime up to the stage when the sea reached its present level.

Double Nob and Airport Creek Formations.—The Double Nob Formation is interpreted as a Pleistocene palaeosol formed in a similar environment to black soil plains. The formation occurs as a gently undulating sheet some 2.5–3 m below present mean sea level and obviously in the past it formed the subaerial surface of a savannah plain. It predates the Christine Point Clay and was developed by degradation of the calcareous tidal sedi-

ments of the Airport Creek Formation. Sediments of the Airport Creek Formation would have been deposited during an earlier marine incursion and the soil formed during the subsequent subaerial period.

Mowanjum Sand.—From its stratigraphic relationships the Mowanjum Sand predates all 3 marine Quaternary units. Although the Mowanjum Sand was emplaced as the first Quaternary unit in the area, its seaward margin has been repeatedly reworked and therefore it *appears* to interfinger with all the other younger marine units. Glacial periods (or sea level lows) of the Pleistocene are represented as an unconformity between the three marine units. The tongues of Mowanjum Sand extend along the unconformities that separate marine units.

Carbon dating.—Carbon dating of mangrove stumps has been carried out in this area by Jennings and Coventry (1973) and by Jennings (1975). Wood from the Doctors Creek Formation gave ages of about 5 840–7 450 years B.P. (Jennings 1975). Although carbon-14 dating in mangrove sediments can be somewhat tenuous, these dates essentially agree with the assignment of the Doctors Creek Formation using stratigraphic criteria to a Holocene age. Jennings and Coventry (1973) dated mangrove stumps under sand spits (Point Torment Sand) at 500–1 190 years B.P. This gives an indication of when the Point Torment Sand was first emplaced; it agrees with the conclusion, deduced from stratigraphic criteria that the formation is the youngest in the area.

If the carbon-14 dating can be relied upon then it appears that for the Christine Point Clay to be Holocene, it would have to be *deposited and eroded* in the interval of 7 500–12 000 years B.P., a period generally conceded to be a time of rapidly rising sea levels. The conclusion reached here is that the Christine Point Clay is of late Pleistocene age.

Conclusions

Six major Quaternary formations are recognised underlying the tidal flats of King Sound. The oldest unit, termed the Mowanjum Sand, is a formation of red sand that forms the hinterland of King Sound. The subsequent succession consists of four marine units separated by unconformities; their contact is marked by soils or large scale erosional interfaces. Three units were deposited in tidal flat environments but each is lithologically distinct. The oldest Pleistocene marine unit is called the Airport Creek Formation; a soil, the Double Nob Formation, separates it from the overlying, Christine Point Clay, also Pleistocene in age. A Holocene unit, the Doctors Creek Formation, fills large-scale hollows or embayments erosionally cut into the Pleistocene units. The youngest unit, the Point Torment Sand is a shoreline deposit largely formed where tidal erosion has cut the tidal flats back into the hinterland formed of Mowanjum Sand.

Today in areas where erosion is dominant the older Pleistocene formations crop out on the tidal flats. Here they are either exposed or are covered by a Modern Veneer that is frequently stripped away. Thus much of the tidal flats represents an eroding unconformity surface. The Holocene Doctors Creek Formation is also being eroded in most localities where it is present.

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The transition from mainland to island, illustrated by the flora and landbird fauna of headlands, peninsulas and islands near Albany, Western Australia*

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Abstract

Lists of species of plants and landbirds present on 11 islands and 17 coastal mainland sites near Albany have been used in regression analyses to study how the floras and landbird faunas of islands come to differ from those of coastal mainland areas. For a particular area or elevation, plant species richness decreases as follows: mainland areas sheltered from prevailing swell, mainland areas fully exposed to prevailing swell, sheltered islands, exposed islands. These differences become more pronounced the larger the area or the higher the land. It is suggested that most extinctions on these islands result from the action of storm waves and continual deposition of seaspray, the low frequency of fires and the presence of colonially-nesting seabirds. The number of landbird species decreases in the following sequence for any particular sized area: sheltered mainland, sheltered island, exposed mainland, exposed island. This reflects mainly changes in the extent of forest, determined largely by exposure to seaspray. These gross differences between coastal mainland areas and islands are paralleled on representative 4 ha plots. Attention is drawn to interesting, particularly puzzling, distribution patterns of selected native plant species and landbird species. The distribution of weed species on the islands and coastal mainland sites is interpreted in terms of a dynamic equilibrium dependent on introduction by European man and Silver Gulls and establishment on nutrient-rich soils produced by colonially-nesting seabirds.

Introduction

Although biogeographic studies of floras and landbird faunas on islands have been popular since last century (e.g. Darwin 1845, Hooker 1847-1860, Moseley 1892, Wallace 1911), few such studies have been accompanied by ecological comparisons with mainland sites. Mathematical analyses over the last two decades have shown that the number of plant or landbird species present on islands can usually be closely predicted from island area (review in Abbott 1974a). Just why island floras and faunas should have fewer species than floras and faunas on equal-sized areas on the adjacent mainland has been given little attention despite the widely accepted model proposed by MacArthur and Wilson (1967). Islands, of course, have distinct boundaries whereas equal-sized areas on the mainland invariably are difficult to delineate. A coast along which there are numerous peninsulas, headlands, capes as well as islands partly overcomes this difficulty of defining boundaries. Although I have studied the floras and landbird faunas of the 121 islands near Perth (Abbott 1977, 1978a), the adjacent mainland is of uniform outline and so is unsuitable for a comparative biogeographic study of island and mainland floras and avifaunas.

The coast near Albany (Fig. 1) has a configuration admirably suited for such studies, and in addition the flora is exceptionally rich and varied, making the search for and collection of plant species very rewarding. This paper has three aims. The first is to examine how species richness for the plants and landbirds changes with diminishing area, isolation, elevation and exposure to wave action and seaspray. Because peninsulas are intermediate between islands and headlands, their study should throw light on the processes that change the flora and avifauna of a landmass as it becomes an island. Second, the composition of the plant and bird communities present on islands will be described and analysed with reference to the coastal mainland sites. Finally, the spread of weed species onto islands and coastal mainland sites by gulls and European man will be examined.

Geographical setting

The coast near Albany (Fig. 1) is a drowned one, and in the 150 km length of coast considered for this paper there is one large peninsula, two promontories and numerous smaller headlands. The bathymetry of the seas shown in Figure 1 is only known adequately in and near King George Sound; on the basis of R.A.N. Hydrographic chart No. 118 I have reconstructed the sequence of changes in coastal configuration resulting from the postglacial rise of sealevel. This, in conjunction with information provided by Hails (1965)

* Appendices 1 and 2 are Supplementary Publications and are not printed with the paper. Copies are lodged with the Society's Library (c/- Western Australian Museum, Perth W.A. 6000) and with the National Library of Australia (Manuscript Section, Parkes Place, Barton A.C.T. 2600) and photocopies may be obtained from either institution upon payment of a fee.

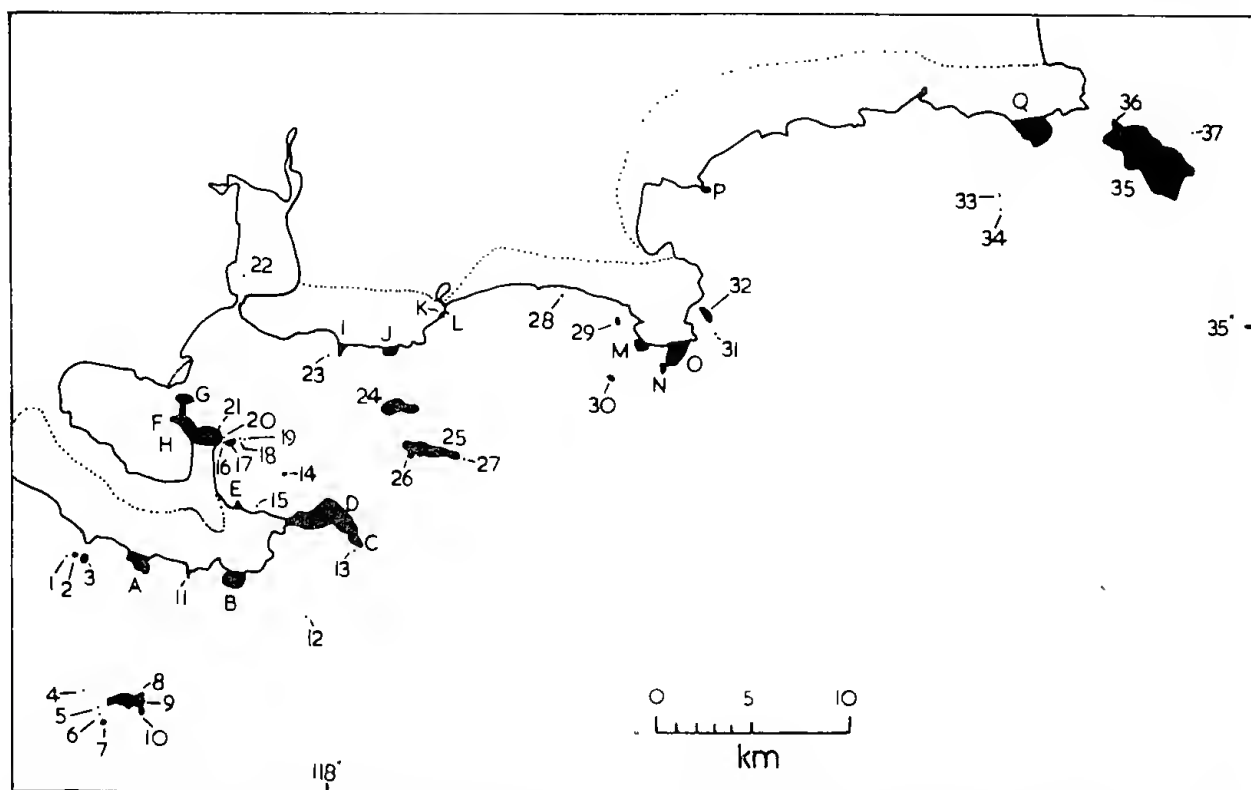


Figure 1.—Map of Albany region of south-western Australia showing coastal sites (A-Q) and all islands (1-37). Vegetated islands numbered 2, 3, 6, 29, 30 were not visited. The dotted line represents the approximate southern boundary of farming or settlement.

and Thom and Chappell (1975), indicates approximately when the largest islands became isolated: Eclipse Island (13 000 yr BP), Breaksea Island (9 000 yr BP) and Michaelmas Island (7 000 yr BP). Bald Island became isolated 10 000 yr BP (Storr 1965).

The region has an indented coastline with precipitous cliffs, mainly of adamellite and gneiss (Stephenson 1973, 1974), alternating with smooth sandy beaches (Jutson and Simpson 1917). All islands, however, lack sandy beaches although cobble and boulder beaches of limited extent are found on the lee (northern) sides of Bald, Eclipse, Michaelmas and Breaksea Islands. The Vancouver Peninsula (GH in Fig. 1) has been formed by deposition of windblown sand between two islands and the mainland (Jutson and Simpson 1917), probably after 6 000 yr BP. The ridge between Bald Head (C in Fig. 1) and Torbay Inlet, as well as the Mt Gardner complex, have also been tied to the mainland by the silting up of swamp and deposition of sand. The gneiss and adamellite are overlain by aeolianite in certain areas (see Table 1).

The soils are shallow sands (Northcote *et al.* 1967); those over adamellite, gneiss or granite have a pH of 3-5, whereas those over aeolianite are of pH 6-8 (from samples collected on Eclipse and Breaksea Islands). Further details of these soils are provided for Chatham Island by Abbott and Watson (1978).

The climate of the region is typically Mediterranean. Data from Breaksea and Eclipse Islands (Anon 1975; unpublished records of Bureau of Meteorology) show that the islands have lower maximum temperatures and higher minimum temperatures and receive over 100 mm less rain annually than the nearest recording stations near Albany. For the area shown in Figure 1 there is a rainfall gradient decreasing from west to east of about 1 000 mm to 750 mm annually. This is reflected

in a vegetational change evident on the coast near North Point (P in Fig. 1). East of this the vegetation is dominated by low heath whereas west of North Point woodland and forest predominate.

Man's impact on the environment is well documented. The Albany area was occupied by Aboriginal man when discovered by Europeans in 1791 (Vancouver 1801). These people extensively and regularly used fire in their hunting (Hallam 1976). As they did not possess watercraft (Flinders 1814) and could not swim (Nind 1831), the islands were unvisited and so escaped frequent firing of the vegetation. European man now farms much of the hinterland (Fig. 1), but because of the poor soils near the coast none of my mainland sites has ever been farmed or cleared, and few have been grossly tampered with. Fishing tracks or roads have been cut through most of these sites. European man, has, however, had more impact on the habitats of the larger islands; this began in the 1820s when sealers arrived (Cumpston 1970) and doubtless involved fires (e.g. Lockyer 1827) and certainly affected some plant and animal populations (see later). Breaksea Island had a manned lighthouse between 1858 and 1926, and Eclipse Island had one between 1926 and 1976. Limited clearing of vegetation occurred, and the presence of one or two horses in the earliest days had a largely unknown effect on vegetation (Bald Island was used for agistment late last century and early this century). Some of the smaller islands have been more adversely affected: Mistaken Island was set ablaze in 1803 by the Baudin expedition (Cornelle 1974) and goats were grazed there in the 1830s (Clark 1841). Site F was formerly an islet on which a powder magazine was placed in about 1844 to prevent tampering by aborigines, but in the 1870s a causeway was constructed to it (H. Sunter-Smith 1976, pers. comm.).

Table 1

Area, maximum elevation, and total number of plant and landbird species found on mainland sites and islands studied

Code in Figure 1	Name (if any)	Visits	Area (ha)	Maximum elevation (m)	No. vascular plant species	No. landbird species**
Mainland Sites						
A*†	Cave Pt	22–23 Sept. 76	61	80	104	5
B**†	Peak Hd	30 Sept. 75 19 Dec. 76	46	150	125	4
C*	Bald Hd	27 Nov. 75 28 Oct. 76	30	122	85	5
D*†	Flinders Pen.	27 Nov. 75 24 Sept. 76 28 Oct. 76	309	234	166	19
E	Waterbay Pt	21 Sept. 76 9 Dec. 78	4	40	129	3
F	Geak Pt	16 Sept. 76	0.3	6	54	0
G	Pt Possession	24 Nov. 75 18–19 Sept. 76	17	46	164	10
H	Vancouver Pen.	15–25 Sept. 76	168	81	292	21
I†	Ledge Pt	25 Sept. 76	13	52	129	4
J†	Herald Pt	26 Oct. 76	25	69	160	7
K†	Islet Pt	21 Dec. 76	3	30	88	1
L†		26 Nov. 75 21 Dec. 76 7 Dec. 78	1.3	23	56	2
M**†	False I.	27 Oct. 76	18	84	45	4
N**†	C. Vancouver	27 Oct. 76	8	51	38	1
O*†		27 Oct. 76 17 Sept. 78	69	137	140	7
P*	North Pt	24 Sept. 76	10	27	40	4
Q*†	Mermaid Pt	26 Oct. 76	158	210	150	14
Islands						
1*		—	0.004	6	0	...
4*	Northwest Rk	—	0.002	2	0	...
5*		—	9	12	0	...
6*		—	9	18	0	...
8*	NE pen., Eclipse I.	11–12 April 75	1.2	12	16	0
9*	Eclipse I.	4–15 April 75	104	109	51	4
10*	Cliff Hd	—	12	26	0	...
11*		—	0.7	15	0	...
12*	Vancouver Rk	—	3	5	0	...
13*	Northumberland Rk	—	0.5	4	0	...
14	Seal I.	28 Nov. 75	1.8	32	22	0
15	Flat Rk	28 Nov. 75	0.3	3	1	0
16	I. next to Mistaken I.	23 Sept. 76	0.08	4	31	0
17	Mistaken I.	15 Sept. 75 23 Sept. 76	9.9	44	61	2
18	W. Sister Rk	—	0.001	2	0	...
19	E. Sister Rk	—	0.001	1	0	...
20		—	0.04	2	0	...
21		—	0.2	3	0	...
22	Green I.	28 Nov. 75	1.7	12	30	0
23	Gull Rk	28 Nov. 75	2.5	10	26	0
24†	Michaelmas I.	4–14 Sept. 75	90	152	78	11
25*†	Breaksea I.	23 Aug.–1 Sept. 75	102	102	61	4
26*†	S. pen., Breaksea I.	27–28 Aug. 75	2.7	42	29	0
27*		—	1.2	20	0	...
28*	Black Rk	—	1.5	12	0	...
31*		—	0.003	2	0	...
22*	Coffin I.	27 May 76	28	45	30	4
33*	N. Twin It	—	1	26	0	...
34*	S. Twin It	—	1	26	0	...
35*†	Bald I.	14–25 May 76	717	311	104	15
36*†	N. pen., Bald I.	15–18 May 76	6	40	13	0
37*	Bird Rk	—	0.001	4	0	...

* Indicates mainland sites and islands fully exposed to the swell from the SW; the remainder are sheltered.

† Indicates mainland sites and islands with aeolianite.

** Omitting raptors and presumed vagrants.

Those islands marked—under Visits were flown over in April 1977 and some were observed from other islands or the mainland through binoculars.

Previous biological investigations of the Albany coastline are many, as King George Sound until 1900 was the major port of Western Australia. Diels (1906) and Souster (1948) provide reviews of botanical collecting in the region but for the present paper most of these collections are of limited use because the exact locality was not recorded. An important exception is L. Preiss who collected 43 plant species on several of my mainland sites in October and December 1840 (Lehmann 1844–1847). I have re-collected 27 of these and a further two cannot satisfactorily be linked with modern botanical nomenclature, leaving only eleven not accounted for. On the other hand, studies of the island floras and faunas are very limited. The early naval expeditions of Vancouver (1801), Flinders (1814), Baudin (Cornelle 1974) and King (1827) visited Seal Island and Green Island. Others provide scattered references to plants and animals (Lockyer 1827, Campbell 1890, 1900, Clark 1841). Reports published this century are those of Bassett Hull (1922), Warham (1955), Storr (1965), Fullager and van Tets (1976), Serventy and Whittell (1976) and Smith (1977a). Reference to relevant aspects of these papers will be made later.

Methods

Eleven islands and 17 coastal mainland sites (Fig. 1) were visited between 1975 and 1978 as part of a study of the ecology of the passerine bird *Zosterops lateralis* (Abbott in prep.). Visits to the 4 largest islands were each of about 12 days (Table 1), while the remaining islands were visited for between 30 minutes and 5 hours, depending on their area. Mainland sites were visited, depending on their extent, for 2–9 hours at one time. Some sites were visited more than once (Table 1). Although all islands in the region are numbered in Fig. 1, I was unable to land on five (numbers 2, 3, 7, 29, 30)—all vegetated but exposed fully to the swell.

During my visits collections of plant species were made and I kept a list of species of plants and birds present. On the 4 largest islands and on one of the mainland sites, fifty 1 m² quadrats were randomly distributed in a 4 ha plot. Landbirds were netted for study in this plot.

Results

The data base for the majority of this paper is the list of plant species and bird species found at each site (Appendices 1, 2). The total number of plant and land-bird species found at each site, along with various physical attributes of the sites, is summarized in Table 1. The total area of all islands (1 106 ha) and all mainland sites (941 ha) is remarkably similar. Despite this, the islands have fewer species of plants and land-birds than mainland sites of comparable area. The first point to establish is whether each plant family has been equally impoverished in species on the islands. Appendix 1 shows that only 15 of the 77 families found were not represented on any island: Ophioglossaceae, Dennstaedtiaceae, Lindsaeaceae, Xanthorrhoeaceae, Phylodraceae, Haemodoraceae, Olacaceae, Loranthaceae, Lauraceae, Tremandraceae, Polygalaceae, Onagraceae, Loganiaceae, Lentibulariaceae and Orobanchaceae. Two families (Aspleniaceae, Tropaeolaceae (introduced)) were found only on islands. Thus, the large-scale impoverishment of plant species on the islands represents a general impoverishment within families, and not the absence of a majority of plant families.

Seven families widespread on the mainland sites were present on only one island (Restionaceae, Casuarinaceae, Santalaceae, Phytolaccaceae, Stackhousiaceae,

Sterculiaceae, Goodeniaceae). The extent of impoverishment of plant species on the islands can be quantified in terms of those families containing 10 species or more (Table 2). Values of impoverishment range from 0 (all species represented on at least one island) to 92% (i.e. nearly all species absent from islands), with a median value of 61–66%. Impoverishment has not been random between families because some families are better represented on islands than others.

Table 2

Impoverishment of insular floras in terms of families containing 10 or more species. Alien species are excluded

Family (No. species)	No. species found on at least one		% impoverishment
	mainland site	island	
Poaceae (11)	10	7	30
Cyperaceae (18)	18	7	61
Restionaceae (12)	12	1	92
Liliaceae (12)	11	5	55
Orchidaceae (20)	20	4	80
Proteaceae (41)	41	4	90
Chenopodiaceae (10)	9	9	0
Mimosaceae (14)	14	5	66
Fabaceae (29)	29	5	83
Dilleniaceae (10)	10	1	90
Myrtaceae (30)	30	13	57
Apiaceae (11)	10	6	40
Epacridaceae (17)	17	3	82
Asteraceae (33)	31	18	42

Comparison of plant species richness

The variation in plant species richness on the mainland and islands has been analysed in terms of area, elevation and degree of exposure to the prevailing south-west ocean swell. Coefficients of correlation were calculated between area and elevation for six types of site (sheltered or exposed mainland sites, sheltered or exposed unvegetated islands, and sheltered or exposed vegetated islands) in Table 3, and between plant species richness and area and elevation for sheltered and exposed mainland sites and sheltered and exposed vegetated islands in Tables 4 and 5. These analyses were necessary to show which mathematical model best fitted the data. From Table 3, a double logarithmic model yielded the highest correlation coefficients. On the other hand, Tables 4 and 5 show respectively that a semilogarithmic and an arithmetic model are most appropriate. The appropriate mathematical model has been used to compare islands and mainland (Figs 2–4) by analysis of covariance. Details of the statistical tests made have been collected together in Table 9.

Area v. elevation (Fig. 2).—There were no significant differences in slope or intercept for the following comparisons: sheltered mainland v. exposed mainland, sheltered mainland v. sheltered vegetated islands, exposed mainland v. exposed vegetated islands, and exposed unvegetated islands v. exposed vegetated islands. Hence categories were then combined as in Figure 3. It was found that the logE/logA regression line for islands devoid of vegetation had a significantly lower slope than that for the vegetated islands but that the intercepts did not differ significantly. This graph shows that islands with an area of about 1 ha or more and elevation 7 m or higher can support at least one plant

Table 3

Area (A): elevation (E) relationships for mainland sites, vegetated islands and unvegetated islands. The correlation coefficients and their significance are shown for the four mathematical models examined

Places	Sample size	Models			
		<i>E v. A</i>	<i>ln E v. ln A</i>	<i>E v. ln A</i>	<i>ln E v. A</i>
Mainland					
sheltered	8	0.73*	0.92**	0.98***	0.51 ns
exposed	9	0.85**	0.87**	0.92***	0.70*
all sites	17	0.80***	0.92***	0.82***	0.64**
Unvegetated islands					
sheltered	4				
exposed	14	0.43 ns	0.76**	0.66**	0.47 ns
all	18	0.51*	0.80***	0.71**	0.53*
Vegetated islands					
sheltered	7	0.98***	0.93**	0.85*	0.76*
exposed	7	0.98***	0.95**	0.86*	0.79*
all	14	0.93***	0.93***	0.84***	0.61*

Significance of correlation coefficients: ns $P > 0.05$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Table 4

Plant species (S): area (A) relationships for mainland sites and vegetated islands. The correlation coefficients and their significance is shown for the four mathematical models examined

Places	Sample size	Models			
		<i>S v. A</i>	<i>ln S v. ln A</i>	<i>S v. ln A</i>	<i>ln S v. A</i>
Mainland					
sheltered	8	0.90**	0.96***	0.94***	0.73*
exposed	9	0.79*	0.94***	0.96***	0.71*
Islands					
sheltered	7	0.78*	0.57 ns	0.80*	0.43 ns
exposed	7	0.91**	0.90**	0.90**	0.76*

Conventions as in Table 3

Table 5

Plant species (S): elevation (E) relationships for mainland sites and vegetated islands. The correlation coefficients and their significance are shown for the four mathematical models examined

Places	Sample size	Models			
		<i>S v. E</i>	<i>ln S v. ln E</i>	<i>S v. ln E</i>	<i>ln S v. E</i>
Mainland					
sheltered	8	0.91**	0.85**	0.76*	0.93***
exposed	9	0.92***	0.88**	0.88**	0.88**
Islands					
sheltered	7	0.84*	0.70 ns	0.85*	0.51 ns
exposed	7	0.96***	0.90**	0.91**	0.84*

Conventions as in Table 3

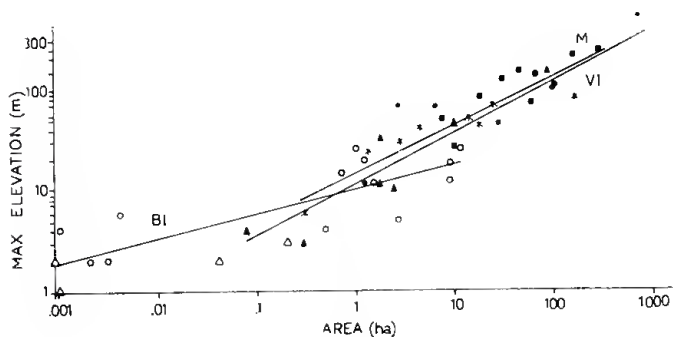


Figure 2.—Double-logarithmic plot of elevation v. area for mainland sites (sheltered *, exposed ■) and islands (sheltered vegetated ▲, sheltered bald △, exposed vegetated ●, exposed bald ○). M, VI and BI represent regression lines for mainland sites, vegetated islands and bald islands respectively.

species. That is, islands of these minimum dimensions are not subject to wave action intense enough to wash away soil forming by subaerial erosion of rock.

Number of plant species v. area (Fig. 3).—The regression line for sheltered mainland sites had a significantly higher slope and intercept than that for the sheltered islands; that for the exposed mainland sites differed significantly in slope only from the regression line for exposed islands. There was no significant difference in slope or intercept for the comparison of regression

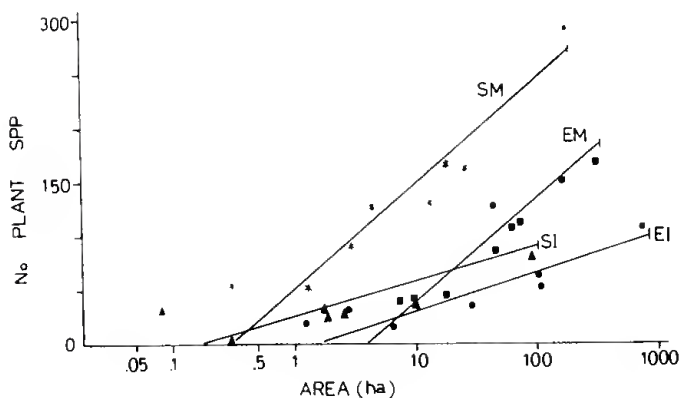


Figure 3.—Relation between number of plant species and ln area for sheltered mainland sites (SM), exposed mainland sites (EM), sheltered vegetated islands (SI) and exposed vegetated islands (EI). The respective regression equations are $Y = 61.9 + 37.2 \ln X$, $Y = -45.1 + 38.5 \ln X$, $Y = 29.0 + 9.1 \ln X$, and $Y = 3.5 + 12.6 \ln X$.

lines for sheltered islands and exposed islands. However, regression lines for sheltered and exposed mainland sites did differ significantly in intercept but not slope, whereas the lines for exposed mainland sites and sheltered islands differed significantly only in slope.

Number of plant species v. maximum elevation (Fig. 4).—Regression lines for exposed mainland sites and exposed islands differ significantly in slope and in intercept, as do those for sheltered mainland sites v. sheltered islands, and sheltered mainland sites v. exposed mainland sites. There were no significant differences in slope or intercept between sheltered and exposed islands, and between exposed mainland sites and sheltered islands.

The significance of these findings for understanding the transition from mainland site to island is clear from Table 6, for 3 different sized areas. It is necessary to

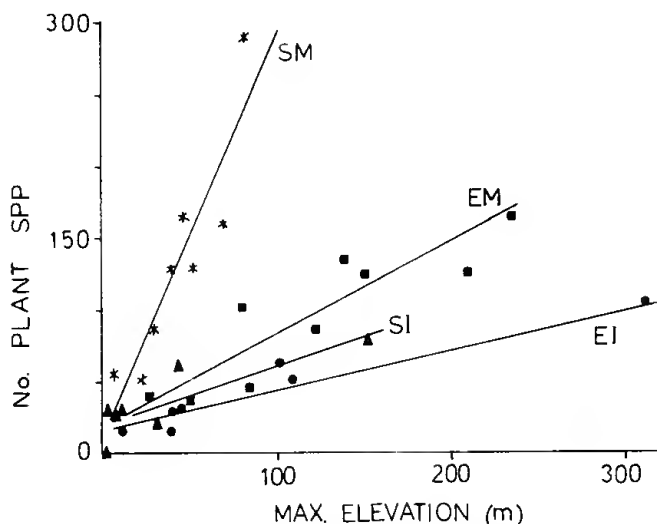


Figure 4.—Relation between number of plant species and elevation for sheltered mainland sites (SM), exposed mainland sites (EM) sheltered vegetated islands (SI) and exposed vegetated islands (EI). The respective regression equations are $Y = 8.6 + 2.9 X$, $Y = 19.6 + 0.6 X$, $Y = 20.7 + 0.4 X$, and $Y = 15.0 + 0.3 X$.

Table 6

Number of species of plants expected to be present on 10, 50, and 100 ha areas on mainland and islands (based on regression equations given in legend to Fig. 3)

Place	Area (ha)		
	10	50	100
Mainland			
sheltered	148	207	233
exposed	44	106	132
Islands			
sheltered	50	65	71
exposed	33	53	62

assume that all, or the majority, of the plant species that are at present on the mainland sites occurred there when the islands formed. A sheltered mainland area that through rising sea level becomes a sheltered island should lose about 70% of the plant species present, whereas an exposed island formed from an exposed mainland area should lose 25–50% of its plant species. Because of the nature of the assumption stated above these figures are maxima. Possible reasons for the disappearance of plant species from such islands relative to mainland sites of similar area, elevation and degree of exposure include: freedom from fire; presence of colonially-nesting seabirds; increased exposure to salt spray; and attenuation of re-colonization as species disappear after isolation. These factors will be fully considered later.

Number of species of landbirds

The analysis is similar to that applied above with number of plant species, except that number of plant species itself is an additional variable to area, elevation and degree of exposure. Nevertheless, area gives the highest correlation coefficients (Table 7).

Table 7

Correlation coefficients and their significance for number of landbird species (B) versus area (A), elevation (E), and number of plant species (P). Based on an arithmetic mathematical model

Place	Sample size	Comparison		
		B v. A	B v. E	B v. P
Mainland sheltered	8	0.93***	0.82*	0.96***
Mainland exposed	9	0.97***	0.86**	0.76*
Islands sheltered	7	1.00***	0.98**	0.82*
Islands exposed	7	0.97***	0.97***	0.94**

Conventions as in Table 3.

Because some exposed and sheltered islands and one mainland sheltered site lack landbird species, those mathematical models using log B could not be applied. The semilogarithmic model involving log area, log elevation or log number of plant species gave lower correlation coefficients than the non logarithmic analyses; therefore only the latter are given in Table 7.

Regression lines for number of landbird species v. area are shown in Fig. 5. Those for sheltered and exposed mainland sites differ significantly in slope and intercept, as do those for sheltered islands v. exposed islands, and exposed mainland sites v. exposed islands. The regression line for sheltered islands has a higher slope than that of the line for the exposed mainland sites. The sheltered mainland regression line has a higher intercept than the line for the sheltered islands.

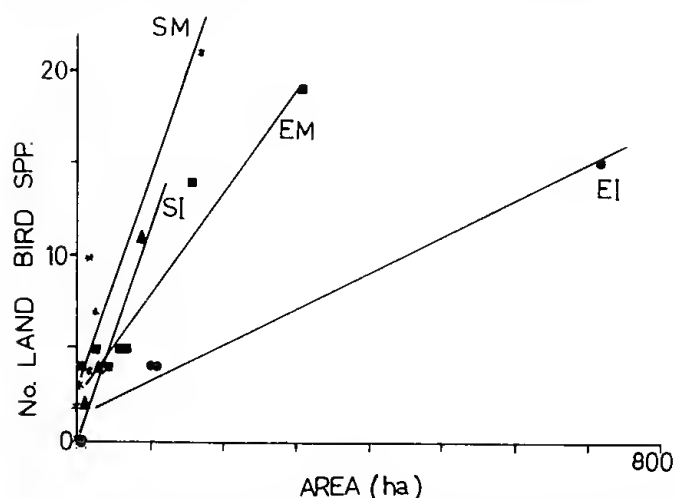


Figure 5.—Relation between number of landbird species and area for sheltered mainland sites (SM), exposed mainland sites (EM), sheltered vegetated islands (SI) and exposed vegetated islands (EI). The respective regression equations are $Y = 2.73 + 0.11 X$, $Y = 2.27 + 0.06 X$, $Y = -0.01 + 0.12 X$, and $Y = 1.15 + 0.02 X$.

The number of species of landbirds that could disappear from mainland sites of 3 different areas as they become islands is given in Table 8. For areas of 100 ha there is a particularly interesting result. The sheltered islands have over 50% more species than the exposed mainland sites. This presumably indicates the greater importance of habitat structure over floristic diversity; the large (100 ha) exposed mainland sites consist mainly of low closed-heath and herbfield whereas the large

Table 8

Number of species of landbirds expected to be present on 10, 50, and 100 ha areas on mainland and islands (based on regression equations given in legend to Fig. 5)

Place	Area (ha)		
	10	50	100
Mainland sheltered	4	8	14
Mainland exposed	3	5	8
Islands sheltered	1	6	12
Islands exposed	1	2	3

sheltered islands have forest present on the highest parts and most of the sheltered side. Small (10 ha) exposed mainland sites, however, have more species of landbirds than small sheltered islands. This is both a reflection of inadequate cover on the islands, as well as presumptive high extinction rates and low immigration rates of landbirds (Abbott 1978a).

Percentage frequency of plant species

Quantitative studies of 4 ha plots on the four large islands and one mainland site (a sheltered one on Vancouver Peninsula) reveal that the general impoverishment in plant species already described for total island area exists also at the scale of fifty 1 m² quadrats randomly placed in a 4 ha plot. There are about 2 to 3 times as many species in the 50 mainland quadrats as the island quadrats (Table 10). Even if only those species with frequency of 10% or more are considered, the mainland quadrats still have many more plant species (Table 10).

Distribution patterns

Plant species.—The two most widespread species are *Poa poiformis* (on 17 mainland sites and 11 islands) and *Carpobrotus virescens* (16 mainland sites, 12 islands). These are followed by *Scirpus nodosus* and *Rhagodia radiata* (present on 27 of 31 sites), the introduced *Sonchus oleraceus* (26), *Crassula macrantha*, *Apium prostratum* and *Senecio luttus* (24), *Sporobolus virginicus*, *Lepidosperma gladiatum* and *Samolus repens* (22), *Agonis flexuosa*, *Leucopogon revolutus* and *Olearia axillaris* (21), *Lobelia alata* (20), *Hibbertia cuneiformis* (19), and *Threlkeldia diffusa*, *Anthocercis viscosa* and the introduced *Hypochoeris glabra* (18). These are species able to survive both on islands and mainland. In no case can we say why, because the necessary physiological studies have yet to be made.

Equally interesting are anomalous distribution patterns, in which plant species occur either on many sites, or only on a small subset of sites. The patterns described below could be explained by random immigration or extinction, competitive exclusion, or differences in soil properties between sites. Experimental studies, either in the glasshouse or field, will be necessary before definite conclusions can be drawn.

Banksia praemorsa: Although present on many of the mainland sites, its only insular occurrence is Bald Island. This is also one of the very few island occurrences of the genus in Western Australia.

Callitris preissii: Present only on Bald Island and the adjacent mainland site Q.

Table 9
Summary of analyses of covariance

Dependent and Independent Variables	Figure	Comparison	Adjusted Independent Variable	Significance of difference between	
				slopes	intercepts
In E, In A	2	SM v. EM	2.9	ns	ns
		SM v. SI	1.4	ns	ns
		SI v. EI	1.9	ns	ns
		EM v. EI	3.5	ns	ns
		SI v. EM	2.4	ns	ns
		EI bare v. EI vegetated	0.25	ns	ns
P, In A	3	all bare islands v. all vegetated islands	-0.26	<<0.01	ns
		SM v. EM	2.9	ns	<<0.01
		SM v. SI vegetated	1.4	<<0.01	<<0.01
		SI veg. v. EI veg.	1.9	ns	ns
		EM v. EI vegetated	3.5	<<0.01	<<0.01
		SI vegetated v. EM	2.4	<<0.01	ns
P, E	4	SM v. EM	85	<<0.01	<<0.01
		SM v. SI vegetated	40	<<0.01	<<0.01
		SI veg. v. EI veg.	66	ns	ns
		EM v. EI vegetated	110	<0.01	<<0.01
		SI vegetated v. EM	85	ns	ns
		SM v. EM	55	<0.01	<0.05
B, A	5	SM v. SI vegetated	23	ns	<0.05
		SI veg. v. EI veg.	76	<<0.01	<<0.01
		EM v. EI vegetated	104	<<0.01	<<0.01
		SI vegetated v. EM	51	<0.01	ns
		SM v. EM	55	<0.01	<0.05
		SM v. SI vegetated	23	ns	<0.05

A—area, E—elevation, P—number of plant species, B—number of landbird species, SM—sheltered mainland sites, EM—exposed mainland sites, SI—sheltered islands, EI—exposed islands, ns— $P > 0.05$.

Disphyma clavellatum: Occurs only on the most exposed mainland sites and islands, whereas *Carpobrotus virescens* has a much wider distribution. An experimental study of competition in mixtures of the two species under several regimes of salinity would be useful.

Cheilanthes tenuifolia: Present on the 4 largest islands and Mistaken Island, but only occurs on two mainland sites (G, H).

Rhagodia radiata: Present on all mainland sites and on all islands as large as or larger than Mistaken Island, as well as the islet very close to this island. It is, however, absent from Seal Island and Gull Rock.

Agonis flexuosa: Occurs on all mainland sites except L and N and on all medium to large-sized islands except, strangely, Coffin Island.

Chamaelaucium ciliatum and *C. sp. nov.*: Present on the 3 adjacent prominent headlands B, C and O.

Darwinia vestita: Occurs on 3 sheltered mainland sites, one exposed mainland site, and on Bald Island.

Melaleuca lanceolata: Found only on 2 islands (Eclipse, Bald) and on the two adjacent mainland sites (B, Q).

M. microphylla: Similar distribution to *M. lanceolata*, but this species also occurs on a third mainland site, P.

Thryptomene saxicola: Although present on all 4 large islands and found on mainland sites D, H and I, it is unaccountably missing from O and Q.

Logania fasciculata: Found only on 5 exposed mainland sites.

Anthocercis viscosa: Although present on most mainland sites, and on the smaller islands (Mistaken, Coffin, Inner, Gull Rock, Rock Dunder), it is missing from the 4 large islands. In the Archipelago of the Recherche this species does occur on large islands.

Landbirds.—The landbird species with the widest distribution on islands and mainland sites are the Welcome Swallow (present on 20 islands and mainland sites), Silveryeye (20), New Holland Honeyeater (18), White-

browed Scrub-wren (13) and Kestrel (11). However, as indicated in Appendix 2, some of these occurrences are only of presumed vagrants. Considering resident or breeding species of passerine landbirds, 18 of the 31 species were not recorded as breeding or resident on any island. Interestingly, only one of these species (*Sericornis fuliginosus*) is known to occur on islands elsewhere in Western Australia.

Biogeographical considerations proposed for southern Australia by Abbott (1974b) suggest that many of these species were likely to have been present on the islands when they became isolated, but have since become extinct. How could these species have become extinct on the 4 largest islands considered in this paper? Eclipse Island is the oldest and most distant from the mainland and therefore has had more time for extinctions to occur and has given less opportunity for species on the island to immigrate to the island. Michaelmas Island is the youngest, so there has not been so long a time for extinctions to accumulate. Differences in the plant communities between islands are also probably relevant. Why the islands of south-western Australia should have fewer species of landbirds than coastal mainland sites has already been reported on (Abbott 1978a), but why certain species are well represented on islands whereas others are not has not been addressed before for these islands.

The 8 honeyeater species present in the areas studied have broadly similar food preferences (nectar, insects) but only 3 species occur on islands. The New Holland Honeyeater is widely distributed on mainland sites and less so on the islands. I have used my records of feeding sites of this species on the mainland sites near Albany (and elsewhere) to establish which species of flowers it will feed at; I then list which of these plant species occur on the large islands, examine their flowering periods (based on Beard 1970) and attempt to account for the presence/absence of New Holland Honeyeaters on/from the larger islands.

Table 10

Percentage frequency of plant species in six island plots and one mainland plot (based on fifty 1 m² quadrats).
Species with frequency < 10% are omitted.

Species	Island						Mainland
	Eclipse		Breaksea	Michael- mas	Bald		Quaranup
	Plot 1	Plot 2			Plot 1	Plot 2	
* <i>Ehrlharta longiflora</i>	12	..	..	..	..
<i>Danthonia caespitosa</i>	24	..
<i>Poa poiformis</i>	..	10	..	..	60	48	..
* <i>Zantedeschia aethiopica</i>	74	..	..	..	..	..	..
<i>Carex preissii</i>	22	..	..	..	..
<i>Lepidosperma angustatum</i>	14	..
<i>L. gladiatum</i>	10	..	..
<i>Scirpus cernuus</i>	16	..	..	..	..
<i>S. nodosus</i>	..	16	..	..	..	16	..
<i>Anarthria gracilis</i>	10
<i>A. scabra</i>	66
<i>Hypolaena exsulca</i>	22
<i>Loxocarya flexuosa</i>	20
<i>Lyginia barbata</i>	16
<i>Stypandra grandiflora</i>	14
<i>Xanthorrhoea preissii</i>	10
<i>Parietaria debilis</i>	22	28	..	..	..
<i>Nyctzia floribunda</i>	20
<i>Rhagodia radiata</i>	38	22	24	..	..
<i>Titrekeldia diffusa</i>	18	..	..
<i>Carpobrotus virescens</i>	12	82	10	..	..	..	..
<i>Calandrinia calyptata</i>	12	..	..	..
* <i>Stellaria media</i>	..	10	..	..	..	..	..
<i>Clematis pubescens</i>	58	..	14	..
<i>Drosera erythrorrhiza</i>	16
<i>D. pallida</i>	46
<i>Crassula macrantha</i>	20	..	..	..	..
<i>Acacia pulchella</i>	22
<i>Templetonia retusa</i>	24	..	..
* <i>Geranium molle</i>	12	..	..	..
<i>Oxalis corniculata</i>	10	..	14	..	..
<i>Chorilaena quercifolia</i>	12	..	..	..
<i>Amperea ericoides</i>	28
<i>Phyllanthus calycinus</i>	20	18	..
<i>Spyridium globulosum</i>	12	..	..
<i>Thomasia solanacea</i>	24	..	..
<i>Hibbertia cuneiformis</i>	22	20	..	18	..
<i>H. cunninghamii</i>	12
<i>H. pulchra</i>	18
<i>Pimelea clavata</i>	12	..	..
<i>Agonis flexuosa</i>	44
<i>Eucalyptus angulosa</i>	84	..	..	..
<i>E. calophylla</i>	48
<i>E. marginata</i>	22
<i>Melaleuca lanceolata</i>	38	..	..	..	38	..	..
<i>M. microphylla</i>	36	..	..	..	..	..	..
<i>M. thymoides</i>	36
<i>Thryptomene saxicola</i>	54	..	..	38	..
<i>Verticordia plumosa</i>	..	14	..	..	..	..	..
<i>Trachymene pilosa</i>	24
<i>Andersonia sprengeloides</i>	..	12	..	..	..	..	16
<i>Astroloma drummondii</i>	10
<i>Leucopogon oxycedrus</i>	20
<i>L. revolutus</i>	16	..	..	..	18
<i>Lysinema ciliatum</i>	46
* <i>Anagallis arvensis</i>	24	..	..	..	..
<i>Opercularia hispidula</i>	14
<i>Stylidium adnatum</i>	..	12	..	22	..	..	..
* <i>Hypochoeris glabra</i>	26
<i>Millotia tenuifolia</i>	10
<i>Senecio lantus</i>	..	14	50	26	24	..	..
No. species with frequency > 10% recorded in fifty 1 m ² quadrats	4	7	14	10	12	8	27
Total No. species recorded in fifty 1 m ² quadrats	12	13	30	25	21	30	97

* Indicates naturalized alien species.

Eclipse Island has a large area (25 ha) of *Melaleuca lanceolata* and *M. microphylla* with respective flowering periods from August to January and September to October. The absence of New Holland Honeyeaters from Eclipse Island could therefore be explained by a lack of nectar between February and July. Breaksea Island has only a small clump of one plant species that produces suitable food, namely *Agonis flexuosa*. This

flowers between August and December, so the lack of nectar from January to July could account for the absence of New Holland Honeyeaters from Breaksea Island. The remaining 2 large islands have large populations of this species of honeyeater. Food species and their flowering times are as follows—Michaelmas Island: large areas of *Eucalyptus angulosa* (March-August), *Agonis flexuosa* (August-December) and

smaller areas of *Eucalyptus cornuta* (November) and *Agonis marginata* (February-June); Bald Island; large areas of *Melaleuca lanceolata* (August-January), *M. microphylla* (September-October) and *Agonis flexuosa* (August-December) with smaller areas of *Eucalyptus lehmannii* (July-September), *Agonis marginata* (February-June), *Banksia praemorsa* (July-December) and *Calothamnus quadrifidus* (December-July). These last 3 species occur in the open-heath unit (Abbott in prep.). For both Michaelmas and Bald Islands there is virtually all-year round availability of nectar.

Presumably, similar reasoning applies to the other honeyeater species, but their absence from Michaelmas and Bald Islands may result from competitive interactions with the New Holland Honeyeater.

The probable reason that the Silvereye is widely distributed on the islands is that it is ecologically versatile, eating insects, nectar, and small fruits of *Rhagodia*, *Threlkeldia*, *Enchylaena* and *Tetragonia amplexicoma*, all species of plants common in places on the islands.

Why the fourth most widely distributed species, the White-browed Scrub-wren, should be absent from 3 large islands with apparently suitable habitats (Eclipse, Breaksea, Michaelmas) may be explained by reference to mainland site M and Mistaken and Bald Islands. I think that scrub-wrens did once occur on all large islands but became extinct on some of them for reasons unknown. The occurrence of this species on Bald Island suggests that an island of 700 ha area can retain a viable population of scrub-wrens, whereas 100 ha (the approximate area of the other 3 large islands) is too small. The presence of this species on site M, almost detached from the mainland, and on Mistaken Island, only 10 m from the mainland, shows that the species can live on small, close islands or quasi-islands.

Its immigration rate to these islands or quasi-islands must be high, but not high enough to Michaelmas, Breaksea or Eclipse Islands which are over 2 km from the mainland. Diamond (1975) and Abbott (1978a) have provided other evidence emphasizing the real importance of narrow straits as barriers to the movement over water of many passerine species.

The most abundant species on the islands sampled quantitatively (Table 11) were the Silvereye on 3 islands, the New Holland Honeyeater on 2 islands, and the Brown Thornbill and Red-eared Firetail on Bald Island. On the one mainland site sampled the New Holland Honeyeater and Silvereye were most abundant.

Bald and Michaelmas Islands show several marked avifaunal similarities. The Grey Fantail, Golden Whistler, White-breasted Robin, Brown Thornbill and White-naped Honeyeater (possibly only vagrant on Bald Island) occur only on these 2 islands, probably because both islands have extensive areas of forest on them. Michaelmas and Bald Islands are the only islands on which the White-breasted Robin (endemic to Western Australia) occurs.

The spread of weeds

Weeds, i.e. naturalized alien plant species, have only been present in the Albany district since 1826, and hence have had less time to colonize islands than native plant species. On this basis they should be more prominent in coastal mainland areas than on nearby islands. However, coastal mainland soils have low concentrations of phosphorus and nitrogen (Burvill 1965, Donald 1964, Wild 1958), but carry heath communities very rich in plant species (Table 1; Marchant 1973). As many weed species require fertile soils, they may be unable to persist in coastal soils. On islands, in contrast, colonially-

Table 11

Relative abundance of bird species mist-netted on four large islands and on one mainland location

Species	Island								Mainland	
	Eclipse		Breaksea		Michaelmas		Bald		Quaranup	
	N	RA	N	RA	N	RA	N	RA	N	RA
Brown Quail	—	—	1	1.2	—	—	+	+	—	—
Shining Bronze-Cuckoo	—	—	—	—	4	4.3	—	—	—	—
Laughing Kookaburra	+	+	+	+	2	2.2	+	+	+	+
Welcome Swallow	+	+	1	1.2	2	2.2	+	+	+	+
White-breasted Robin	—	—	—	—	2	2.2	1	2.5	3	3.6
Golden Whistler	—	—	+	+	+	+	+	+	1	1.2
Grey Fantail	—	—	—	—	+	+	+	+	1	1.2
White-browed Scrub-wren	—	—	—	—	—	—	5	12.5	4	4.8
Western Gerygone	—	—	—	—	+	+	—	—	3	3.6
Brown Thornbill	—	—	—	—	5	5.4	8	20.0	2	2.4
White-naped Honeyeater	—	—	—	—	9	9.8	+	+	—	—
New Holland Honeyeater	—	—	—	—	12	13.0	8	20.0	33	39.8
Brown Honeyeater	—	—	—	—	2	2.2	—	—	3	3.6
Western Spinebill	—	—	—	—	—	—	—	—	7	8.4
Silvereye	110	100.0	84	97.7	54	58.7	8	20.0	26	31.3
Red-eared Firetail	—	—	—	—	—	—	10	25.0	+	+
Total No. birds netted	110		86		92		40		83	
Total No. net-hours	534		334		381		400		468	
Total No. birds netted/100 net-hours	21		26		24		10		18	
Total No. species netted	1		3		9		6		10	
Netting dates	3-17 April 75		22 Aug.- 2 Sept. 75		3-15 Sept. 75		13-26 May 76		15-25 Sept. 76	

- N Number trapped of each species.
- RA Relative abundance (%) of each species trapped.
- + Present but not netted.
- Absent.

nesting seabirds fertilize soils with phosphates and nitrogenous compounds (Gillham 1956). As most weeds and few sclerophyllous species are tolerant of fertile soils (Gillham 1961), weeds should flourish on islands.

Because coastal sites and islands are of unequal area and elevation and consequently have different sized floras (Table 1), it is inappropriate to compare numbers of weed species directly because large areas are more likely to have more weed species. A more valid approach is to list all of the native plant species found on the smallest islands or parts of islands, 49 species in all. These species must be tolerant to exposure to seaspray, a condition characteristic of small islands. It is necessary to assume all species of weeds are capable of establishing on islands. The proportion of weed species present at each site was calculated on the basis of how many of these 49 species and of the 66 weed species were present at each site (Table 12). In the following analyses, statistical significance was determined using the Mann-Whitney test (Siegel 1956).

Table 12

The number of alien plant species on mainland sites and vegetated islands visited

Code in Fig. 1	No. of the 49 native plant species suited to survive on small islands occurring on site/island	No. alien plant species	% aliens
Mainland sites			
A	23	6	20.7
B	25	3	10.7
C	22	3	12.0
D	22	6	21.4
E	19	15	44.1
F	18	18	50.0
G	24	11	31.4
H	31	39	55.7
I	18	8	30.8
J	23	7	23.3
K	19	10	34.5
L	18	4	18.2
M	17	2	10.5
N	19	1	5.0
O	21	1	4.5
P	16	3	15.8
Q	23	8	25.8
Vegetated islands			
8	15	1	6.3
9	23	11	32.4
14*	14	9	39.1
15	1	0	0
16	19	10	34.5
17	24	18	42.9
22*	11	19	63.3
23*	10	15	60.0
24	30	10	25.0
25	31	17	35.4
26	25	2	7.4
32	17	6	26.1
35	31	8	20.5
36	11	0	0

* Indicates islands with colonies of Silver Gulls.
% aliens = $100 \times \text{col. 3} / (\text{col. 2} + \text{col. 3})$.

Coastal sites and islands have similar proportions of weed species ($n_1 = 14$, $n_2 = 17$, $P > 0.05$, 2-tailed test; see Fig. 6 (I)). Even if those sites disturbed by European man (i.e. those with buildings, vehicle tracks, grazing by animals introduced by man) are removed from analysis, no significant difference results ($n_1 = 8$, $n_2 = 10$, 2-tailed $P > 0.05$). Comparison of disturbed coastal sites with undisturbed ones shows that, as expected, disturbed sites have a greater proportion of

weed species ($n_1 = 7$, $n_2 = 10$, 1-tailed $P < 0.01$). However, there is no significant difference in proportion of weed species on disturbed islands as compared with undisturbed ones.

These results can best be explained (Fig. 6 (I)) in the framework of the equilibrium theory (MacArthur and Wilson 1967). Weed species have only been in the Albany district for the last 150 years; some were deliberately introduced for agriculture but most were inadvertent introductions. The source area for colonization of the coastal sites and islands is Albany and the farming areas inland from the coast (Fig. 1). Immigration rates of weed species onto the coastal sites are probably high, because of the closeness of these sites to the source area, and because tracks to fishing places pass through some of the coastal sites so that European man must have introduced some. However, extinction rates of weed species in coastal sites should be high because of low fertility levels in the soil (Specht 1963, Grundon 1972) and possibly through competition for space from the native flora. Immigration rates to the islands are probably low (because of distance from source areas) but extinction rates should be lower than on the mainland as a result of the higher fertility levels of island soils. More knowledge about the phosphorus and nitrogen requirements of the 66 weed species and differences in performance when grown on island and coastal mainland soils would enable precise statements to be made about extinction rates (cf. Rorison 1971). Also, 21 weed species are found only on coastal sites, and 18 only on islands (Appendix I). This probably reflects differences in dispersal abilities and fertility requirements between species.

Up to 8 species of seabirds (Pacific Gull, Silver Gull, Little Penguin, White-faced Storm-Petrel, Crested Tern, Great-winged Petrel, Flesh-footed Shearwater and Little Shearwater) breed on the islands shown in Figure 1 (Abbott 1978b, in press, Kolichis and Abbott 1978, Fullagar and van Tets 1976). Five of these species feed exclusively at sea. A further 2, Crested Tern and Pacific Gull, visit rivers and beaches but rarely venture farther inland. The Silver Gull alone crosses to and from the mainland in large numbers, apparently on a daily basis during the breeding season, and scavenges food from rubbish tips and parks. The 3 islands near Albany with colonies of Silver Gulls (Seal and Green Islands, Gull Rock) have a significantly greater proportion of weed species than the undisturbed islands without gull colonies ($n_1 = 3$, $n_2 = 5$, 1-tailed $P = 0.018$). How Silver Gulls transport weeds is unknown, though Gillham (1956) records that the faeces of 3 gull species present on Skokholm Island (Wales) frequently contained seeds of weeds. On islands with gull rookeries near Perth, the immigration rate of weed species is higher than to islands of comparable size without gull rookeries (Abbott 1977).

In summary, my interpretation is that weed species have higher immigration rates onto coastal mainland sites than onto islands as a result of direct spreading by European man and of proximity to settled areas which are the source areas of weeds. The extinction rate of weed species on coastal mainland sites should be higher than on islands because soil fertility on the former is too low for persistence. The Silver Gull is probably the main vector of weeds to islands because it is the only seabird species near Albany that regularly crosses in large numbers to and from the mainland where they gather at rubbish tips and on lawns in parks, places where weeds are common. These relations are set out in Fig. 6 (II).

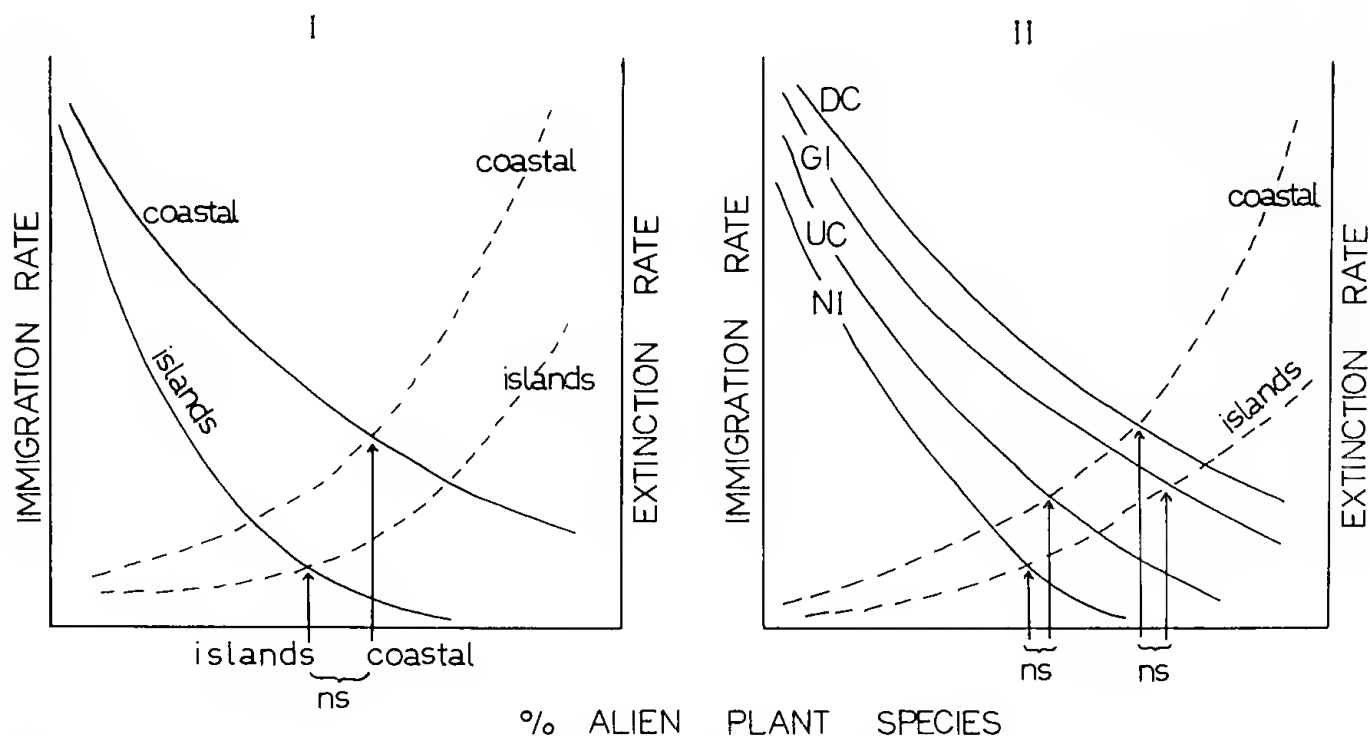


Figure 6.—Proposed model of the proportion of weed (alien plant) species on islands and coastal mainland sites in terms of I. A balance of immigration and extinction rates, II. A balance of both rates taking into account the influence of European man and the Silver Gull. Abbreviations under II: DC, disturbed coastal sites; GI, islands with gull rookeries; UC, undisturbed coastal sites; NI, islands lacking gull rookeries. ns, not significant ($P > 0.05$).

Discussion

Possible causes of differences between plant communities

Three factors, degree of exposure, presence of nesting seabirds, and relative freedom from fire, at face value are important in explaining floristic and vegetation differences between islands and coastal mainland sites (Abbott and Black 1978). The area of an island and its maximum elevation jointly determine how severe wave action will be to the island environment. If the island is too small or too low, storm waves will wash over the island removing soil and vegetation. This will not happen to islands of sufficiently large area and of high elevation, but the weather side will have more bare rock and prostrate halophyte-dominated vegetation than the lee side. The sheltered side will probably have large areas of taller vegetation. In contrast, exposed mainland sites will generally lack tall vegetation unless valleys or large hills are present in which case small areas of taller vegetation can develop.

Many plant species are unable to survive high levels of salt on their leaves (Parsons and Gill 1968). This leads to zonation both on islands and mainland. Exposed mainland sites have a wide zone of salt-tolerant species near the coastline whereas on sheltered mainland sites this zone is a narrow one, occurring just above high water mark. Small, low, exposed islands generally show no zonation because most of their plant species are halophytic.

Because seabirds almost exclusively nest on islands, the manurial effect of their guano on island soils leads to differences in species composition between islands and mainland. Many sclerophyllous species are unable to survive and weeds establish and flourish (Gillham 1960). The influence of degree of exposure to saltspray and density of seabirds outlined in a scheme for several islands in the Archipelago of the Recherche (Abbott

and Black 1978, p. 121) appears to apply validly to the Albany islands considered in this paper. There are of course differences in representation by various species, as some in the Albany district do not extend as far east as the Esperance district and vice-versa; also the halophytic genus *Atriplex* is poorly represented in the Albany area.

Rarity of fires on islands has probably had more effect on floristic composition than vegetation structure. It probably has allowed the development and survival of certain monospecific plant communities, for example *Melaleuca* forests on Eclipse and Bald Islands and on other islands round the south-western Australian coast (e.g. Rottnest, Garden). Low frequency of fires on islands may account largely for species impoverishment. Russell and Parsons (1978) have shown that in coastal heaths in Victoria species richness declines with time since the last fire by about 15% in 20 years. Lack of fire probably alters the competitive advantage amongst plant species in a community, particularly as it pertains to the recruitment of seedlings into the community. On islands, the recolonization of species lost by lack of fire is probably mainly determined by the distance of the island from the mainland.

It is, however, difficult to stress any one of these 3 factors just considered. The first 2, degree of exposure to seaspray and presence of nesting seabirds, are probably more important in explaining floristic and vegetation differences between islands, whereas the presence of nesting seabirds and the infrequency of fire on islands seem more important in accounting for differences between islands and mainland, as the following example shows. Mistaken Island is burrowed, where soils are deep enough, by Little Penguins. The island is sheltered from prevailing winds and sea and supports vegetation up to 6 m tall. Nearby mainland area G (Fig. 1) is

at the end of a peninsula, is of similar rock type, soil type, exposure and elevation but of course lacks nesting seabirds and was no doubt frequently burnt by aborigines. This mainland site has many of the elements of species-rich coastal heath near Albany including *Darwinia diosmoides*, *Lhotskya erieoides*, *Melaleuca thymoides*, *Agonis flexuosa*, *Eucalyptus* spp. whereas Mistaken Island is dominated by *Agonis flexuosa* and to a lesser extent by *Pimelea elavata*, *Acacia eyelops*, *Anthocercis viscosa* and the alien grass *Ehrharta longiflora* (Appendix 1). These two places afford one of the two most striking comparisons known to me. The other is between Breaksea Island (*Rhagodia*-dominated vegetation) and nearby Flinders Peninsula (species-rich open-heath).

An experimental approach, simulating the effect of seabirds on a coastal mainland plot, and of repeated fires on an island plot, seems necessary to distinguish the relative contribution of the fire and seabird factors.

Large-footed surface-nesting species of seabirds, particularly the Pied Cormorant which is so abundant on some of the islets near Fremantle (Abbott 1977), are absent from the islands of the Albany region. Sea lions are now very scarce on the islands covered in this paper although before the 1820s they may have had some effect on the vegetation of Seal Island (Abbott 1979). Hence for the islands near Albany it is unlikely that plant communities were subject to the destructive effects of seabirds and seals.

Possible causes of differences between landbird faunas

I have shown in a general study of islands round south-western Australia that not only do large islands have more species of landbirds than small ones but island habitats also have fewer species of landbirds than coastal mainland habitats of similar structure (Abbott 1978a). I interpreted these facts to mean that once species of landbirds became extinct on islands, they are unlikely to succeed in re-establishing because of their low vagility. In this paper I have suggested that this same argument applies to the White-browed Scrub-wren, whereas there is reasonable evidence to indicate that the New Holland Honeyeater may be absent from certain large islands because a year-round supply of nectar (as suggested by the flowering phenology of species) is unavailable. This argument may also apply to several other species of honeyeaters. Probably those species of landbird dependent on plant resources such as nectar, fruit and seeds for food will be absent from islands that do not supply such favoured items in sufficient quantity all year.

It is important when comparing island and mainland landbird faunas that habitats of similar structure are considered. Michaelmas Island has more species of landbirds than several adjacent mainland sites solely because its lee side possesses forest in contrast to the mainland sites which are too exposed to support anything but heath.

Impact of European man

Plants.—Although 2 early botanists (G. Maxwell, L. Preiss) collected plants from Breaksea and Mistaken Islands respectively, neither attempted to list the total flora. Thus, with no baseline, it is not possible to evaluate European man's effect on the abundance of native plant species on the islands. His impact on the mainland coast, through the introduction of exotics, is probably similar to that described for a coastal mainland site near Melbourne (Kirkpatrick 1974). His effect through grazing and firing is better understood, and has

already been outlined (see also Kirkpatrick 1975). Settlement at Albany has probably allowed the Silver Gull population to increase substantially over levels before 1826. As this species is probably the chief vector of weeds to their nesting islands, their increase has probably speeded up the colonization of weeds to islands.

The long-term influence of rabbit populations on vegetation on Breaksea, Michaelmas, Eclipse and Mistaken Islands, placed on these islands well before the species crossed to Western Australia from eastern Australia, is unknown. It is likely to be similar to that described for Carnac Island (Abbott 1980).

Laudbirds.—The extinction of several landbirds is due to the activities of European man last century, mainly sealers on the islands and settlers on the mainland. Because full lists were not made on my mainland areas, it is difficult to be certain which species may have then been present. Probably *Dasyornis braehypterus* and *Atrichornis clamosus* occurred on several of the sites. Although for the region depicted in Figure 1 both species are known at present to be most abundant on the Mt Gardner promontory, it is invalid to suppose the habitats they occur in there are necessarily their preferred ones or the only ones they can survive in. Rather, a change in fire regime from Aboriginal man to European man may have been responsible (Smith 1977b). I suspect that the Rock Parrot was more widely distributed on the mainland than now; I found this species in small numbers only on 3 mainland sites.

Known extinctions of landbirds on islands (with earlier references to their occurrence) are as follows:—Breaksea Island: Brush Bronzewing (Lockyer 1827) Little Grass Bird (Campbell 1900); Mistaken Island: Brush Bronzewing (Clark 1841), Red-eared Firetail, Brown Thornbill, White-breasted Robin, Sacred Kingfisher (Carter 1909) (Several of the last 4 species may have been vagrants only); Michaelmas Island: Grey Currawong (Bassett Hull 1922), though possibly only a visitor; Green Island: Rock Parrot (Vancouver 1801, King 1827, p. 130).

Rock Parrots were found by me in large numbers only on Coffin Island. Brown Quail were abundant on Bald and Breaksea Islands, particularly on the latter, whereas they seemed to be absent from my mainland sites. Feral cats and foxes on the mainland sites may be responsible for this difference.

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A new species of *Stylidium* (Stylidiaceae) from Western Australia

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Abstract

A new species of *Stylidium*, *S. pendulum* is described. The species shows affinities with *S. coroniforme*, *S. macrocarpum*, *S. tenuicarpum* and *S. ricae* but with few other species of the genus.

Introduction

While collecting material of the genus *Stylidium* in 1972 for cytological study, a distinctive undescribed species was found near Mullewa. It is described here so that the name may be available for a comprehensive cytological review of the genus in preparation by Dr S. H. James of the University of Western Australia.

Stylidium pendulum Keighery sp. nov.

Figure 1 A-E, G-K

Herba perennis caespitosa robusta, caudice crasso saepe polycephala. Foliomina basalia dense conferta, erecto-patentia, lineari-oblancoolata, 2-6 plerumque 4 cm longa, ad 2 mm lata, longimucronata, glabra, margine hyalino. Racemus simplex 14-20 plerumque ca 15 cm altus, scapo piloso, glanduloso, 1-3 bracteato, 2-4 cm longo. Inflorescentiae bracteae lanceolatae, 1-2 mm longae, 1 per pedicellam bracteolae minutiae, 2 per flores. Pedicelli 1-4 mm longi. Calycis tubus ad anthesium 1-2 cm longus, glanduloso-pubescent, linearis. Calycis lobi 2-3 mm longi obtusi. Corollae lacinae ad 4-6 mm longae, 2 mm latae, extus glanduloso-pubescentes, armeniatae, ovate. Labellum conspicuum, appendiculis 2 minutis instructum. Columna ca 7-10 mm longa. Capsula linearis, 1.5-2.5 cm longa. Chromosomatum numerus gametae $n = 14$.

Caespitose perennial herb (dying back to a rootstock during the summer), rosettes single or several from a thick, short stem, often many headed. Leaves erect or spreading, narrow, oblanceolate, acuminate, pale green, glabrous, flat, with narrow transparent margins, mucronate 2-6 (mostly 4) cm long, 1.5-2 mm wide. Inflorescence a simple raceme, 14-20 cm tall, pilose with glandular and simple hairs, almost all glandular hairs near base, 1-3 bracts on scape, no small leaves. Scape bracts 2-4 cm long. Buds long, straight, at first pendulous, appressed to scape, then turning upwards through 150° to open. One bract subtending each pedicel, lanceolate, 1-2 mm long. Bracteoles 2 per flower, minute. Pedicels 1-4 mm long. Ovary linear, 1-2 cm long at anthesis, glandular pubescent (with no simple hairs). Calyx lobes 2-3 mm long, obtuse. Corolla apricot with a red stripe, lobes broadly ovate, tube 1-2 mm long, lobes laterally paired at 45° angle, approx-

imately equal, 4-6 mm long, 2-4 mm wide, underside pubescent with glandular hairs. Throat barc, labellum conspicuous, with partially divided prominent appendage. Column 7-10 mm long. Stigma green, solid. Ovule number 45-50. Capsule at maturity 2 cm long, brown. Seeds small, brown, pitted, rounded. Many collapsed seeds present. Chromosome number $n = 14$, from pollen grain mitosis.

Holotype: 479.3 km north of Perth on Wubin to Mullewa road, lateritic soil in leaf litter under *Acacia* and *Casuarina* spp., 1/8/1972, flowered in glasshouse Botany Department, University of Western Australia, Collected 20/9/1972 G. J. Keighery, 173. *Holotype*: PERTH; *isotypes*: MEL, PERTH.

Other Collections: 1½ km east of Pindar on Mullewa to Yalgoo Road, 28/9/1974 G. Perry, 367. PERTH.

Discussion.—The species is named after its pendulous buds which are at first straight and closely appressed to the stem, unlike other species of the section which have curved, often erect, buds. The species is most closely related to *S. macrocarpum* (Benth.) Erickson and Willis, *S. coroniforme* Erickson and Willis, *S. tenuicarpum* Carlquist and *S. ricae* Carlquist. It can be easily distinguished from *S. macrocarpum* which has rosy pink corolla lobes that are directly laterally paired, the labellum possessing many lobes and a paniculate inflorescence; from *S. tenuicarpum* which has short, triangular scales forming the leaf margin (Fig. 1 F and G), only non glandular hairs on the scape, an oblong yellow corolla and no bracts below the flowers on the scape; from *S. coroniforme* in lacking a conspicuous dorsal margin to the leaf, having a flat not finger-like stigma, possessing appendages to the labellum and lacking throat appendages. Finally it can be distinguished from its closest relative *S. ricae* Carlquist by its obtuse calyx lobes, solitary flowered lateral inflorescences, leaves having a hyaline margin of triangular scales and the leaves possessing an acute tip. Living plants of *Stylidium ricae* also differ in the shape and colour of the labellum and its lobes (Erickson 1958, plate 42, fig 12, and especially plate 37 where the species is illustrated in colour from life). A detailed comparison of *S. pendulum* and these related species is given in Table 1.

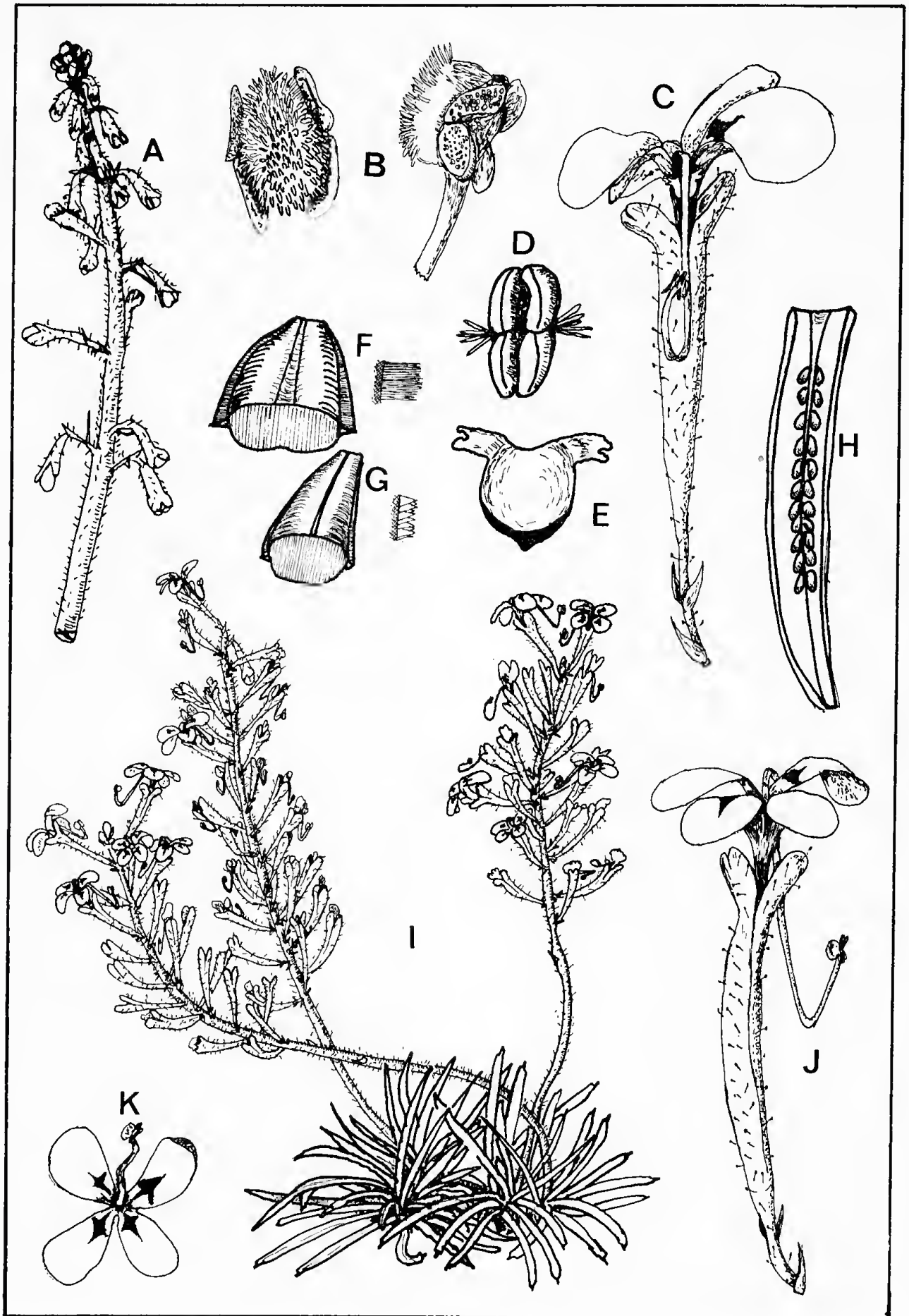


Table 1

A comparison of *S. pendulum* and related species

	<i>S. coroniforme</i> (type)	<i>S. macrocarpum</i> (type)	<i>S. ricae</i> (type)	<i>S. tenuicarpum</i> (type)	<i>S. pendulum</i> (type)
leaf margin	white entire	green, few triangular projections	few triangular projections	short white, triangular scales	long triangular scales
leaf apex	mucronate-ciliate	acute	acute	mucronate	mucronate
inflorescence	simple raceme	paniculate	paniculate	simple raceme	simple raceme
scape hairs	glandular, base glabrous	glandular/non glandular	glandular/non glandular	non glandular	glandular/non glandular
corolla colour	pink	pink	pink	yellow	apricot
petals paired	directly laterally	directly laterally	directly laterally	directly laterally	angled
shape of petals	1 oval	round-oblong	round-oblong	oblong	broadly ovate
shape of calyx lobes	narrow, blunt	broad, blunt	narrow, acute	acute	obtuse
labellum appendages	none	large, multi lobes	narrow, no lobes	narrow, no lobes	broad, two lobes
stigma shape	finger like	flat cushion	flat cushion	flat cushion	flat cushion
throat appendages	2, hair like	none	none	none	none
chromosome number (2n)	?	26	28	26	28
scape bracts	no	no	no	no	yes

Acknowledgement.—I should like to thank B. J. Keighery who provided the chromosome count, and Dr S. H. James of the Botany Department, University of Western Australia who provided plants and information on *S. macrocarpum*, *S. ricae* and *S. tenuicarpum* for comparison. The work was carried out while I was in receipt of a University of Western Australia Research studentship.

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Figure 1.—*Stylidium pendulum* (A–E, G–K) and *S. tenuicarpum* (F). A.—young inflorescence showing pendulous buds x $\frac{1}{4}$. B.—two views of the stigma x 25. C.—abaxial view of flower x 4. D.—anthers x 25. E.—labellum x 25. F.—(*S. tenuicarpum*) T. S. leaf looking towards base, enlargement of hyaline margin x 25. G.—T. S. leaf x 4, margin x 25. H.—L. S. calyx ovary x 4. I.—whole plant showing habit x one-fifth. J.—adaxial view of flower x 4. K.—top view of flower x 4.

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The seagrass fish fauna of Geographe Bay, Western Australia

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Manuscript received 20 March 1979; accepted 23 May 1979

Abstract

Samples of the fish fauna inhabiting the seagrass beds (*Posidonia* spp.) of Geographe Bay, Western Australia, collected by a small beam trawl, are dominated by the odacid *Neoodax radiatus* (662 of 1265 individuals). Eighteen other species occur, including one new record for Western Australia. Five of the species are represented by less than 6 individuals. Flora and invertebrate fauna from the seagrass beds were found in the guts of most of the fishes.

Introduction

Seagrasses of various species form large meadows in embayments around the south-west of Australia (Cambridge 1975). They are thought to be important breeding grounds (Hoese 1978; Kikuchi and Peres 1977) and serve as an important source of food for certain fishes (Brook 1977; Carr and Adams 1973; Kikuchi and Peres 1977).

The fish fauna of seagrass beds have been described for some eastern Australian localities by Conacher (1977), Hoese (1978), Hutchings and Recher (1975) and Shepherd (1974), but not for Western Australia. This paper describes the fish fauna of the seagrass beds of Geographe Bay, Western Australia.

Geographe Bay (33°S, 115°E) constitutes the coastline from Bunbury to Cape Naturaliste. Twelve locations between Capel Beach and Quindalup were examined (Fig. 1). The seagrass beds were in water

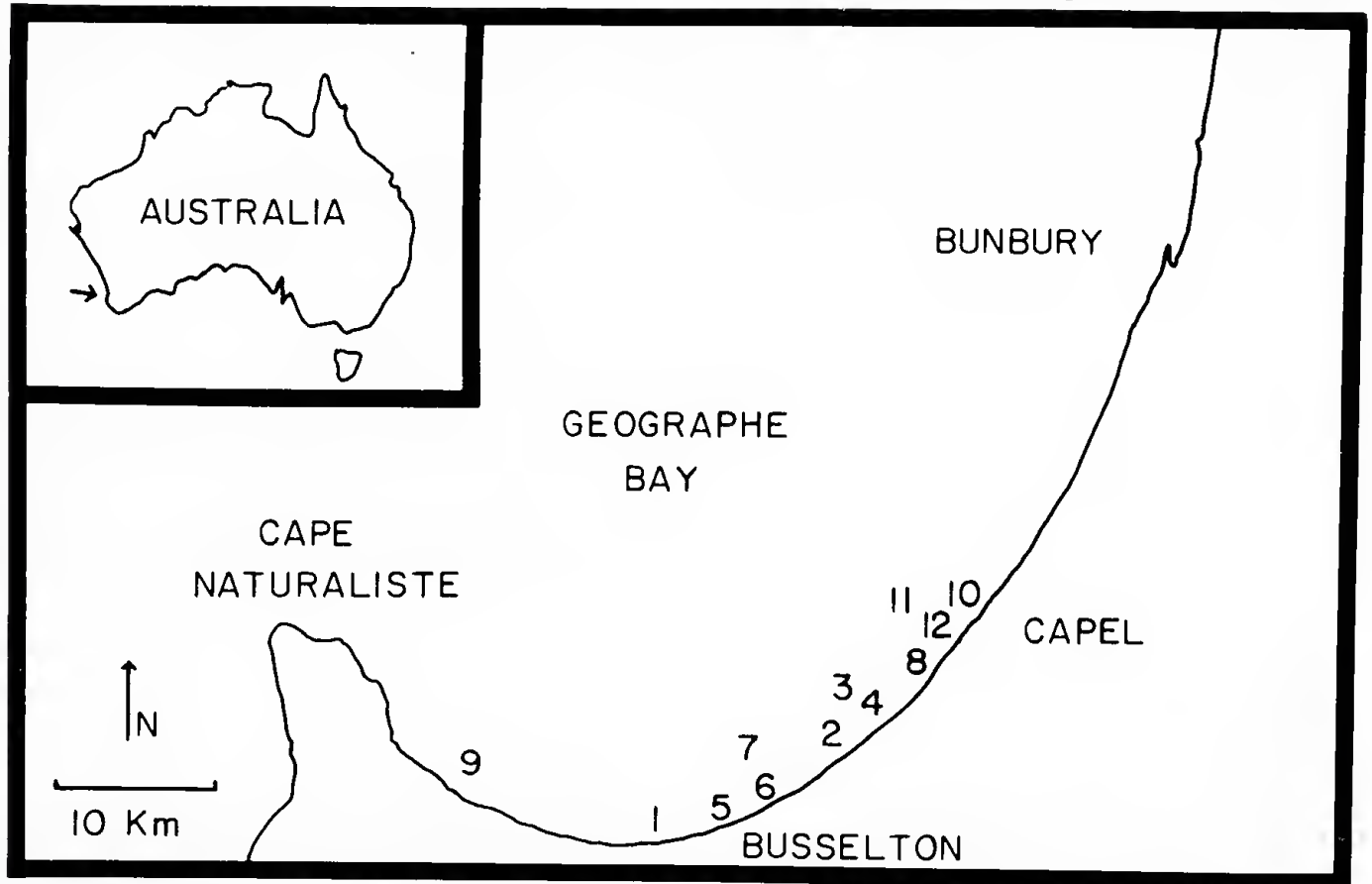


Figure 1.—Location of study sites and date of sampling in Geographe Bay. Details of study sites are: 1: 100 m off Acacia Caravan Park, 5 m deep, 26 Dec 1972; 2: 800 m off Wonnerup Beach, 5.5 m deep, 30 Dec 1972; 3A: 800 m off Wonnerup Estuary, 7 m deep, 3 Jan 1973; 3B: 800 m off Wonnerup Estuary, 7 m deep, 25 April 1975; 3C: 800 m off Wonnerup Estuary, 7 m deep, 25 Dec 1977; 4: 200 m off Wonnerup Estuary, 5 m deep, 3 Jan 1973; 5: 800 m offshore, west of Busselton Jetty, 5 m deep, 4 Jan 1973; 6: 800 m offshore, east of Busselton Jetty, 4.5 m deep, 5 Jan 1973; 7: 1000 m offshore, east of Busselton Jetty, 7 m deep, 5 Jan 1973; 8: 200 m offshore, half-way between Wonnerup and Forrest Beaches, 5 m deep, 13 Jan 1973; 9: 100 m off Quindalup Beach, 5 m deep, 14 Jan 1973; 10: 100 m off Forrest Beach, 5 m deep, 28 Jan 1973; 11: 800 m off Forrest Beach, 5 m deep, 2 Feb 1973; 12: 100 m offshore, west of Forrest Beach, 6 m deep, 2 Feb 1973. All distances offshore are approximate.

depths ranging from 4.5 m to 7.0 m and consisted entirely of *Posidonia* spp. except for sites 10 and 12 which included some *Amphibolis antarctica* (Labill.) Sonder et Aschers. Geographe Bay has at least 3 species of *Posidonia*, but the beds examined consist predominantly of an undescribed member of this genus (Cambridge, pers. comm.).

Methods and results

Samples were taken by beam trawl, mouth dimensions 88 cm by 36 cm. The net was made of 1.5 mm mesh. The trawl was lowered onto the seagrass bed and towed by a small motor boat. The distances towed were between 30 and 50 m with a duration of 1 to 2 minutes. All trawls were in summer, during daylight and a number of trawls were made at each location.

A location was deemed to have been sampled adequately if by repeated samples no additional fishes were added to the total number of species. Figure 2 gives an example of the species-sample curve for site 3C.

The fishes were sorted from the algae and seagrass and either preserved in 10% formalin for gut analysis or taken back to the laboratory alive for observations on behaviour.

Stomach contents were examined under a binocular microscope and items identified as far as possible. The standard length of the fish was measured and various food items scored as present or absent. Identification of food items was aided by examining the invertebrates which were also collected by the trawl. The results of the gut analysis are included in the annotated list of fish species below.

The species abundance data are presented in Table 1. A total of 1265 specimens were collected, comprising 19 species, however, the community is clearly dominated by *Neoodax radiatus* as 662 or 52.3% of the fish belong to this species. It is only displaced from dominance of all sample locations by the presence of abundant small juveniles of *Apogon rueppellii* and *Acanthaluteres spilomelanurus*.

Representative specimens of fishes were deposited with the Western Australian Museum and the catalogue numbers are given in Table 2. The minimum and maximum lengths in Table 2 are based on standard length measurements of both museum speci-

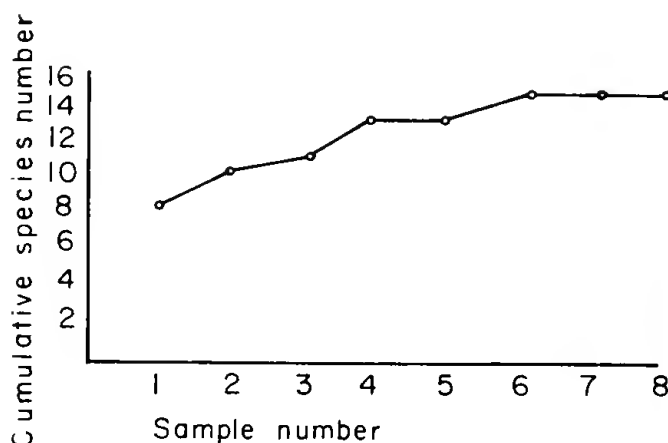


Figure 2.—The cumulative species number for consecutive samples taken from study site 3C.

Table 1

Numbers of individuals of each species caught at each sampling locality. Localities are shown in Figure 1.

Species	Locality															Total
	1	2	3A	4	5	6	7	8	9	10	11	12	3B	3C		
Aspasminae sp. 1	3	1	1	2	2		1	1	3					5	19	
Aspasminae sp. 2		1		1		3	1		3					5	14	
Aspasminae sp. 3														4	4	
<i>S. argus</i>	4	5	7	5	1	4		4	4	9	17	1	4	17	82	
<i>S. poecilolaemus</i>					1		1							2	4	
<i>G. marmoratus</i>				1			1							4	6	
<i>A. rueppellii</i>									80	2				68	150	
<i>S. cephalotes</i>			1	2	1	5	1	1		2				2	13	
<i>P. aurantiacus</i>	4	35	4	11			15	5		7	2	4			87	
<i>N. radiatus</i>	81	98	32	49	36	26	61	53	14	40	25	56	29	62	662	
<i>N. semifasciatus</i>		1							3	10				12	26	
<i>C. australis</i>	7	7		1		1		1		1				3	21	
<i>H. adelaidae</i>		4		2			5	6		2			1	1	21	
<i>A. haackeanus</i>		1													1	
<i>A. spilomelanurus</i>	21	6	3	2	2	4	6	1	4	1	3	3		59	115	
<i>S. granulatus</i>	1	6	11		1		2	2		2	2			1	28	
<i>B. jacksonianus</i>			1		1			1		1	3		1	3	11	
<i>M. freycineti</i>												1			1	
<i>A. nichthemerus</i>										1					1	

Table 2

The size range (mm) and the catalogue numbers of the specimens deposited in the Western Australian Museum.

Species	Length Range (mm)	W.A. Museum catalogue numbers
Aspasminae sp. 1	23-40	WAM P26455-013, WAM P21336, WAM P21337, WAM P25466-001, WAM P21572-75
Aspasminae sp. 2	4-11	WAM P26455-012, WAM P25466-002
Aspasminae sp. 3	4-11	WAM P26455-011
<i>S. argus</i>	16-235	WAM P26455-001, WAM P21011-19, WAM P25259-001
<i>S. poecilolaemus</i>	108-205	WAM P26455-002, WAM P21010
<i>C. marmoratus</i>	44-56	WAM P26455-003, WAM P22596
<i>A. rueppellii</i>	5-45	WAM P25259-003, WAM P26455-014
<i>S. cephalotes</i>	13-32	WAM P25259-005, WAM P26455-009, WAM P21091-72
<i>P. aurantiacus</i>	16-70	WAM P26456, WAM P21563-70
<i>N. radiatus</i>	10-141	WAM P25259-001, WAM P20926-33, WAM P20926-36, WAM P26455-004, WAM P21020, WAM P21553-4
<i>N. semifasciatus</i>	11-38	WAM P26455-005, WAM P21009
<i>C. australis</i>	20-104	WAM P21040, WAM P26455-010
<i>H. adelaidae</i>	14-50	WAM P26455-015, WAM P21041, WAM P25259-004
<i>A. haackeanus</i>	94	WAM P22597
<i>A. spilomelanurus</i>	5-70	WAM P21039, WAM P26455-008, WAM P25334-001
<i>S. granulatus</i>	23-68	WAM P25336-001, WAM P26455-006, WAM P21036
<i>B. jacksonianus</i>	13-21	WAM P26455-007, WAM P21582-83
<i>M. freycineti</i>	75	WAM P26456-002
<i>A. nichemerus</i>	28	WAM P21551

mens and samples used for gut analysis and indicates the size range of specimens trawled from the seagrass.

The arrangement of the families in the annotated list below, follows that of Greenwood *et al.*, (1966).

Annotated species list

Order Gobiesociformes

Gobiesocidae—Clingfishes

Aspasminae sp. 1

This clingfish is a member of a new genus and species (Briggs, pers. comm.). The salient features include a rectangular snout, body greatly compressed dorso-ventrally, gill membranes free from the isthmus, no opercular spine, and a large sucker in two parts. Counts were as follows: dorsal rays 4-6, anal rays, 5-7, pectoral rays 15-20, ventral rays 4, and caudal rays 10. Colour of adults in preservative was yellow-brown. Colour when alive was green or brown. It appears to be restricted to the seagrass, but its habits are not known.

Aspasminae sp. 2

This clingfish also represents a new genus and species (Briggs, pers. comm.) It can be distinguished from the above species by its smaller size and pointed snout. It is greatly compressed dorso-ventrally with gill membranes united posteriorly with the isthmus, operculum with a strong spine and a large sucker in two parts. Counts were as follows: dorsal rays 3, anal rays 2, pectoral rays 17-18, ventral rays 4 and caudal rays 10. Colour of adults in preservative was uniformly yellow-brown. Colour when alive was green or brown. It lays 6 to 12 eggs on the surface of the seagrass and the parents remain with

the eggs. This species is found in slightly shallower water than the previous species. The feeding habits are not known.

Aspasminae sp. 3

This unidentified clingfish can be separated from the above species by its rounded snout. It also has a body greatly compressed dorso-ventrally, gill membranes free from the isthmus, no opercular spine and a large sucker in two parts. Colour of preserved specimens is uniform yellow. Colour when alive was yellow-green with longitudinal rows of small blue dots, and other blue dots between. Its habits are not known.

All the above clingfish adhere to blades of seagrass by means of their ventral sucker. These species have not been found elsewhere and are most likely restricted to seagrass beds.

Order Gasterosteiformes

Syngnathidae—Pipefishes

Stigmatophora argus (Richardson)

Syngnathus argus Richardson, *Proc. Zool. Soc. Lond.* 8: 29 (1840); type locality, not given.

This was the most numerous species of pipefish found in the seagrass. The gut contents of 12 specimens between 185 mm and 235 mm in length, consisted entirely of copepods. *S. argus* is widely distributed around Australia, Indonesia, Melanesia and Fiji.

Syngnathus poecilolaemus Peters

Syngnathus poecilolaemus Peters, *Monatsb. Akad. Wiss. Berlin*, 1868, p. 548 (1869); type locality, Adelaide, South Australia.

The gut contents of one 205 mm specimen contained filamentous algae while that of a 224 mm specimen contained crustaceans. This species is found in southern Western Australia and South Australia.

Order Scorpaeniformes

Scorpaenidae—Scorpion Fishes

Gymnapistes marmoratus (Cuvier)

Apistus marmoratus Cuvier, *Histoire naturelle des poissons*, 4: 416 (1829); type locality, 'Timor'. (probably Western Australia).

Only juveniles were found in seagrass beds. The guts of 2 specimens, 54 mm and 52 mm in length, contained shrimps, amphipods, isopods and copepods. This species was rare despite having a southern Australian distribution. Grant (1972) has published on the biology of *G. marmoratus* based on samples from Tasmania. He found it associated with the seagrass *Zostera* sp., with reproduction initiated at 2 years and spawning in August and September. Grant's work indicated that shrimps and crabs are the major food items with other fish species being consumed by larger individuals.

Order Perciformes

Apogonidae—Cardinal Fishes

Apogon rueppellii Gunther

Apogon rueppellii Gunther, *Catalogue of the Fishes in the British Museum* 1: 236 (1859); type locality, Victoria.

The large number of specimens caught at stations 9 and 3C were all juveniles, having a length less than 2 cm. The guts of 7 specimens were found to contain amphipods, isopods, and copepods. This fish is found on all Australian coasts.

Siphamia cephalotes (Castelnau)

Scopelus (Neoscopelus) cephalotes Castelnau, *Res. Fish. Aust.* 1875, p. 46 (1875); type locality, Adelaide.

Most specimens were juveniles, one fish, 25 mm in length contained a shrimp in its gut. This species is found in all Australian states except Queensland.

Labridae—Wrasses

Pseudolabrus aurantiacus (Castelnau)

Cheilinus aurantiacus Castelnau, *Proc. Zool. Acclim. Soc. Vic.* 1: 245 (1872); type locality, St. Vincents Gulf, South Australia.

Five specimens were measured and examined for gut contents. The results were: 60 mm, *Posidonia* leaf, foraminifers and amphipods; 67 mm, algae, shrimps, amphipods; 70 mm, molluscs, shrimp and foraminifers; 45 mm, *Posidonia* leaf, molluscs, isopods and shrimp. *Posidonia* leaf and algae do not appear to form a major part of the diet. *P. aurantiacus* is found in South Australia and Western Australia.

Odacidae—Weed Whitings

Neoodax radiatus (Quoy and Gaimard)

Malacanthus radiatus Quoy and Gaimard, *Voyage de decouvertes de l'Astrolabe*. Zoologie, 3: 717 (1835); type locality, King George Sound, Western Australia.

This was the most common fish in the seagrass beds of Geographe Bay and with other species of *Neoodax*, it is restricted to this seagrass habitat (Scott 1976). The gut contents of 37 specimens were examined and the results are summarised in Table 3.

Adults are thought to spawn from August through to December and by January, small juveniles are found. *N. radiatus* is distributed from Western Australia and South Australia to Tasmania.

Table 3

The percentage of each food item, and the percentage of fish containing the food item for 37 *Neoodax radiatus*. The size range of the fish was 41 mm to 141 mm with a mean \pm standard error of 91.1 ± 3.77 .

Food item	% of total food items	% of fish with food items
algae	3.7	13.5
<i>Posidonia</i> leaf	5.9	21.6
<i>Amphibolis</i> leaf	0.7	2.7
foraminifers	11.0	40.5
bivalves	2.2	8.1
trochid gastropods	8.1	29.7
unidentifiable molluscs	21.3	78.4
amphipods	7.4	27.0
copepods	1.5	5.4
isopods	9.6	35.1
shrimps	15.4	56.8
unidentifiable crustaceans	11.8	43.2
pycnogonid	0.7	2.7
sand	0.7	2.7

Neoodax semifasciatus (Valenciennes)

Odax semifasciatus Valenciennes, *Histoire naturelle de poissons* 14: 299 (1839); type locality, Indian Ocean.

Four specimens were measured and examined for gut contents, the results being: 32 mm, copepods; 38 mm and 34 mm, copepods and foraminifers; 30 mm, copepods, foraminifers and *Posidonia* leaf. This species was the most common fish observed by Shepherd (1974) in the seagrass beds of Upper Spencer Gulf, South Australia, but in this survey it was caught infrequently and all specimens were juveniles. *N. semifasciatus* has a southern Australian distribution.

Clinidae—Weedfishes

Cristiceps australis Valenciennes

Cristiceps australis Valenciennes, *Histoire naturelle des poissons*, 11: 402 (1836); type locality, Tasmania.

This species was present both as adults and juveniles throughout the sampling area. It is ovoviviparous and is presumed to spawn in the seagrass. Milward (1967) discussed the biology of the clinid fishes of Western Australia and considered this species to be mainly restricted to the seagrass habitat. Milward (1967) states that it consumes fish and crustaceans. I have observed it to eat live fish in aquaria and the guts of 2 specimens, 48 mm and 104 mm, contained shrimps and a crab respectively. *C. australis* has a southern Australian to New Zealand distribution.

Heteroclinus adalaidae Castelnau

Heteroclinus adalaidae Castelnau, *Proc. Zool. Acclim. Soc. Vict.* 26: 68 (1873); type locality, Adelaide, South Australia.

This species also appears to be associated with seagrass beds (Hoese 1976). It is probably ovoviviparous and completes its life cycle in the grassbeds. One specimen, 48 mm in length, had shrimp in its gut. *H. adalaidae* has a southern Australian distribution.

Order Pleuronectiformes

Soleidae—Soles

Aseraggodes haackeanus haackeanus (Stcindachner)

Solea (Achirus) haackeana Steindachner, *Anz. Akad. Wiss. Wein.* 20: 95 (1883); type locality, South Australia.

This was probably an accidental inclusion in the trawl as soles normally inhabit sandy bottoms. It is found in South Australia and is a new record for Western Australia.

Order Tetraodontiformes

Monacanthidae—Leatherjackets

Acanthaluteres spilomelanurus (Quoy and Gaimard)

Balistes spilomelanurus Quoy and Gaimard, *Voyage autour du monde... sur l'Uranie et la Physicienne... Zoologie*: 217 (1824); type locality, Port Jackson, New South Wales.

This leatherjacket only appears in the grass beds as juveniles. Six individuals were measured and examined for gut contents. The results were: 61 mm, algae and foraminifers; 56 mm, algae and unidentifiable calcareous pieces; 63 mm, algae, unidentifiable calcareous pieces and molluscs; 52 mm, green algae and crustaceans; 49 mm and 48 mm, algae and unidentifiable calcareous pieces. *A. spilomelanurus* has a southern Australian distribution.

Brachaluteres jacksonianus (Quoy and Gaimard)

Balistes jacksonianus Quoy and Gaimard, *Voyage autour du monde... sur l'Uranie et la Physicienne... Zoologie* 209: (1824); type locality Sydney, New South Wales.

Two specimens were examined for gut contents. One, 21 mm in length, contained an unidentifiable white material while the other, 19 mm in length, contained algae, eggs and mollusc shells. *B. jacksonianus* has a southern Australian distribution.

Meuschenia freycineti (Quoy and Gaimard)

Balistes freycineti Quoy and Gaimard, *Voyage autour du monde... sur l'Uranie et la Physicienne... Zoologie*: 213 (1824); type locality, Mauritius.

The gut of a 75 mm specimen contained algae. *M. freycineti* has a southern Australian distribution.

Scobinichthys granulatus (Shaw)

Balistes granulata Shaw, *White's voy. New South Wales*: 295 (1790); type locality, New South Wales.

This leatherjacket only appears in the grassbeds as juveniles. Four individuals were measured and examined for gut contents. The results were: 68 mm, algae, eggs, foraminifers, serpulid polychaetes, and molluscs; 50 mm, *Posidonia* leaf, algae, and polychaete tubes; 36 mm, *Posidonia* leaf, algae, foraminifers and shrimp; 28 mm, *Posidonia* leaf, algae, foraminifers and sand. Specimens from the seagrass are unable to capture live shrimp (*Macrobrachium* sp.) in aquaria. However, *Neodax radiatus* is able to bite off the eyestalks of the shrimp, thus allowing the leatherjackets to devour it. *S. granulatus* has a southern Australian distribution.

Diodontidae—Porcupine Fishes

Atopomycterus nichthemerus (Cuvier)

Diodon nichthemerus Cuvier, *Mem. Mus. d'Hist. Nat. Paris* 4: 135 (1818); type locality 'Mers des Indes' (probably Tasmania).

Only one juvenile was collected. *A. nichthemerus* is found in Western Australia, South Australia, and Tasmania.

Discussion

The only fishes in the seagrass that could be regarded as commercially important are three leatherjackets, *Acanthaluteres spilomelanurus*, *Meuschenia freycineti* and *Scobinichthys granulatus*. However, it is possible that the beam trawl fails to capture species which live just above the grassbeds and use the seagrass and its fauna as a food source. Zei (1962) who used a similar type of trawl in the seagrass, *Posidonia oceanica*, comments on the likelihood of missing species by only trawling during the day. This shortcoming may have also affected the present study and the nocturnal composition of the seagrass beds will be determined by future sampling.

The majority of fish from *P. oceanica* communities complete their lifecycles in the seagrass (Zei 1962) and this would appear to be the case for the species from the *P. australis* habitat in Geographe Bay. The only numerous group for which adults were not caught was the monacanthids.

Neodax radiatus was dominant in collections from all but two locations, contrary to studies from other parts of Australia (Conacher 1977, Hoese 1978, Hutchings and Recher 1974, Shepherd 1974), which did not report this species. Other species showing an occasional abundance (*Apogon rueppellii* and *Acanthaluteres spilomelanurus*) were present mainly as small juveniles.

The preliminary examination of the gut contents indicates that most of the fish are carnivorous and that their food source is entirely derived from the seagrass beds.

The only species endemic to southern Western Australia are the three undescribed clingfishes but it is expected that their range will be extended with further work on other seagrass beds. Most of the species have southern Australian distributions. Only *S. argus*, *C. australis* and *M. freycineti* have been recorded outside Australia.

The Syngnathidae, Scorpaenidae and the Labridae are families found in other fish communities from grass beds around the world (Kikuchi and Peres 1977). The seagrass fish community from Geographe Bay differs by the dominance of the Odacidae, which is endemic to the Australian-New Zealand region. More detailed work in the future is planned to investigate seasonality and to give more details on the use of space, time and food and the possible interactions between species.

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The ecology of Star Swamp and surrounding bushlands, North Beach, Western Australia

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Abstract

The vegetation of Star Swamp and its surrounding catchment represents a remnant of the once extensive natural vegetation of the Swan Coastal Plain. Polar ordination techniques were used to analyze the variation in the vegetational composition of the canopy and perennial understorey strata. Size-class analysis was used to analyze the major tree species populations. The major species relationships to water levels of the swamp of soil texture, soil organic matter, soil colour and soil pH were determined. The relationship of environmental factors and the biotic effect of naturalized weedy species on species diversity was also determined.

Areas of seasonal flooding were dominated by Paperbark (*Melaleuca rhaphiophylla*) with an understorey of flooding tolerant herbaceous perennials. Common species of this understorey included *Scirpus maritimus*, *Baumea juncea*, *Gahnia trifida* and *Sporobolus virginicus*. Soils of this region tended to be alkaline, highly organic, greyish in colour, sandy loams and very shallow over a limestone base. Species diversity was low and the infestation by introduced weeds was low.

Upland areas of sandy, slightly alkaline, yellowish soils of moderate depth and degree of leaching were dominated by Tuart (*Eucalyptus gomphocephala*). Areas of slightly acidic soils of greater depth and degree of leaching were dominated by a mixed Banksia—Tuart community. *Xanthorrhoea preissii* and *Hibbertia hypericoides* were widespread understorey species while species such as *Mesomelaena stygia*, *Scaevola caesceus* and *Dryandra uivea* were restricted to areas of the mixed Banksia—Tuart Woodland. Understorey species diversity was highest in areas of the mixed Banksia—Tuart Woodland and was inversely related to the degree of weed infestation.

Control of the degree of inundation in the lowland areas and weed control measures for upland areas appear most urgent requirements for maintenance of the natural status of the Star Swamp bushland.

Introduction

Star Swamp is a wetland area within a region of undeveloped bushland located in the Perth metropolitan suburb of North Beach, Western Australia (31°51'S, 115°45'E) (Fig. 1). The swamp is a fresh water body, 4 ha in area, and is surrounded to the north, east, and south by approximately 90 ha of a mixture of woodland communities.

The area is situated approximately 600 m from the Indian Ocean on Spearwood Dune System soils (Bettenay *et al.* 1960). The wetlands would appear to have developed as an interdunal depression or possibly as a result of past marine activity in the zone between the Quindalup and Spearwood Dune Systems. Upland areas of the Spearwood System consist of a core of aeolianite with a hard capping of secondary calcite overlain by variable depths of yellow and brown sand (McArthur and Bettenay 1960). Originally the material was calcareous throughout but leaching of the surface soils has removed carbonates from the upper horizons to be precipitated below to form layers and columns of hard compact limestone.

The Spearwood dunes have had a complex history, being subjected to both deposition and later erosion. Much of the western surface sand has blown inland and, in conjunction with deeper leaching of the eastern region, has formed deep soils designated as the Karrakatta Soil Association (Seddon 1972). In the natural state this soil association supports a tall open forest of Tuart (*Eucalyptus gomphocephala*), Jarrah (*E. uararginata*), and Marri (*E. calophylla*). In the western portion of the Spearwood System, the dunes are generally younger and the soils are shallower. This soil type has been referred to as the Cottesloe Soil Association (Seddon 1972). These soils carry much the same species composition as the deeper Karrakatta soils, however, Tuart is much more common than Jarrah and Marri. It is only on the Cottesloe soils that Tuart is found in pure stands (Seddon 1972).

Star Swamp and its surrounding bushland occur on the soils belonging to the Cottesloe Association. However, while Seddon (1972) states that the main plant formations of these soils are Tuart-Jarrah-Marri tall open forest or a closed heath, the presence of species of the *Banksia* woodland formation in the

bushland at Star Swamp could indicate a much deeper soil profile (Bell *et al.* 1979). A woodland dominated by *Banksia attenuata*, *B. menziesii* and *Casuarina fraserana* is more typical on the deeper, leached soils of the older Bassendean Dune System (Seddon 1972).

Major objectives of the present study included an analysis of the stratal components of plant communities of the wetland and their immediate surrounding upland in relation to some environmental, edaphic and anthropogenic factors and the establishment of base-line data to develop a management programme for maintenance of this metropolitan bushland region.

Tree stratum

Methods

The Star Swamp bushland study area was gridded into $\frac{1}{4}$ ha square blocks (Fig. 1). The sampling grid of eleven rows each of six blocks contained a diversity of vegetational, environmental, edaphic and anthropogenic characteristics and was chosen for intensive analysis. The rows were numbered from north to south. Blocks within the rows were numbered west to east. The most northwest block (1,1) was a residential block and was therefore not considered. Also blocks (10,1) and (11,1) were so greatly disturbed that it was considered that data gained by sampling would not have added substantial information to the analysis of the area.

Maximum, minimum and mean elevation data for each block were approximated by superimposing the grid area on a topographic map. The mean elevation data were used to produce a contour computer map of the topography of the Star Swamp grid area (Fig. 2).

In each block, all stems ≥ 4 cm diameter at breast height (dbh) were identified to species and the dbh was recorded. In instances where a tree branched from the base, each branch was measured and recorded separately. In addition each stem (or basal branch) was noted as alive or dead. A block importance value for each tree species was determined as the mean of the relative basal area and relative density percentages. Importance values for each block were used as the input data for a Polar Ordination (Cottam *et al.* 1973) using the Ordiflex Program of the Cornell Ecology Series (Gauch 1973).

Tree diameters were sorted into size-classes. Each class covered 12 cm. Where a multi-branched tree was measured the size-class was determined by summing the individual branch measurements. Size-class analysis was performed on all trees of the intensive study area and then on only those trees recorded as alive. The relationship between tree size and the number of individuals in size-classes was tested against the negative exponential model (Johnson and Bell 1975). The quality of the statistical fit was assessed by a Kolmogorov-Smirnov test (Snedecor and Cochran 1967).

Results and discussion

Fourteen tree species were identified in the intensive study area. The most common tree species were

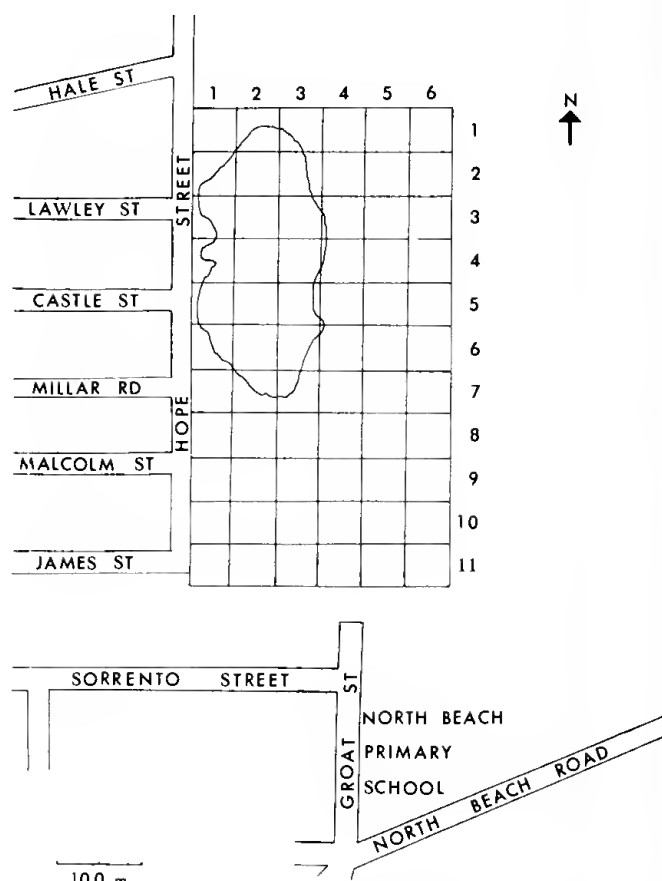


Figure 1.—Sampling grid for the Star Swamp bushland study area of North Beach, Western Australia. Approximate location of the 2 m contour is outlined.

Melaleuca rhapsiophylla (Swamp Paperbark), *Eucalyptus gomphocephala* (Tuart), *Banksia attenuata* (Narrow-leaved Banksia), *Banksia menziesii* (Menzies' Banksia) and *Eucalyptus marginata* (Jarrah). Other species reaching tree size (≥ 4.0 cm dbh) in the study area were *Acacia cyclops*, *Acacia saligna*, *Banksia grandis*, *Casuarina fraserana*, *Dryandra sessilis*, *Hakea glabella*, *Jacksonia furcellata*, *Jacksonia sternbergiana*, and *Olea europaea*.

The analysis of the tree stratum was centred on the distribution and habit of four of these species, namely *Melaleuca rhapsiophylla*, *Eucalyptus gomphocephala*, *Banksia attenuata* and *Banksia menziesii*, since they were the most common by far and may be considered as indicator species for certain environmental and edaphic conditions.

Melaleuca rhapsiophylla was confined to the north-western portion of the study area, dominating blocks 1-3 of rows 2-7. In the 18 blocks where *Melaleuca rhapsiophylla* was present, the Paperbark density ranged from 380 to 4 stems ha^{-1} and averaged 184 stems ha^{-1} . Basal area for *Melaleuca rhapsiophylla* averaged 19.7 $\text{m}^2 \text{ha}^{-1}$ but reached a maximum in block (3,2) of 58.6 $\text{m}^2 \text{ha}^{-1}$. The first axis of the polar ordination (Fig. 3a) tended to separate those blocks dominated by Paperbark from the other blocks (Fig. 3b).

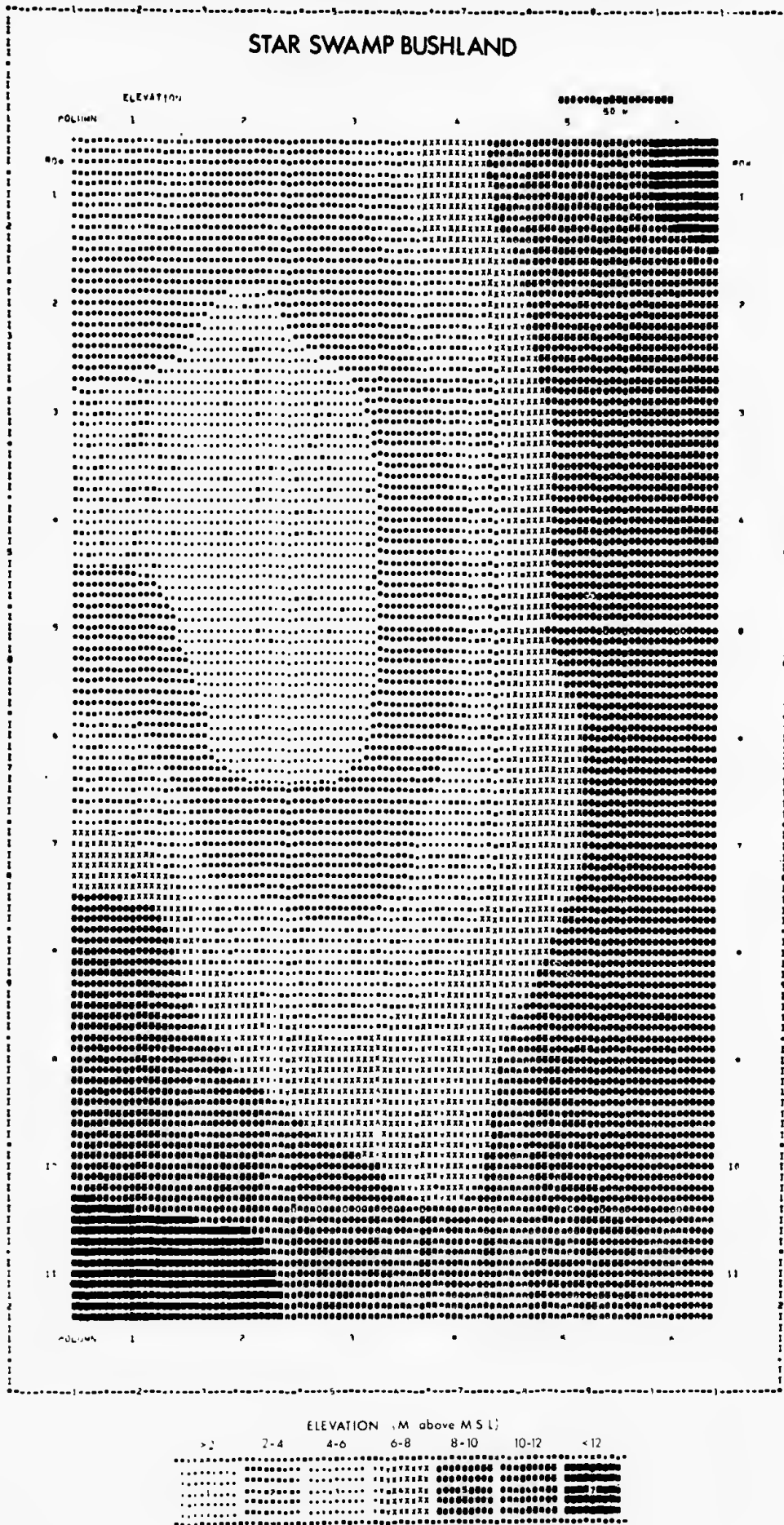


Figure 2.—Computer simulated contour map of the mean elevations of the blocks of the Star Swamp study area.

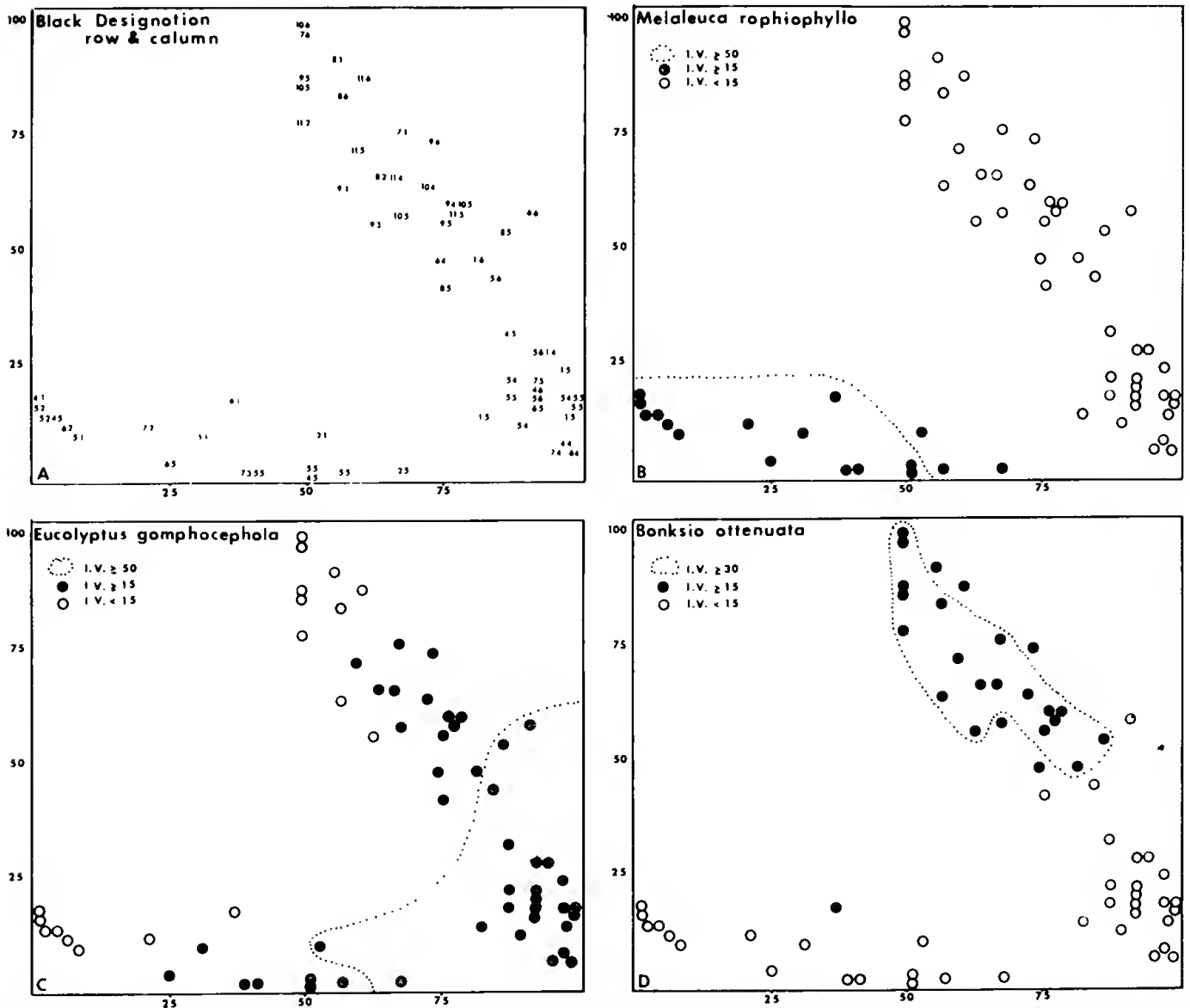


Figure 3.—Polar ordination of the overstorey importance value data for the Star Swamp intensive study area. The distribution of the 63 samples in the first two axes of the polar ordination (A) and degree of dominance by *Melaleuca raphiophylla* (B), *Eucalyptus gomphocephala* (C), and *Banksia attenuata* (D) are represented.

Eucalyptus gomphocephala was the most widely distributed of the tree species of the study area, being present in 45 of the 63 sampling blocks. Tuart predominated in the blocks to the east and north-east of the Paperbark-dominated region. Average Tuart density was 34 stems ha⁻¹ and the average basal area for this species was 11.57 m² ha⁻¹. Basal area totals for Tuart were therefore approximately 60% of the Paperbark totals even though the tree density values for *Eucalyptus gomphocephala* were less than 20% of the *Melaleuca raphiophylla* density values. Blocks dominated by Tuart were positioned at the opposite end of the primary axis of the polar ordination from the Paperbark-dominated blocks (Fig. 3c).

Banksia attenuata and *Banksia meuziesii* were concentrated in the southern half of the study area. In addition *Banksia attenuata* occurred on the eastern boundary of the study area. *Banksia attenuata* was predominant but generally shared the important values with *Banksia meuziesii*, *Eucalyptus gomphocephala*, and *Eucalyptus marginata*. *Banksia attenuata* was recorded from 28 blocks (Fig. 3d). In these 28

study blocks, the species had an average density of 86 stems ha⁻¹ and an average basal area of 3.29 m² ha⁻¹. *Banksia meuziesii* also occurred in each of these blocks and averaged 55 stems ha⁻¹ and 2.35 m² ha⁻¹ for density and basal area respectively.

Ordination of the tree stratum importance value data distributed the blocks into three rough groupings. The density and distributions of the dominant tree species on the ordination suggested the designation of three communities: (1) a Paperbark-dominated woodland, incorporating the blocks dominated by *Melaleuca raphiophylla*; (2) a Tuart-dominated woodland, including blocks dominated by *Eucalyptus gomphocephala*; and (3) a mixed *Banksia*-Tuart woodland incorporating the remaining blocks of predominantly *Banksia attenuata* and *E. gomphocephala* with inclusions of *E. marginata* and *B. meuziesii* although clinal relationships between the blocks are apparent. The positions of blocks (1,6), (2,6), (6,6), (8,3), (8,4) and (8,5) illustrate this point. They appear as transition plots midway between more easily classified blocks of the Tuart and the mixed

Banksia-Tuart communities. Also noteworthy were blocks (1,2) and (6,1) which contained two rather distinctively different assemblages of plants and were artificially combined because of the position of the sampling grid. General appearance of the three communities is depicted in Figure 4.



Figure 4.—General habitat appearance of the communities of the Star Swamp intensive study area, including the Paperbark woodland (A), the Tuart woodland (B) and the mixed Banksia-Tuart woodland (C).

Analysis of the tree stratum of the Star Swamp bushland by size-classes revealed additional information. Generally the numbers of trees within the diameter class decreased with increasing size (and presumably age) (Fig. 5). The relationship was,

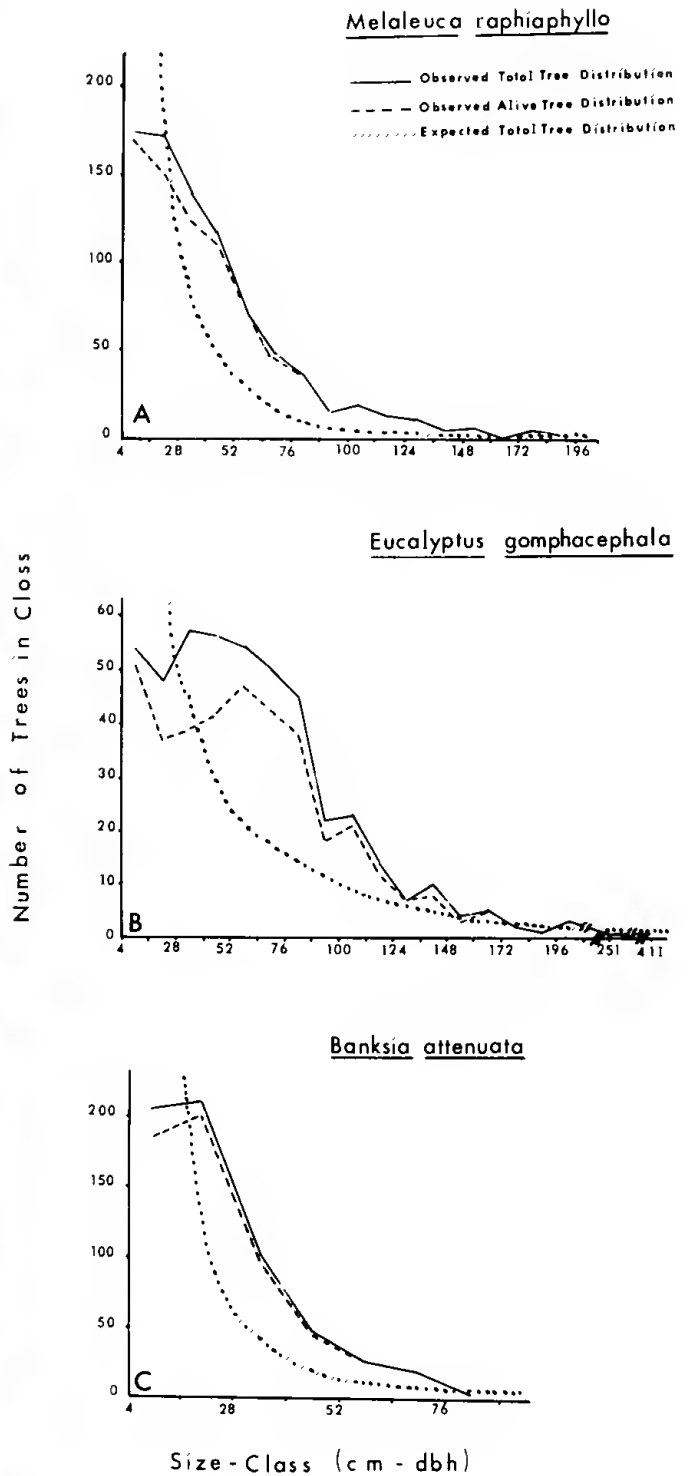


Figure 5.—Size-class analysis of the populations of *Melaleuca raphiophylla* (A), *Eucalyptus gomphocephala* (B), and *Banksia attenuata* (C). The observed total tree distribution, the distribution of the population of living trees separately and the expected total tree distribution using the negative exponential model are illustrated for each species.

however, not linear and conformed more closely to the negative power curve indicating decreasing mortality with increasing age (Johnson and Bell 1975).

For all of the major species in the study areas, the numbers of trees in the smaller (and presumably younger) size-classes, were considerably less than

expected. The reduced numbers of trees in the small size-classes, indicated that conditions for seedling establishment have been less than optimal in the recent past. The large disparity between the observed and expected values in the small size-classes generally affected the analysis of the quality of the statistically fitted curves and the negative exponential model. None of the curves were statistically significant indicating that factors in addition to age need to be considered in the distribution of size-classes at Star Swamp.

The less than expected total tree numbers in the smallest size-classes probably reflects reduced seedling establishment. The difference between the total tree distribution value and the alive tree value for a given tree size-class, however, reflects the mortality of that particular class. Only the smallest size-class in the *Banksias* reflects a large difference (Fig. 5c). The mortality of the younger *Banksias* is most likely the result of greater fire frequency in the recent past. Although no precise records have been kept, local residents report that in the recent past, the upland portions of the natural area have experienced numerous burns. These frequent fires could be the reason for the large numbers of dead standing stems of the smallest size-class.

Tuart mortality is apparent in all but the very largest of the classes (Fig. 5b). The increased frequency of fires could have had an effect on the youngest trees but death in the older size-classes is probably attributable to a more complex set of circumstances. Metropolitan populations of *Eucalyptus gomphocephala* are generally deteriorating (Beard 1967). Few seedlings can be found and the estab-

lished trees show progressive deterioration of the crown ultimately resulting in death. The progressive dieback of the crown and the inability to restore foliage is caused by leaf-chewing phasmids and other defoliating insects thought to be correlated with the reduction of bird populations throughout the metropolitan area (Beard 1967). A second major insect enemy is the Tuart bud weevil (*Haplonyx fibialis*) which bores through the unopened young buds to lay an egg. The insect then cuts off or rings the bud at its base so that it either falls directly or is later dislodged by the wind. On contact with the soil surface moisture the bud tissue softens and becomes more easily available to the growing larvae. The ground beneath Tuarts in late summer is often littered with fallen buds that have failed to open, each drilled by a small hole (Seddon 1972).

Most upland Tuarts in the bushland at Star Swamp have the stag-horned appearance of a dying crown. Average percentage dead tree material in the sampling blocks with a minimum elevation above 2 m was 9%. By far the greatest Tuart mortality, however, occurs in the lowland blocks surrounding the swamp (Fig. 6). In blocks where the minimum elevation was less than 2 m but greater than 1 m, the percentage of the Tuart basal area recorded as dead was 19%. In the study blocks where minimum elevations were below 1 m, the percentage of dead tree material for Tuart averaged 82%.

Paperbark also showed mortality in many of the smaller size-classes (Fig. 5a) indicating causes of death were not restricted to the smallest and presumably youngest trees. *Melaleuca raphiophylla* did not occur in blocks where the minimum elevation

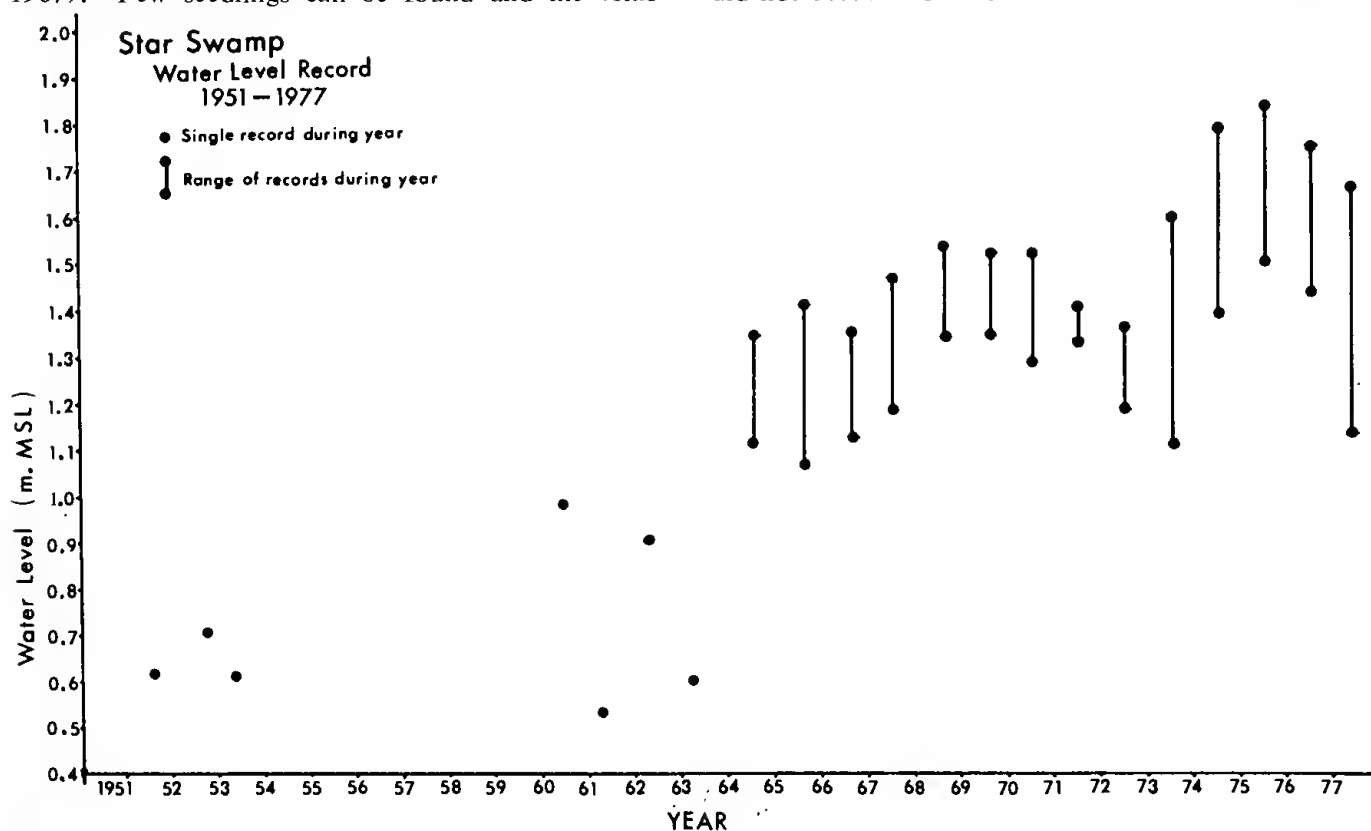


Figure 7.—Water level records for Star Swamp. Single winter records for earlier years and the range of water level values for multi-record years are plotted for the period of record. The data were supplied by the Division of Ground Water of the Metropolitan Water Board.

was greater than 2 m, but for blocks less than 2 m but greater than 1 m minimum elevation the percentage mortality among the Paperbarks was 0%, while blocks with minima below 1 m, percentage mortality was 7%. The data on percentage dead tree material for Tuart and Paperbark suggest that habitat conditions relating to elevation in the swamp region are affecting tree survival as well as seedling establishment.

Data on water level in Star Swamp have been collected at irregular intervals since establishment of a water level observation bore on the eastern margin of the swamp in 1951 (Fig. 7). Generally there has been a rise in water levels over the period of record, with maximum levels reached in the winter of 1975. This rise in water levels at Star Swamp is in conflict with the general trend observed for other Perth metropolitan water bodies (Burton 1976). Perth lake water levels were generally at minimum levels in the early sixties and then again in the mid-seventies. Peak water levels were recorded in the late sixties. Star Swamp levels rose during the wet rainfall years of the late sixties but instead of falling again during the seventies, the swamp water levels continued to rise. Burton (1976) hypothesizes that this rise of water tables in Star Swamp is a consequence of vegetation clearing and residential development to the west, and to a limited extent immediately north of the swamp.

The water run-off from the storm water drains has probably caused the high water levels in Star Swamp and maintained the lake through the summer drought period. The effect of permanent flooding on soil oxygen levels has probably caused the mortality observed in the lowest elevation Tuarts and Paperbarks. Seddon (1972) states that Paperbarks can tolerate winter flooding but rooting zones must be free from saturation for certain periods during summer. The general avoidance of habitats having periodically flooded soils by Tuarts would indicate that the species would be even more intolerant of prolonged saturation than the Paperbarks. The general increase in percentage mortality with decreasing elevation at Star Swamp seems to result from the maintenance of high water levels in the lake by runoff from the developed area in the western slope of the catchment. Further increases in water levels at Star Swamp could eventually lead to the death of all trees such as has occurred at Lake Claremont, formerly Butler's Swamp (Evan and Sherlock 1950).

Edaphic conditions

Methods

Soil properties for each of the 63 blocks were determined from samples taken from the centre of the sampling block. Samples were taken to a maximum depth of 50 cm from the surface and depending on colour differences, one to three depth samples were returned to the laboratory for analysis. The air-dried samples were tested for colour, organic matter, texture and pH. Colour descriptions for all depth samples were made using the Munsell colour notations (Munsell 1954). Organic matter content of the block samples was determined by loss on ignition (Bear 1964). Textural analysis for soil particle size distribution employed the Buoyoucos hydrometer method (Buoyoucos 1936). Soil pH was determined in 5:1 distilled water to soil mixtures using a glass electrode. Samples were prepared 24

hr preceding measurement and placed in a mechanical shaker for the final 45 minutes. Replicate samples of all measurements were averaged.

Results and discussion

Soil conditions determined for the intensive study blocks were presented on the vegetation polar ordinations to observe the relationship between the edaphic conditions and the dominant species of the region (Fig. 8). Soils colours for all levels of the block samples were analysed and appeared to represent two distinct groups. The swamp soils, in grey tones (2.5 YR) throughout the profile, range to the darker values and more subdued chromas with depth (Fig. 8a). Because of the general similarity of the soil profile in these immature entisols, only the upper horizon data has been presented. The remaining soils of the study area were in brownish tones (10 YR), with the top soils mainly recorded as dark browns or dark grey brown. As depth increased in these upland sites the colour changed to lighter browns and grey browns until the deeper soils reflected a yellowish-brown colour value and hue.

The soils of the *Melaleuca*-dominated blocks were again different from the remainder when percentage organic matter and textural percentages were measured (Figs. 8b and 8c). Swamp block soils were generally 3 to 5 times as high in percentage organic matter when compared to the upland block samples. All samples of the area were sandy textured but the greater content of clay- and silt-sized particles in the swamp soils were classified as loam sand or sandy loam and the soils in blocks above the influence of flooding levels were classified as sand (Buckman and Brady 1969).

Unlike the previous edaphic conditions which separated into two major groups, soil pH tended to separate into three groups. The swamp blocks dominated by *Melaleuca raphiophylla* had slightly alkaline top soils with pH values generally in the 7.5 to 8.0 range (Fig. 8d). Soils of the Tuart woodland blocks generally were in the 7.0 to 7.5 range. The blocks of the mixed *Banksia*-Tuart woodland community had soil pH values in the slightly acidic 6.0 to 6.5 range. Soil pH was the only edaphic condition which could be related to the three community partition of the tree stratum.

Generally the soils of the Spearwood Dune system are weakly leached with low calcium levels, high iron content, and have weakly acid pH conditions (Havel 1976). In a study of the relationship of broad soil and vegetation groupings at a slightly more northerly Spearwood soil location at Gngangara, Hopkins (1960) recognized four site types based on differences in leaching of the topsoils and the location of depositional limestone. (1) Poor *Banksia* scrub (*Banksia attenuata*, *B. menziesii*, and *B. ilicifolia*) on deep sands with a deposition horizon more than 3 m from the surface. (2) Jarrah-Marri forest (*Eucalyptus marginata* and *E. calophylla*) on flats with a deposition horizon within 2 m of the surface. (3) Tuart forest (*Eucalyptus gomphocephala*) on yellow sand over limestone. (4) Paperbark (*Melaleuca preissiana*) on swampy areas.

The mixed *Banksia*-Tuart woodland designated blocks at Star Swamp could probably be interpreted as an amalgamation of the first two site types of Hopkins. The more acid conditions of the top soils indicated leaching of the calcium to greater depths

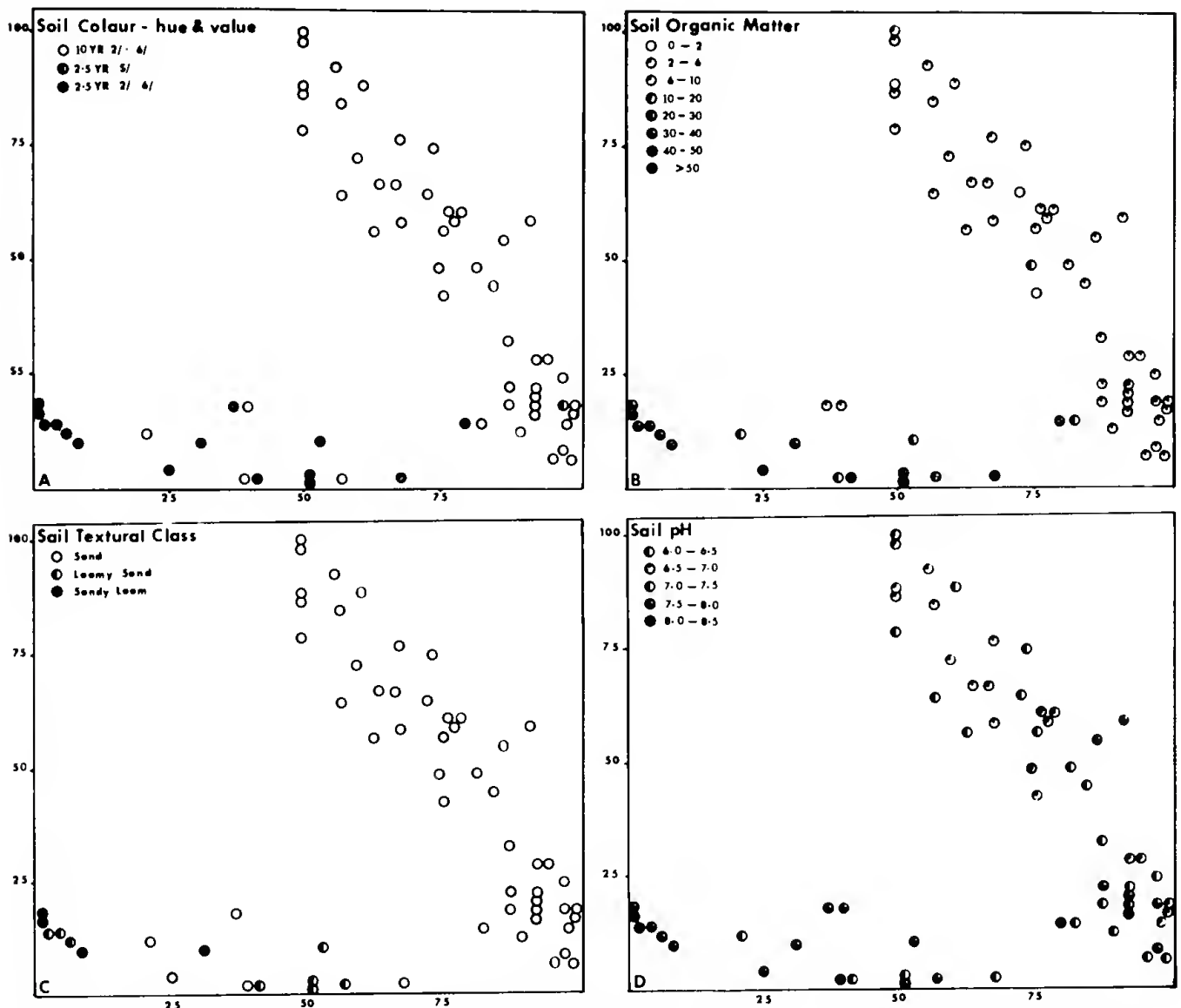


Figure 8.—Edaphic conditions of soil colour, soil organic matter, soil texture and soil pH drafted onto the vegetation ordination. For value of each parameter refer to legends on each graph.

than in the Tuart and Paperbark communities. The slightly alkaline conditions of the Tuart blocks at Star Swamp probably indicated that the limestone is relatively close to the surface. Depositional horizons in the Paperbark community are quite near the surface and top soils with pH levels greater than 7.5 indicate higher calcium carbonate levels.

The vegetation communities at Star Swamp therefore also represent a cline of increasing profile depth and leaching, but the generally high pH levels probably indicate that the profile depths may not be as great as those of the Gngangara region.

The first ordination axis appears to separate the vegetation at Star Swamp into areas depending upon the tolerance of species to flooded conditions. The second polar ordination axis appears to be a gradient of leaching from the weakly-leached areas in the lower elevations to the more strongly-leached sands of the mixed Banksia-Tuart woodland. The major environmental gradients involving moisture and the

degree of soil leaching confirm previous observations on tree species distribution on the Spearwood soils of the Swan Coastal Plain (Havel 1976).

Perennial shrub and herb stratum

Methods

The perennial shrub and herb stratum at Star Swamp was quantified by sampling eight 4 m² quadrats in each of the 63 sampling blocks. The quadrats were placed along a transect from one corner across the centre to the far corner. Within each quadrat the shoot cover percentage of each species was recorded. Samples within each block were averaged. Understorey species cover values for the most important 61 species were used for Polar Ordination (limited computer storage required reduction of species numbers to 61; the matrix was reduced using the eident value concept of Dale and Williams (1978) which determines importance as the ability of a species to differentiate samples in subsequent ordinations). Understorey species richness

and species diversity for each block were determined. Richness was merely the number of species present in the plot. Species diversity, which takes into account both the number of species and the equitability of their arrangement, was assessed using the Shannon-Wiener index (Shannon and Weaver 1944, Pielou 1966).

A subjective estimation of the degree of adventive weed infestation was also recorded for each block. This estimation index was based on a rank of numbers from 0 to 10, with 0 indicating no infestation, 5 indicating that approximately 50% of the area was under weed cover, and 10 representing total infestation of the sample block.

Results and discussion

The polar ordination of the block samples of the understorey stratum at Star Swamp resulted in a general clustering of the upland blocks (Fig. 9a),

regardless of the overstorey composition which was separated from those samples from the Paperbark community (Fig. 9b). The wide separation of the blocks in the Paperbark community was caused by the restricted distribution of a number of wetland species. *Scirpus maritimus* (Fig. 9d) occurred throughout the Paperbark blocks but *Gahnia trifida* (Fig. 9c), *Typha orientalis* (Fig. 9e), *Baumea juncea* (Fig. 9f), *Sporobolus virginicus* (Fig. 9g) and *Centella asiatica* (Fig. 9h) were species occurring in only selected locations in the swamp region. All are species tolerant of periodic flooding and good indicators of this severe habitat factor.

In contrast to the separation of the samples of the Paperbark-designated community, the samples of the remaining blocks were arranged together, indicating similar vegetative constitutions. A number of species were widely distributed in the upland areas and appeared in most samples. Among these species were

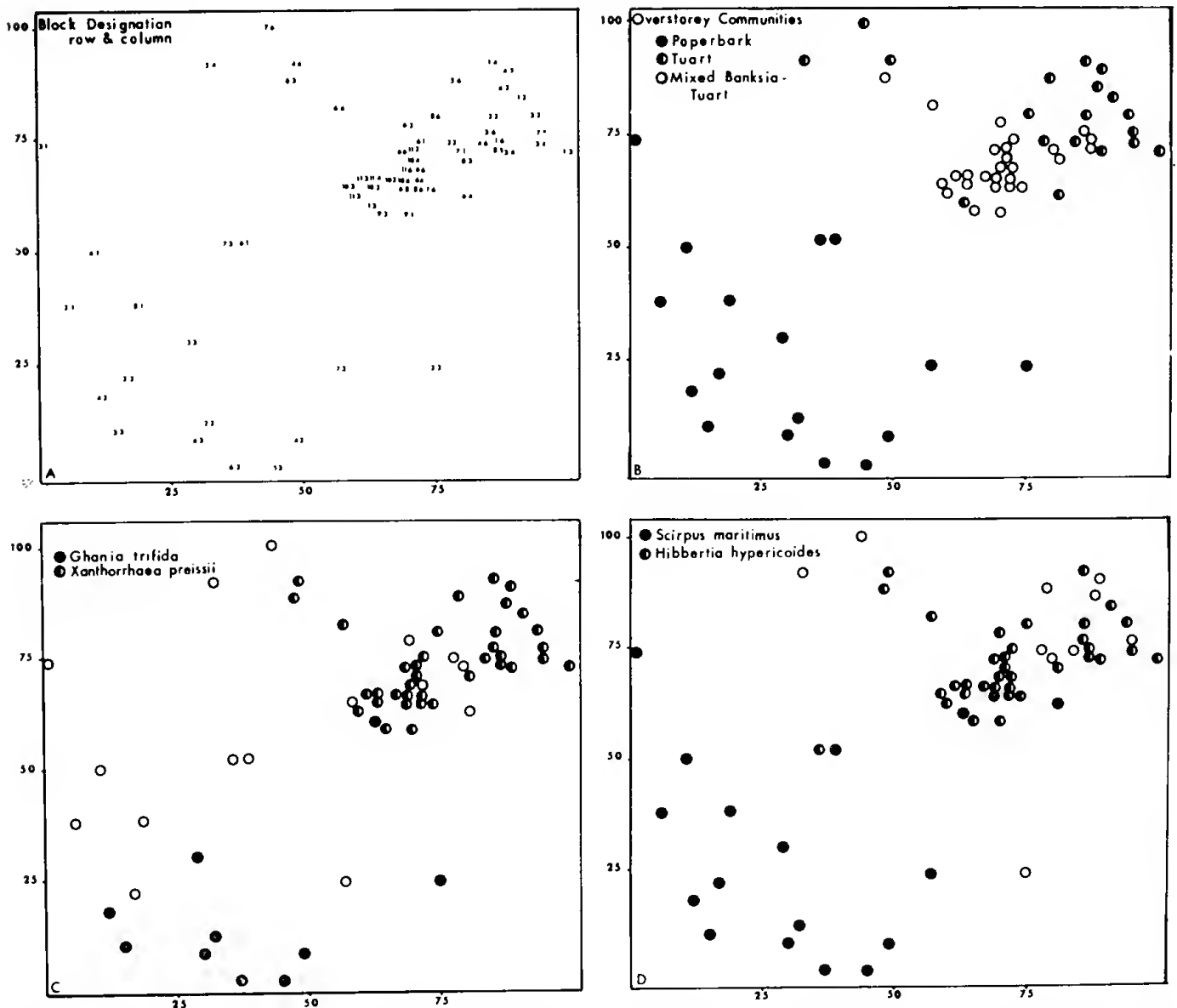


Figure 9.—Polar ordination of the understorey sample data from the Star Swamp study area. A. Row and column designation of each block for location of subsequent values. B. Overstorey community designation. C-H. Presence of designated species in block sample.

Xanthorrhoea preissii (Fig. 9c), *Hibbertia hypericoides* (Fig. 9d), a *Loxocarya* species (Fig. 9e), *Conostylis aculeata* and *Pelargonium capitatum*. Certain species, however, were restricted to the mixed Banksia-Tuart woodland regions. These were *Mesomelaena stygia* (Fig. 9f), *Dryandra nivea* (Fig. 9g), *Scaevola canescens* (Fig. 9h) and *Petrophile macrostachya*. None of the 61 species used in the ordination were restricted to Tuart overstorey blocks and the separation seemed to be based on differing cover percentages of a basic series of species. Of the 35 species rejected by the eident value system, only *Templetonia retusa* and *Melaleuca huegelii*, and seedlings of *Eucalyptus gomphiocephala* and *Melaleuca raphiophylla* were found in the Tuart blocks but excluded from the mixed Banksia-Tuart areas. *Xanthorrhoea preissii* and *Hibbertia hypericoides* have previously been reported to occur on both shallow and deep soils of the Bassendean system (Havel 1976). At Star Swamp on soils of the Spearwood system, these two species occurred in a wide range of the upland blocks, further indicating their ap-

parent broad range of ecological tolerance. Havel (1976) also states that *Xanthorrhoea preissii* is a good indicator of moist sites. None of Havel's dry site indicators occurred in the block samples. The areas of upland surrounding the swamp apparently lie in the moist end of the moisture continuum of habitats on sands of the Swan Coastal Plain.

A sub-group of five blocks, (4,4), (5,4), (7,4), (8,2), and (8,3), appears on the ordination separated from the major cluster of the upland block samples. These blocks differ primarily in large cover percentages of *Acacia saligna*, a species most commonly distributed at fringes of the swamp but occurring in the blocks designated as Tuart and Mixed Banksia-Tuart woodlands. *Acacia saligna* is generally widespread and also found in the wetter areas often on disturbed land (Seddon 1972).

Tabulating the species occurring in the three designated communities, we found that the Paperbark vegetation totalled only 31 species, of which 50% were restricted to the Paperbark swamp blocks. The species total in the Tuart blocks was higher at 51

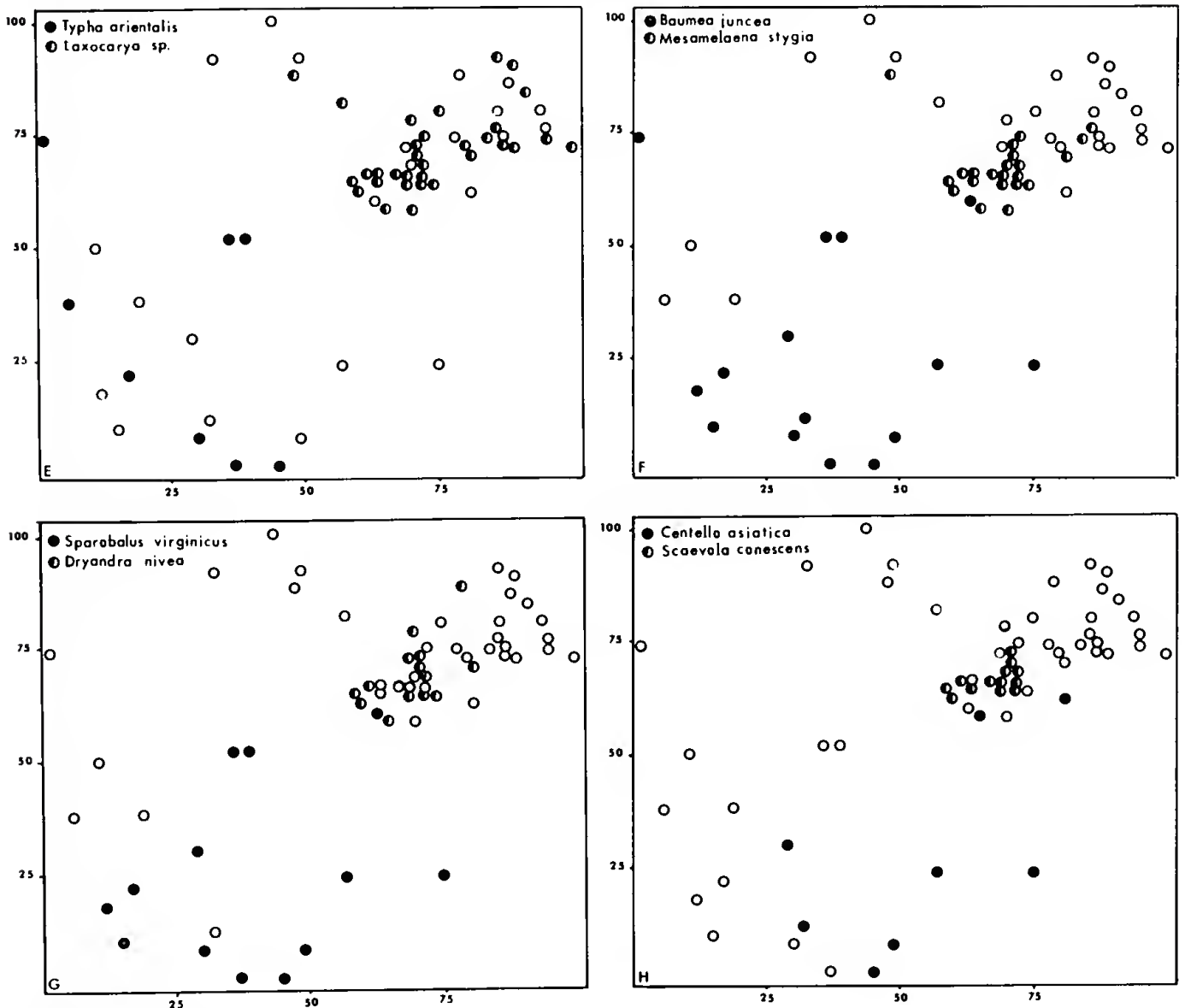


Figure 9.—continued.

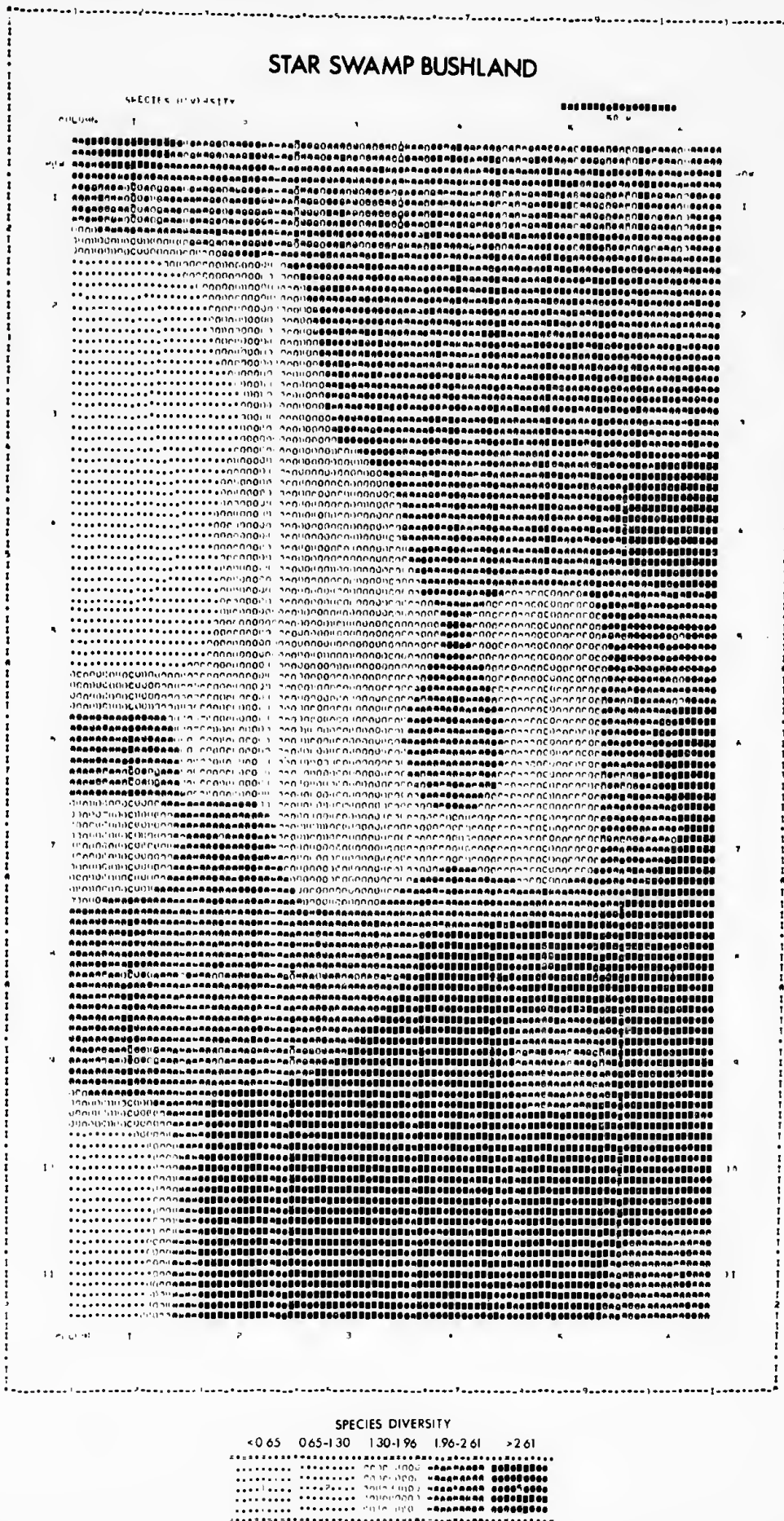


Figure 10.—Species diversity contour map. Simulated computer map based on the Shannon-Wiener index values for each block.

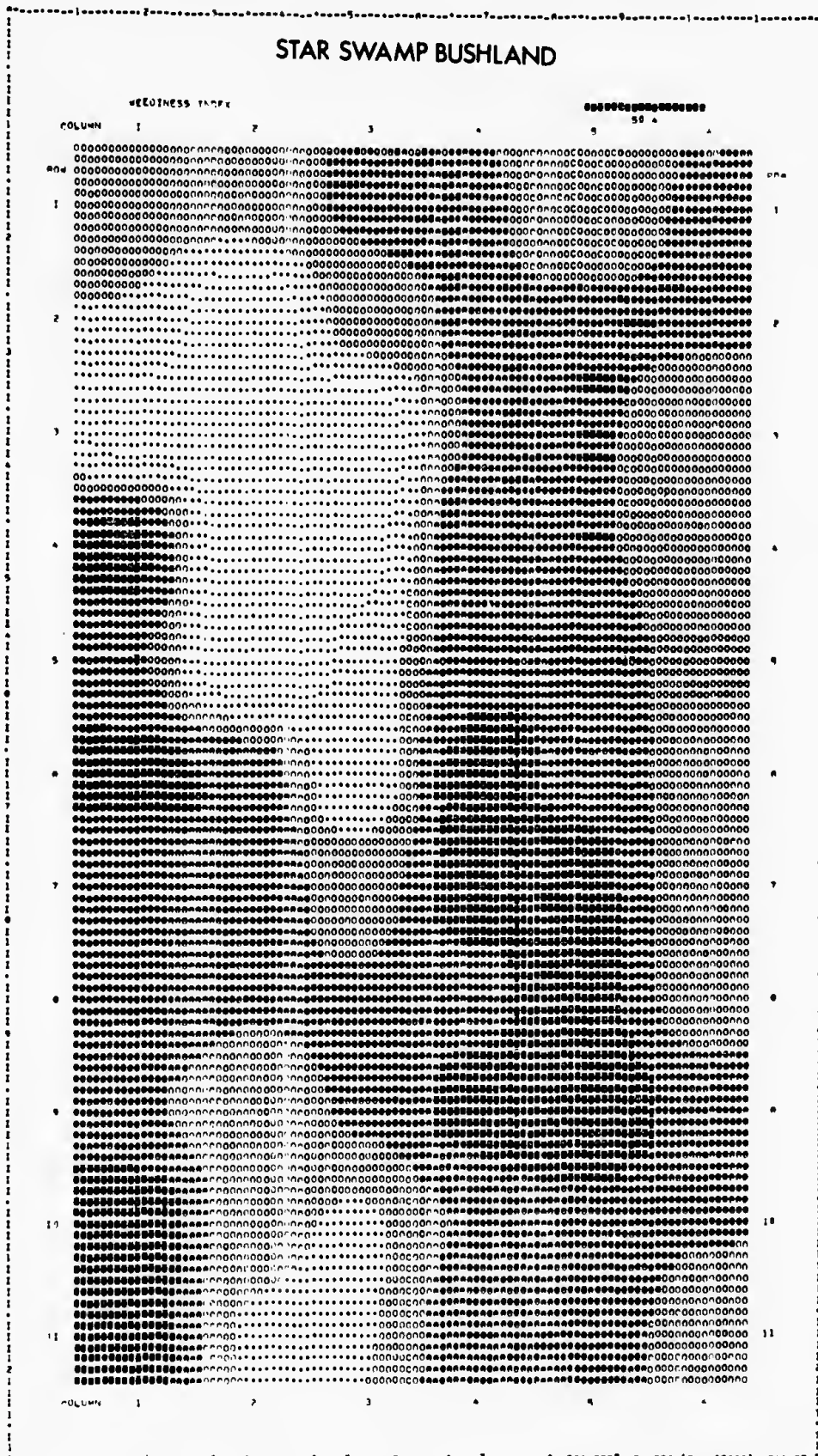


Figure 11.—Weediness index contour map. Simulated computer map based on the subjective weediness index value for each block.

species, but only 8% were recorded as restricted to this region. The mixed Banksia-Tuart understorey was richest with 73 species of which 31% were restricted to the region. When the community understoreys were compared it was evident that the shrub and herb strata of the Tuart and mixed Banksia-Tuart communities were most similar with 44 species shared or 55% of species in common. Species similarity in the understorey samples of the Paperbark and Tuart was next highest with 14 species shared or 21% of species in common. The Paperbark and mixed Banksia-Tuart woodlands were most dissimilar with only 11 species occurring in both regions or 12% of their species in common. In the understorey, therefore, there appears an intergrading continuum of species from the areas of Paperbark overstorey through the Tuart dominated regions to the leached-soil areas of the mixed Banksia-Tuart overstorey.

Generally the species richness and species diversity of the block samples increased with elevation (Fig. 10). Lowest Shannon-Wiener index values were calculated for the Paperbark swamp areas. The highest species diversity values occurred in blocks with an overstorey of mixed Banksia-Tuart. The correlation between species diversity and mean elevation was statistically significant ($r = 0.68$ $P < 0.05$). Areas of severe habitat conditions generally support fewer species (Bell 1980). The saturated soils of the swamp severely restricts the number of potential inhabitants in the low-lying blocks. Strong dominance by single species in areas of the swamp further restricts the Shannon-Wiener values by affecting species equitability. Upland areas contained more species and generally the cover values for species were more equitably distributed. It was apparent, however, that upland areas with infestations of exotic species had lower species diversity values. Species diversity was inversely related to the index of weediness derived from the percentage cover values for exotics for each block (Fig. 11). Correlations between the Shannon-Wiener index values and the subjective Weediness Scale values was also significant ($r = 0.25$, $P < 0.05$ for blocks above mean elevation of 2 m). Species diversity, therefore, is affected not only by severe conditions of soil saturation in the low elevational areas but also the percentage cover by the aggressive weedy species introduced from Mediterranean and South African areas. Weed concentration seems also to be negatively associated with canopy cover (Wycherley 1973). Although light interception values were not measured in the current study, the crown-affected areas of the Tuart woodland have severe infestation of weedy exotics. Understorey species distributions at Star Swamp respond to a number of habitat conditions. In the lowland areas, saturated soil and flooding are major factors affecting species survival. In upland areas, soil moisture, leaching as indicated by soil pH, and the presence of weeds all affect the distribution and association of understorey species.

Conclusions

The objective analysis of the vegetation in the intensive study area of the Star Swamp bushland provided confirmation of the earlier subjective assessment of Bell *et al.* (1979) of the presence of three basically different woodland communities. The composition of these woodland communities is strongly influenced by the tolerances of the species to the

condition of the soils and the periodic lowland flooding. Weed infestations are having a severe effect on the species richness and diversity of the upland areas. Without adequate control measures the native Western Australian species will probably be replaced by exotic species adapted to high-light, disturbance areas. The integrity of the vegetation in the lowland areas seems dependent on the restriction of the increase in water levels experienced in the catchment since the establishment of residences on the western slope. Resident development of further areas in the catchment will increase drainage into the Star Swamp lake with the accompanying increase in Paperbark and Tuart mortality. Management of this metropolitan bushland for the continued enjoyment of the people of metropolitan Perth will require a sensible interaction of the use of fire, weed control measures, flood level and a basic knowledge of the ecological characteristics of the species inhabiting the region.

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Western Australian geology: an historical review to the year 1870

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Abstract

The elucidation of the geology of Western Australia, prior to 1870, was often of secondary importance to those making the discoveries; however, the tangible results of these pioneers formed the basis of later investigations of the nineteenth century. The maritime surveys of the Dutch, French and English observed, in detail, the nature of bottom sediments, where soundings were taken, and the geology of the coasts where contacted. With the establishment of the Swan River Colony and the slow expansion of European settlement expeditions of discovery returned to Perth with detailed observations of the country traversed. The combined efforts of the Gregory brothers in addition to the treks of the German geologist von Sommer, added significantly to the previously poor knowledge of the geology of the interior of Western Australia. With the departure of the Gregorys and von Sommer from the colony, interest in the geology of the vast territory lapsed until the appointment of H. Y. L. Brown as Government Geologist in 1870.

Introduction

Just over 150 years ago, on 2 May 1829, Captain Charles Fremantle of H.M.S. *Challenger* landed at the mouth of the Swan River, and took formal possession of "all that part of New Holland which is not included within the territory of New South Wales". In 1 June 1829 Captain James Stirling arrived in the transport vessel *Parmelia* to take charge of the new Swan River Colony which was officially proclaimed on 18 June 1828. Stirling had previously examined the Swan River region in 1827 and reported favourably on it.

As the colony struggled for existence and then slowly prospered the demand for additional arable and grazing land increased along with the need for exploitable mineral deposits. This paper is an attempt to review the early observations on the geology of the colony and to document those who made the observations up to the appointment of Henry Yorke Lyell Brown as Government Geologist in 1870.

The history of official government appointees to investigate the geology of the colony (and later, State within the Commonwealth of Australia) has been well outlined in a series of historical reviews (Woodward 1890a, Maitland 1910, 1919 and Connolly 1976). A broader review of the development of the geological sciences in Western Australia, which includes previously unpublished information about the geologist Ferdinand von Sommer has recently been published (Lord 1979). The history of European settlement in Western Australia has been summarised by Bolton and Hutchinson (1973) in an article providing background information

against which the early history of geological explorations can be viewed. My review is based on published information—a full bibliography being attached. Further relevant information for the period undoubtedly exists in print, as the sources are very diffuse, and I shall be grateful for any literature omitted from the present survey.

Two valuable bibliographies include many of the sources mentioned—Etheridge and Jack (1881) and Maitland (1898). In addition three recent articles have considerable relevance to this review. The comprehensive survey by Vallance (1975) on the origins of Australian geology places many of the early observers of Australian geology in their historical context especially with regard to the philosophical arguments within geology in Europe during the early nineteenth century. The review of the history of the geological sciences in Australia by Branagan and Townley (1976) provides a useful survey of the geological investigations being undertaken in the other Australian colonies during the period under consideration in the present survey. Darragh's (1977) investigation into the origins of the earliest geological maps of the Australian continent is valuable in drawing attention to the remarkable work of Jukes (1850) hence posing the question as to the source of Jukes' information on Western Australia.

The history of geological investigations in Western Australia for the first 40 years of the colony reveals an initial period of preliminary discovery (1829-1840) followed by an extended period of expansion of activity (1841-1861), embracing two main peaks of investigation (the late 1840s and the late 1850s), in turn followed by a period of limited geological exploration (1862-1870).

The period prior to settlement

Isolated observations on the geology of the areas of the coast of Western Australia had been made prior to the establishment of the Swan River Settlement, with several collections of rock specimens being returned to Europe for examination. The earliest European observations on the coast of Western Australia verified by written records are contained in the early accounts of the Dutch and although invariably overlooked their journals occasionally contain information of geological interest. Fortunately these journals have been compiled into a comprehensive volume by Heeres (1899). As can be seen from the map produced by Isaac de Graaff (reproduced in Heeres 1899 opposite p.87) compiled after the voyage of Willem de Vlamingh in the years 1696-97, most of the western coast of Australia from the "Swaene-Revier" to the Golf van Carpentaria" (constituting the region of "Hollandia Nova") was known, while the southern coast of what is now Western Australia was known by 1630 (map in Heeres 1899, opposite p. 10). The early accounts portrayed the classic inhospitable land; for example the journal of Jan Carstensz (1623; Heeres 1899, p.22-44) contains such comments as "... a barren and arid land . . . natives are in general utter barbarians . . . they are utterly unacquainted with gold, silver, tin, iron, lead or copper". Observations of geological interest in this and other journals are few; however, they include notes on the nature of bottom sediments where soundings were taken and the colour of water flowing from the mouths of rivers.

The occurrence of the coastal dune calcarenites ("coastal limestone") of Western Australia occupied much of the interest of the early English and French voyagers such as Vancouver, Baudin and Flinders as has been reviewed by Vallance (1975, p.25-27). The French especially wrote at length on the distribution of this rock, in particular the journals of Peron (1807, p.110), Peron and Freycinet (1816, p.131) and Freycinet (1828, p.470). The accounts of these expeditions were the source of the information in the article by "a gentleman in the service of the Hon. East India Coy" (Anonymous 1830c) on the physical character of Peron Peninsula and Shark Bay. The article contains scattered references to the "calcareous and shelly sandstone". Von Buch (1814), when in Paris in 1810, examined the collection made by the Baudin expedition (1803-04) and made notes on the yellow sandy limestone from Seal Bay and Dirk Hartog Island (containing *Strombites* and *Patella*), the limestone from the Swan River and the granitic rocks from near King George Sound.

The French expedition of the *Astrolabe* in 1826-1829 sheltered in King George Sound during October 1826 and made extensive observations on the region. (D'Urville 1830 p.88-115). As a result of this French "intrusion" close to New South Wales the then Governor of that colony despatched Major E. Lockyer in charge of a small company from Sydney to found a garrison settlement. Lockyer established an outpost at Albany annexing the surrounding territory on 21 January 1827.

The earlier English maritime surveys of the coasts of Australia by P. P. King during the years 1818-1822 have left a legacy of journals rich in observations (King 1827). King made many observations

on the "coastal limestones" of King George Sound and considered they were composed of "merely sand agglutinated by calcareous matter" rather than coral (the earlier suggestion of Vancouver 1798, Vol. 1, p.49) or petrified vegetable matter (King 1827, Vol. 1, pp.12-13). King returned to King George Sound and made general observations in the granite of the area (Vol. 2, pp.152-153). Later (Vol. 2, p.185) the unusual rocks of Dirk Hartog Island attracted his attention; he noted that they consisted of "a congeries of quartzose sand, united in small circular kernels by a calcareous cement, in which some shells were found imbedded." The most significant geological contribution of King's journals is contained in the appendix describing his collection of rocks by W. H. Fitton (King 1827, Vol. 2 pp.556-629; also published separately, Fitton 1826). Points of interest in Fitton's account range from general observations on the hills near Port Keats being flat topped and hence having "very much the aspect of the summits in the coal formation" to warnings on the dangers of lithological correlation "since it appears that the accretion of calcareous matter is continually going on at the present time, and has probably taken place at all times, the stone thus formed, independent of the organised bodies, which it envelopes will afford no criterion of its date," (King 1827, Vol. 2, p.592, Fitton 1826, p.30). Fitton ascribed the occurrence of the "coastal limestone" above sea level to upheavals and earthquakes, continuing the tradition of relating its occurrence to some type of catastrophe (see Vallance 1975, pp.25-27 for a full discussion). Fitton concluded his remarks with "Instructions for collecting geological specimens" which are still as relevant today as when they were written.

The period of preliminary discoveries 1829-1840

After settlement, many brief geological observations were made in the immediate district surrounding the new towns. Brief geological observations made by M. Frazer, the botanist who accompanied James Stirling on his 1827 expedition to the Swan River, were published the same year as settlement (Anonymous 1829, 1830a, b.) These observations were general remarks on the soils and lithologies present. The early observations of Stirling, from the first months of settlement are given by Barrow (1831). Barrow's account illustrates the preoccupation of the colonists with agricultural and pastoral advancement, containing as it does extensive observations on the soils of the region; nevertheless the delineation of "primitive" areas of granite from more recent calcareous areas was becoming apparent. The collection of journals edited by J. Cross (1833) brings together the many observations of various short expeditions in the south-west of the new colony. These expeditions, which were led by army officers and settlers, contain occasional observations on the state of the land, soils and distributions of rock (i.e. sandstone, ironstone or limestone), however geological observations were of secondary importance in the quest for good land and water. As noted by Quilty (1975, p.69) A. Collie (in Cross 1833, p.174) mentioned that a bend on the Kalgan River "presented the indubitable impressions of shells and other organic remains". The general account of the colony by William Milligan (1837) contains brief geological notes drawn from earlier accounts including that of the Venerable Archdeacon T. H. Scott

(1831) who was "accidentally detained for several months at the settlement". Scott's observations concerned the development of the "coastal limestone" with numerous concretions "having the appearance of inclosing vegetable matter" (Scott p.320); and a brief account of the higher Darling Range to the east, composed "of greenstone and sienite".

The *Beagle* under Captain Robert Fitzroy, called at King George Sound in 1836 on her voyage home and Charles Darwin accompanied Fitzroy on a short excursion to Bald Head. Darwin noted (1839, p.537) that "according to our view, the rock was formed by the wind heaping up calcareous sand, during which process, branches and roots of trees and land shells were enclosed; the mass being afterwards consolidated by the percolation of rain water". Darwin was not impressed with the landscape—"he who thinks with me, will never wish to walk again in so uninviting a country"—or for that matter with Australia as shown by his now famous remark "Farewell Australia! you are a rising infant and doubtless some day will reign a great princess in the south: but you are too great and ambitious for affection, yet not great enough for respect. I leave your shores without sorrow or regret".

The state of the geological knowledge of the Swan River Colony by the end of the 1830s was summarised by Sir James Stirling (1838, p.5). His report was clearly the source of the geological notes on the Swan River Colony given by Nathaniel Ogle (1839, p.24) in his manual for emigrants to the colony of Western Australia. Stirling's report is the first succinct synthesis of the scattered geological observations of Western Australia. His summary, not readily available, is quoted in full: one can note that in 1838 it took two paragraphs to summarise all the geological knowledge of the colony!

"The whole of the occupied portion of the territory appears to rest upon a granitic base; rocks of that description having been found to exist in every district which has been as yet explored. In the neighbourhood of Doubtful Island Bay the granite assumes the stratified form of gneiss, and as red sandstone is found on the north-west coast, and tertiary formations on the shore of the Australian Bight, it is probable that the general dip of the country is in a direction a little to the north of east. To the south of the 31st degree of latitude there are no mountain ranges of any great altitude; the highest as yet known being that of Koikyeunreuff, near King George's Sound which attains to the height of 3,500 feet. On the primitive base of the country, none of the secondary formations have been found to exist; basaltic rocks are not however unfrequent in almost every district in the country; and in one position in Geographic Bay, there is a columnar formation, resembling in its character that which exists on the north coast of Ireland. The principal range of hills extends in a northerly direction from the south coast, near Cape Chatham, for at least 300 miles. The only varieties of rock which have been found on this granite range, are occasional portions of roofing slate, and of indurated clay; but extending from the western base of these hills towards the sea, upon an average breadth of about 20 miles, there is a low and tolerably level plain of diluvial origin, which bears the marks of having been covered by the sea at some remote period. The portion of this plain

nearest to the sea presents limestone hills, which have a slight covering of meagre sandy soil; the remainder varies from sand to clay, with exception of the lands in the immediate vicinity of rivers, which have been affected, and rendered rich, by the overflowing of the streams."

"The mineral substances heretofore discovered, are lime, marl, selenite, slate, siliceous and calcareous petrifications, magnetic iron ore, peacock iron ore, chromate of lead, and crystals of quartz. The very small portion of the territory which has been inspected being almost entirely of a primitive description, a larger list of minerals could not be expected; but when time shall permit the further examination of the northern districts, of the red sandstone formation, it is not unlikely that important mineralogical discoveries may be effected. The discovery of copper ore by Captain King in the vicinity of Camden Bay corroborates this expectation" (Stirling 1838, p.5).

The year 1838 saw the discovery by J. A. L. Preiss of a fossil which Moore (1884, p.376) thought was an "encrinite" and therefore might indicate the presence of "transition or secondary formation" and hence the possibility of coal being found. The reward of 1036 hectares of land to the discoverer of an economic deposit of coal was initiated by the Governor.

The years 1837-39 saw the expeditions of George Grey, his journals (Grey 1841) containing much of geological interest. His account of the northern expedition from Hannover Bay includes notes in which he clearly recognised the volcanic nature of the rocks (Vol. 1, pp.162-163, 168). Some he compared with the vitrified lava of Ascension; others were referred to as basalts. It would appear he regarded the volcanic rocks to be of fairly recent origin (judged from the topography) rather than the Middle Proterozoic Age now ascribed to them (Geol. Surv. W.A., 1975). However he noted the paradox of bedded sandstones (compared with the Old Red Sandstone) resting on basalt at a watershed of the Prince Regent River (Vol. 1, p.192). Vallance (1975, pp.27-28) discusses at length the arguments, raging in Europe in the 1830s and 1840s on the origins of valleys. One can note that Grey was apparently a fluvialist, or at least he was certainly well aware of the erosive powers of running water. On his northern expedition he noted (Vol. 1, p.97) the occurrence of lofty sandstone pillars and "as the tops of all of them were nearly all the same level, that of the surrounding country must at one period have been as high as their present summits—probably much higher". He noted on every side "the same extensive degradation" accompanied by small streams gurgling through caverns "which in the rainy season must become a perfect torrent". He observed the same streams in the rainy season (Vol. 1, p.98). Later, on his remarkable trek to Perth from the wreck of his vessel, he noted the deep gorges of several of the rivers crossed making the equivocal observation that "the ravines, now traversed by water courses or streams, apparently much too insignificant to have grooved them out", (Vol. 2, p.26).

It has occasionally been noted in reviews of Western Australian geology (e.g. Maitland 1900, p.13; Teichert 1941, p.374) that Grey was apparently the first to observe Carboniferous (i.e. Permian) rocks in Western Australia; however, this is apparently

not the case. Although he speaks of limestone in the regions of the rivers and considered that the valleys "partook exactly of the character of those in the Carboniferous limestone districts of England" (Vol. 2, p.26) an examination of his map (Vol. 1.) indicates he was too far to the west to have traversed Permian rocks.

To complete the period 1829-1840 mention must be made of the second volume on geology resulting from Dumont D'Urville's 1837-1840 Voyage au Pole Sud. Although appearing in 1854, the summary of the geology of the western half of the continent only includes information gathered up to 1840 (Grange 1854, pp.77-78).

The period of expansion 1841-1861

By 1841 the exhaustive survey of the coasts of Australia by HMS *Beagle* was under way and the journals of Commander J. L. Stokes contain many geological observations, usually restricted to the occurrence of a particular lithology, made during the course of the voyage. Observations on the cliffs of Hannover Bay (Stokes 1846, Vol. 1, p.107-108) reveal an unusual streak of catastrophism—the cliffs "which rise from 70' to 90' in height, their bases apparently resting amid huge and irregular masses of the same white sandstone as that which forms the cliffs themselves, and from which this massive debris, strewn in all conceivable irregularity and confusion around, appears to have been violently separated by some great internal convulsion". Further to the north-east near Port Keats he found "a few fossils" and named Fossil Head (Vol. 2, p.32-33). As noted by Jukes (1850, p.72) these fossils were subsequently either lost or destroyed; however Stokes in a letter to Jukes (1850, p.72) described them as "casts of shells, not of a recent appearance". Jukes goes on to make what is little more than a remarkable guess (p.73) that they were probably the same age as the "Palaeozoic Formation which is found so largely in New South Wales" (i.e. Permian in modern terms).

While the *Beagle* was charting the shores of Australia, Edward John Eyre was carrying out the heroic trek of crossing the continent from Adelaide to King George Sound (1840-1841). The principal task of his arduous trip, as recorded in his journals (Eyre 1845), was to stay alive; nevertheless, his journals contain geological remarks. His route followed the coast (Fig. 1) and he recorded the change from the Tertiary limestones of the Nullarbor Plain (his "fossil formation") to the granite terrain of King George Sound.

A full description of the ancient sea cliffs, near the present township of Eucla, is given (Vol. 1, p.338-339): "The brown or upper portion consisted of an exceedingly hard, coarse grey limestone, among which some few shells were embedded, but which, from the hard nature of the rock, I could not break out; the lower or white part consisted of a gritty chalk, full of broken shells and marine productions . . . parts of it exactly resembled the formation that I had found up to the north, among the fragments of table land; the chalk . . . was traversed horizontally by strata of flint ranging in depth from six to eighteen inches, and having varying thicknesses of chalk". As a result of his journey and using a variety of observations, including geological, Eyre

(1846) argued strongly against the existence of the inland sea of Australia. For his remarkable efforts in exploration Eyre was awarded the Founders Medal of the Royal Geographical Society of London (Hamilton 1843).

The Swan River Colony was now becoming interested in other means of increasing exports. One such method was through the discovery of raw materials. The discovery and testing of a small deposit of iron ore near the Swan River by J. W. Gregory (1843) suggested the possibility of the discovery of coal in the vicinity (additional remarks to Gregory's paper by J. Harris). The search for coal dominated much of the geological exploration for the new few years in the colony.

The spark was supplied in 1846 on 9 September when "two seams of coal were discovered one about 5 and the other 6 feet in thickness with several beds of shale and sandstone" in the valley of the Irwin River by three of the Gregory brothers (A. C., F. T., and H. C. Gregory—see A. C. Gregory 1848). Contemporary independent comment on the Gregorys' discovery and Western Australian geology in general is offered by Rosendo Salvado (1851, p.64-66 in a much neglected volume published in Rome and now available translated into English by Stormon (1977)).

The Acting Governor of Western Australia F. C. Irwin responded immediately to the discovery of coal by despatching on 2 December 1846 "the colonial schooner "Champion" with a party under the direction of the Surveyor-General, accompanied by Dr. von Sommer, the geologist . . . to Champion Bay, with instructions to examine the country". (Irwin 1847, p.187). Strangely Lieut. Benjamin Francis Helpman's account of the Survey contains no mention of von Sommer, although mention is made of both A. C. and J. W. Gregory. Helpman (Commander of the schooner) and party were back at the Irwin River by 12 December 1846 and noticed "the coal fire made by Messrs. Gregory had left nothing but very fine ashes and no cinders" (Helpman 1848, p.40). Readers of these contemporary journals should be aware of the confusion between the names applied by Grey (1841) and others to rivers in the region; the note and map by Arrow-smith (1848) explain the discrepancies.

Von Sommer's own accounts are enigmatic. Part of his report is condensed and given in Irwin (1848, p.240) which also includes further instructions to von Sommer to explore the south-west of the colony for coal and minerals. Von Sommer's own published accounts of his explorations reveal a wealth of observations on the geomorphology and soils of the country he traversed. Geological observations are succinct and typically contain correlations based on lithology. Von Sommer includes many observations on the Irwin River area mentioning seams up to "five feet thick". Deductions from dip and strike measurements were made as to where further coal might be found to outcrop (von Sommer 1848b, 1849a). Contemporary press reports by "a gentleman holding a high official appointment in the western province" indicate a rather exaggerated translation of von Sommer's thoughts, with seams of coal "up to 12' thick" and "one of the greatest coal fields in the world". One can certainly question the accuracy of the press of that time.

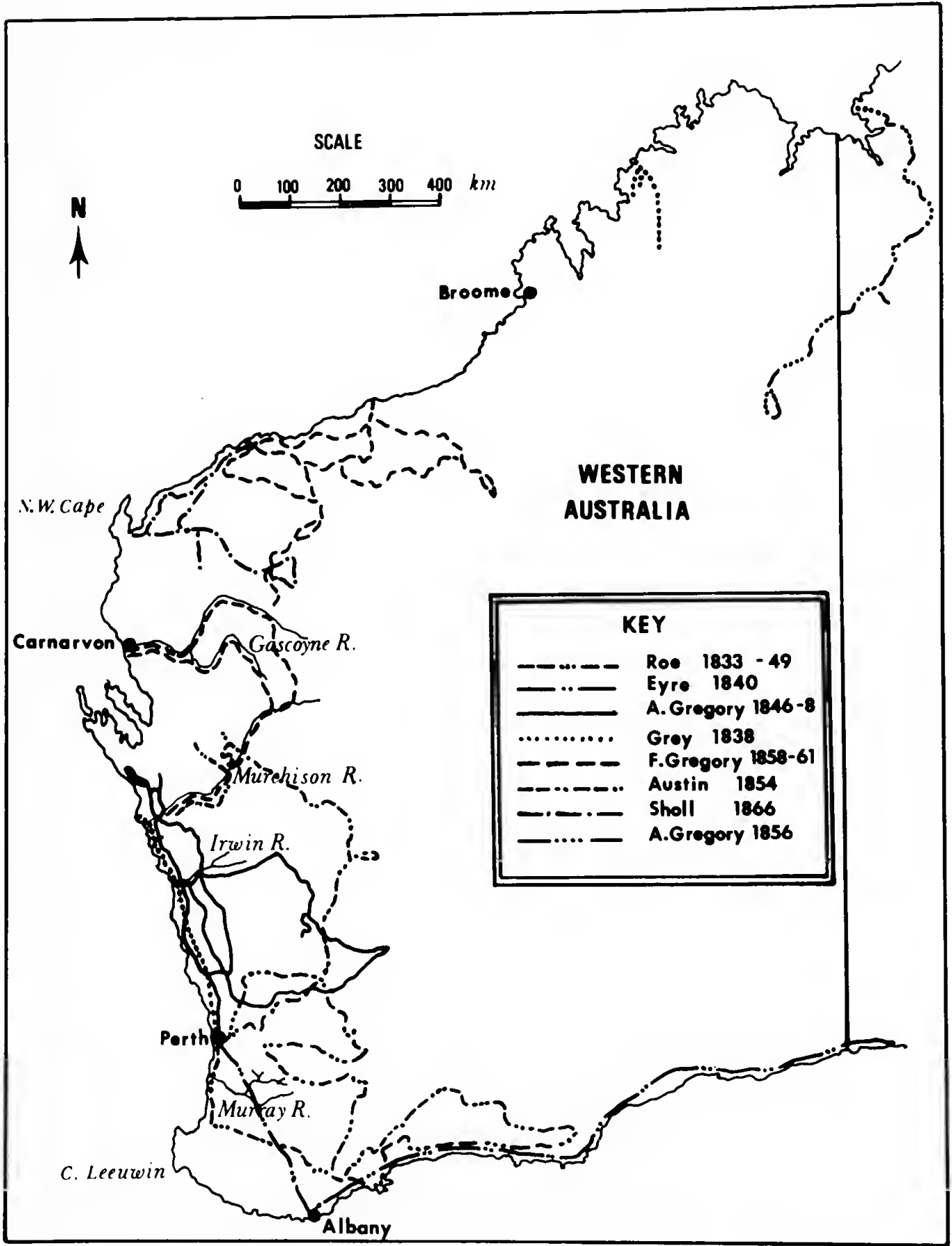


Figure 1.—Map of explorers' routes 1833-1866.

In von Sommer's brief survey of the geology of Western Australia (1849b) several observations on the Irwin River district appear, including dip measurements and a stratigraphic column with the thickness of coal stated to be 1.6 m. (For convenience the press reports are listed in the bibliography as von Sommer 1847 and 1848a—the second being a direct copy of the first). Von Sommer's catalogue of specimens from New Holland (1849c) is noteworthy for its rock classification (including the terms Plutonisch, Neptunisch and Chemisch) and also for its value in giving an indication of the specimens he collected.

After the 1846 expeditions of the Gregorys it appears that a geological map of the colony was produced and presented to the Geological Society of London by J. W. and F. T. Gregory. Regrettably the map and paper were never published although they were noted in the Proceedings of the Society in the form of an abstract (Gregory, J. W. and F. T. 1848). Fortunately J. W. Gregory's views of the geology of Western Australia were published in the colony (Gregory, J. W. 1849). His account reveals the substantial increase in knowledge of the lithology and mineralogy of the colony as well the areal extent and stratigraphic sequence of geological units. A deductive geological history is also provided. The young colony clearly lost a flourishing "amateur" geologist with J. W. Gregory's death in 1850.

A. C. Gregory was again sent north from Perth in August 1848, this time with C. F. Gregory, to examine the country as far north as the Gascoigne (sic) River (Gregory 1852a, p.57). Again he was asked to examine the Irwin River coal and its extent including "to the northward of it in the direction of Shark's Bay where Dr. von Sommer thought the coal seam of the Irwin might again make its appearance" (letter to A. C. Gregory from R. R. Madden, Colonial Secretary, 28 August 1848, quoted in Gregory 1852a, p.58). A few brief observations were made on the Irwin River coal. However, the 1848 expedition was notable for another reason; on 16 October 1848 abundant specimens of galena were discovered, in the bed of the Murchison River. Gregory observed that "the existence of garnets, iron pyrites and a mineral resembling in many of its properties plumbago, specimens of which were found in a gneiss of this district seems to indicate a metalliferous formation" (Gregory, A. C. 1849, p.75; 1852a, p.66).

The discovery of galena initiated a visit to the Murchison River by the Governor, Charles Fitzgerald in December 1848 (Gregory, A. C. 1849, p.78-80 and 1852b). Extensive observations were made on the galena vein and its host rock (Gregory 1852b, p.72), traces of copper being noticed. In a footnote to Gregory's account (1852b, p.73) entitled "extract from the narrative of a journey from York to Champion Bay in the colony of Western Australia . . . by Mrs. Brown of Grass Dale" brief notes are included on the operation of the Geraldine Mine. Connolly (1976, p.80) notes that the Geraldine Lead Mine was established in 1849 and that the first recorded export was of pig lead, to the value of \$2400, and a small quantity of copper in 1853.

The search for coal also extended south of the Swan River Colony. Reports of coal near the Murray River (Urban 1847) and in the vicinity of Cape Riche (Irwin 1848, p.240) were apparently false. Von Sommer, from his observations at the Irwin River, had considered that coal may occur east of King George Sound (Irwin 1848). As if in answer to his predictions the expedition of John Septimus Roe in 1848-49 announced the discovery of coal in the bed of the Fitzgerald River (Roe 1852, p.36) as well as "elongated globules of bitumen". Roe made many geological observations in his journals (1849, 1852) and his sketch map (accompanying the 1852 report) contains many annotations complementing the earlier observations of Eyre. Roe's discovery of coal was another false alarm although many years were to pass before the matter was finally settled. Dixon (1885, p.9), writing of his searches in 1867, found only lignite seams and considered the bituminous substance to have been washed in by the sea. Woodward (1890b, p.50-51) noted the presence of brown carbonaceous material occurring in a series of pockets or hollows resting on the upturned edges of altered slates. He again reiterated the existence of huge quantities of "mineral pitch" washed up on the beach along the southern coast of Australia. Cockbain and van de Graaff (1973) have recently reviewed in detail the history of the discovery and the occurrence of lignite in the Fitzgerald River.

One of the most skilled geological observers to visit the Swan River Colony was J. Beete Jukes naturalist of HMS *Fly* during the surveying voyage of 1842-46. Although brief comments on the geology of Western Australia are made in the various abstracts of his papers (Jukes 1847a,b,c; 1848a,b) it is in his major work (1850) which contains extensive observations and a synthesis of the geology of Western Australia. Jukes published with his book the first coloured geological map of Australia (Darrah 1977); a modest attempt with the colours "dabbed on roughly". His sources of information on the western portion of the continent were his own observations made on an excursion of "two or three weeks" (1850, p.60) and contemporary published journals. He added to the already large literature on the dune limestones observing: "I saw some of these dendritic masses fully exposed and from their peculiar structure and conformation, I believed them to be nothing more than stalactites formed in the sand by the percolation of rain water dissolving and taking up the carbonate of lime found in the sand, and redepositing it in fantastic forms wherever a pre-disposing cause happened to determine it". (p.61). He updated his observations with the London publications of A. C. Gregory, B. F. Helpman and F. von Sommer pointing out the discrepancies between the dip measurements of the Irwin River Coal of Gregory and von Sommer. He considered von Sommer's dip measurements to be more probable and then offers the enigmatic comment "but the remainder of his observations are little to be depended on" (Jukes 1850, p.66).

After the death of J. W. Gregory in 1850 and the departure from the colony of F. von Sommer in 1851 geological investigations decreased in extent. However, expeditions into the vast unexplored territory continued throughout the 1850s adding to the knowledge of the geology of the colony. In the late 1850s the impending International Exhibition in

London (1862) appears to have stimulated further investigations. The extent of the geological knowledge of Western Australia prior to this second wave of expeditions is well illustrated by Bonwick's 1855 text book on the geography of Australia and New Zealand. It contains (p.63-65) a brief summary of Western Australian geology including a note on the bituminous coal of the Murray River, apparently confusing that river with the Irwin.

The expedition of Robert Austin in 1854 (Austin 1856) expanded the explored areas of the colony eastward of the Irwin and Murchison rivers; the detailed published journal contains a map showing the route traversed with the position of each night's camp, and thus the positions of the rocks recorded each day can be noted with some accuracy.

The North Australian Expedition (1856-57) under the command of A. C. Gregory, although covering much of what is now the north-west of the Northern Territory, made a traverse into the far north-east of Western Australia (Fig. 1). Included in the party was a geologist, James S. Wilson, whose articles (Wilson 1857, 1858a, b) contain considerable information on the geology of northern Australia, the sandstones being correlated with the Sydney Basin sandstones. Regrettably, however, much of his discussion concerns regional generalisations rather than specific observations. Accounts of the preparatory stages of the expedition and brief accounts detailing the advancements of the expedition are contained in volumes 1 and 2 of the Proceedings of the Royal Geographical Society, London, in the form of letters of interested persons as well as progress reports (e.g. Baines 1858). One noteworthy item is contained in a letter from John Kent of Sydney to Dr. Shaw, Secretary of the Royal Geographical Society (Proc. Roy. Geog. Soc. 1: 10-11). Kent makes observations on the characters of several members of the expedition team. Of A. C. Gregory he states ". . . I deem him a most competent leader for such an expedition. Spare and active, quiet and reserved in manner, with great firmness of purpose, he is well adapted to conciliate the aborigines and, what is more essential, the elements comprising his own party. I think it would be difficult to find four men better adapted for undergoing fatigue than the brothers Gregory, Wilson and Baines. Of the others I cannot speak so confidently; but the patience and resignation of Dr. Müller have been tested by a seat for three days up a gum tree, waiting for the subsidence of a flood. He is a German botanical enthusiast which will account for this incident in his experience". Dr. Müller, was later Baron Sir Ferdinand von Mueller, Victorian Government Botanist. The progress reports of the North Australian expedition stimulated W. H. Fitton (1857) to again make several observations on the geology of northern Australia. He noted, from published accounts, the similarity between the rocks of the western side of the Gulf of Carpentaria with those in the north-west collected by P. P. King and included that they formed "a great natural division of the country". In actual fact Fitton made a generalised correlation of the Kimberley Basin rocks of north-west Australia with the McArthur Basin rocks of the Northern Territory. Fitton considered the rocks could be correlated with the Old Red Sandstone of Britain.

On his return to Victoria after the North Australian Expedition, F. von Mueller (1858) provided a brief history of exploration in Australia. This is of particular interest as it includes a short account of the physical geography of Western Australia by A. C. Gregory including two maps, one a geological diagram and one a botanical diagram. Although not coloured the geological map appears to be an original of Gregory's as it contains rather more information than Jukes' map of 1850. For his efforts in the exploration of Australia A. C. Gregory was awarded the Founder's Gold Medal of the Royal Geographical Society in 1856, (Murchison 1857).

The late 1850s saw Francis T. Gregory make expeditions to the Murchison, Gascoyne and Lyons rivers, adding greatly to the geological knowledge of the colony. The journals (1859) contain the details of the geological observations which were used to produce the geological map and paper of 1860 (F. T. Gregory 1860; 1861a,b,c). F. T. Gregory discovered the Permian (although he referred most strata to the Carboniferous) sequences outcropping in the region of the Lyons and Gascoyne rivers and indicated the presence of the Mesozoic rocks higher in the sequence. His paper has been taken as the starting point of Western Australian Upper Palaeozoic geology in the past (e.g. Teichert 1941). A collection of rocks and fossils and a copy of the map produced by J. Arrowsmith were presented to the Geological Society of London (Annual General Report of the Society for 1862 p. x-xi, and an appendix to Gregory's paper by T. R. Jones (editor of the Quarterly Journal of the Geological Society) included a short list of identifications of the fossils. It is worth noting that the organization of his paper follows closely the organization of his brother's paper published 13 years previously in the colony; as F. T. Gregory states his geological history "differs but slightly from some geological notes published in the colony some ten years ago by my late brother Mr. J. W. Gregory" (F. T. Gregory 1861a, p.482).

For his efforts in the exploration of Australia, F. T. Gregory was awarded the Founder's Gold Medal of the Royal Geographical Society in 1862 (Murchison 1863). Of his map, H. P. Woodward (1890a, p.5) noted "that no professional geologist would be ashamed to own it and indeed so accurate . . . as I found in that portion I examined last year, that (his) mapping will be retained provisionally for those portions not yet re-examined".

Collections of rocks and fossils and the geological map were exhibited at the International Exhibition, London 1862, the catalogue of which (Andrews 1862) contains general lists as well as detailed notes on the various mines then active in the colony. On the basis of Gregory's collections and those of a Mr. Shenton of the colony sent to a Captain Sanford of Nynehead, Moore (1863) was able to confirm the presence of Mesozoic rocks in Western Australia—the collections being fully described by Moore some years later (Moore 1870).

The closing of the era of Gregory explorations in Western Australia occurred in 1861 with the expedition to north-western Australia. A detailed map of the route taken by the expedition was produced

(F. T. Gregory 1862a) and a lengthy account was published at the time (F. T. Gregory 1862b). Geological observations are numerous, usually restricted to observations of the lithologies occurring on the route. As noted by Darragh (1977, p. 299) a hand-coloured geological map, based on the observations in the journal, exists in the State Library of Victoria map collection. The colouring was apparently carried out by R. B. Smyth the then Victorian Secretary of Mines (see Darragh 1977 for full discussion of Smyth). The base map Smyth used is the map published with the journal in 1862.

The period of recession 1863-1870

By 1863 the Gregorys had moved to the eastern colonies of Australia. While several expeditions took place in the period 1863-1870 geological deductions based on specimens collected were invariably made by geologists residing outside the colony.

The journals of the expedition of H. M. Lefroy eastwards of Perth were regrettably never published in full; however, a typescript is held by the Western Australian Library Board. The journal reveals a careful observer of the granite terrains and salt flats he traversed which is not immediately apparent in the brief published abstract (Lefroy 1864). Lefroy considered that he was observing a mass of granite that was of the original formation of the globe and which had remained undisturbed for many years.

The Rev W. B. Clarke of Sydney had been sent various collections of rocks from Western Australia and wrote numerous articles. He commented (1864) on the possibility of gold being found in the colony and described the collection of granitic and hornblende rocks collected by Hunt in 1864 near Lake Lefroy (Clarke 1866a). A case of fossils from 24 km north of Champion Bay, sent to Clarke in 1863 by F. B. Barlee the Colonial Secretary was revealed by Clarke (1866b and 1868) to contain further evidence of the presence of Mesozoic rocks in the western portion of the continent. While Mesozoic fossils were sent to Clarke, H. M. Lefroy sent Quaternary fossils to the Rev. J. E. Tenison Woods, who used them (1868, p. 45) to question the extent of the Quaternary ice age in Australia.

A visitor to the colony, Edward H. Hargreaves (Hargreaves) after making several excursions decided that the possibility of gold occurring in the colony was nil (Hargreaves 1864). Blainey (1969, pp. 13-19) has created a colourful picture of this fat man who "found it exhausting to shovel gravel or work the cradle all day". If he found it a difficult task to ride a horse from Sydney to Bathurst it appears unlikely that his "various excursions into the interior" of Western Australia went far beyond the outposts of civilization. As A. R. C. Selwyn the Victorian Government Geologist, who was present at the meeting of the Royal Geographical Society in London when Hargreaves' paper was presented, observed "we ought hardly to take an examination of the coastline as a proof that the whole of Western Australia would not be auriferous because if we looked at the enormous expanse of Western Australia it would seem that Mr. Hargreaves had traversed it but to a very limited extent".

The mid 1860s saw the expeditions of James Martin and R. J. Sholl and although their Journals were published they contain only very occasional

references to geology. The 1866 route ascribed to Cowle (Dean 1872) appears to be that of a subsidiary expedition of the Sholl expedition, however, I am unaware of any published account.

The expedition of John Forrest, in search of the remains of Ludwig Leichhardt and party, in 1869 was the first of a series of expeditions ushering a new dawn of geological exploration in Western Australia. The exploration by the Forrests together with the investigations of the new Government Geologist, H. Y. L. Brown and the Work of Rev. C. G. Nicolay in Perth initiated the beginning of a new period of geological exploration in 1870 (Valance 1975, p. 35; Connolly 1976, p. 80-85).

Conclusion

The geological exploration of Western Australia prior to settlement and during the first forty years of the colony was often of secondary importance to those blown off course, seeking shelter or struggling to develop the colony. However, tangible observations and discoveries were made and they formed the basis of much of the later investigations for the rest of the nineteenth century. Although the contributions of these pioneers may now be outdated they represent an important facet of the early stages of development of the State that has just celebrated its sesquicentenary.

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